ORIGINAL ARTICLE

Turkish Pre-service Teachers' Understanding of Daily Life Phenomena Related to Chemistry and Compatibility with the Current Chemistry Curriculum

Oya Aglarci Ozdemir

Marmara University, Istanbul, Turkey

***Abstract**: The aim of this study is to determine Turkish pre-service science teachers' levels of chemical explanations of various daily life phenomena and to investigate whether these examples are in accordance with the high school chemistry curriculum in Turkey. This study was carried out with descriptive research methods. The participants are 71 freshmen pre-service science teachers in a state university in Turkey. The data of the study were collected with the "Chemical Explanations of Daily Phenomena" Questionnaire previously developed in the literature. The phenomena in the questionnaire were related to chemistry concepts such as diffusion, temperature, combustion reactions and the law of conservation of mass, isotopes, reaction rate, redox reactions, and mixtures and solutions. The answers were analyzed in three categories: correct, wrong, and can't determine and the frequencies and percentages of the categories were determined. Also, the learning outcomes in the latest version of the Turkish high school chemistry curriculum were examined in order to determine whether they were related to the chemistry concepts in the questionnaire. Document analysis was utilized to analyze the learning outcomes in the chemistry curriculum. The findings of the study revealed that most of the pre-service teachers answered correctly the questions that are compatible with the chemistry curriculum. Their misconceptions were mostly related to heat transfer and specific heat capacity, the law of conservation of mass, and heavy water and isotopes. The findings indicated that future curriculum changes should integrate some important chemistry concepts closely related to everyday life, such as radioactivity and heat transfer.*

Science Insights Education Frontiers 2023; 16(2):2477-2503.
Doi: 10.15354/sief.23.or311

How to Cite: Aglarci Ozdemir, O. (2023). Turkish pre-service teachers' understanding of daily life phenomena related to chemistry and compatibility with the current chemistry curriculum. Science Insights Education Frontiers, 16(2):2477-2503.

Keywords: *Chemical Literacy, Misconceptions in Chemistry, Pre-Service Teachers, Chemistry Curriculum*

About the Author: *Oya Aglarci Ozdemir, PhD, Department of Chemistry Education, Faculty of Education, Marmara University, 34722 Istanbul, Turkey. E-mail: oya.aglarci@marmara.edu.tr*

Correspondence to: *Oya Aglarci Ozdemir at Marmara University of Turkey.*

Conflict of Interests: *None*

Acknowledgments: *Earlier version of this study was presented at the conference; "2nd International Conference on Science, Mathematics, Entrepreneurship and Technology Education".*

Introduction

THE modern world is changing rapidly with the developments in science and technology. People are expected to adapt quickly to the changing world and to understand the impact of developments in science and technology. Science education is one of the ways to achieve and facilitate this adaptation and offers ways for understanding science and technology. The major aim of science education is scientific literacy. Science educators and science education documents have proposed different definitions and important aspects of scientific literacy (e.g. Bybee, 2012; National Research Council [NRC], 1996; Norris & Phillips, 2003; Roberts, 2007). According to Holbrook and Rannikmae (2009), scientific literacy is closely related to an appreciation of the nature of science, and the development of social values and personal attributes. Scientific literacy is not just for those who aim for a career in Science Technology Engineering Mathematics (STEM) areas, but for all students (Suwono et al., 2017). Bybee (1997) has proposed a framework in which scientific literacy can be examined at four levels (components) for school science education. Those are:

1. Nominal literacy: Students can recognize important scientific terms and concepts, but do not know the meaning of that term/concept and/or have misconceptions about them. For example, students have heard of atoms, cells etc., but they might think atoms are the smallest living organism because cells consist of atoms (Papageorgiou et al., 2016).
2. Functional literacy: Students can use scientific and technological terms and concepts, but they usually have a limited understanding and/or they cannot explain them in their own words. For example, students can speak about melting and dissolving in chemistry lessons, but they cannot fully explain the difference between them.
3. Conceptual literacy: They understand scientific concepts and their relationship with daily lives. For example, they can understand the relationship between force and motion as well as the daily life applications of fundamental laws of physics.
4. Multidimensional literacy: Students understand scientific concepts and phenomena. Also, they can understand various perspectives such as philosophical, historical, ethical, and economic in science and socioscientific issues that are embedded in science-technology- society interactions. For example, students understand what causes global climate change and the effects of global climate change on the environment, human health, and economy.

Scientific literacy includes scientific concepts, phenomena, and ideas from various scientific disciplines and these different levels of scientific literacy suggest that each discipline may have its own specific literacy. Thus, the major aspects of scientific literacy related to different scientific disciplines are very varied (Shwartz et al., 2006). Understanding and investigating the unique nature and characteristics of each discipline will contribute to scientific literacy specific to that field (e.g. biology literacy, chemical literacy, health literacy, etc.) and scientific literacy in general.

There is always a transformation and change in natural phenomena, and whether the phenomena are observable or not, they are related to the chemical reactions. Chemistry involves studying matter and understanding the properties and components of matter that are important in disciplines such as physics, geography, health sciences, and environmental science (Petrucci et al., 2010). The Earth and its surroundings are involved with chemical components and products (Gilbert & Treagust, 2009). A scientific and practical understanding of chemistry can help students to understand the world that they are a part of. Chemistry includes observable (with the senses or the extension of senses-macroscopic level) and submicroscopic properties of matter as well as symbolic representations (Johnstone, 1991) which could be considered as a unique language related to the field. Chemical knowledge and explanations are needed for an understanding of daily life experiences (e.g. cleaning, cooking, and functioning of biological systems) as well as consideration and resolution of global issues (e.g. health issues, energy issues, environmental issues). Students' understanding of chemistry in their daily lives is essential in order to enhance meaningful science teaching (Yadigaroglu et al., 2021). School students should acknowledge the important role of chemistry in their lives as well as appreciate the discipline for their future well-being to have a good quality in their lives.

There are different definitions of chemical literacy stemming from various studies and theoretical frameworks since the 1980s (e.g. Bond, 1989; Cigdemoğlu & Geban, 2015; Shwartz et al., 2006; Kohen et al., 2020; Witte & Beers, 2003). Students' understanding of chemistry and their ability to use chemistry understanding in daily life is referred to as chemical literacy (Tsaparlis, 2000). Witte and Beers (2003) define chemical literacy as students' ability to use the information and scientific knowledge related to a chemical issue/problem and deal with the information to understand daily life problems. Chemical literacy helps students to understand and interpret ideas or discussions about chemistry and use these skills in their decision-making processes (Hofstein et al., 2011; Kohen et al., 2020).

Chemical literacy is an important part of scientific literacy (Mozeika & Bilbokaite, 2010) and comprised of three components: (1) key concepts in fundamental chemistry (such as compounds, elements, element symbols, chemical processes, and atomic models) (2) understanding what chemists and scientist do and what their scientific research is about, and (3) social context-understanding chemistry in real-life related issues (Dori et al., 2018; Shwartz et al., 2013). Shwartz et al. (2006) also mentioned the affective aspect, which refers to having an interest in chemistry-related issues. For example, students' curiosity about the chemicals in cleaning materials, learning about their properties, and using the knowledge when choosing cleaning products can be given as an example of the affective aspect. However, some chemistry teachers might tend to emphasize teaching scientific knowledge, rather than the skills and information that help students to understand the importance of chemistry in daily life. Also, students might think that chemistry concepts and theories are very difficult to learn and/or they have little value for their future professions and lives (Cigdemoglu & Geban, 2015). High school students find chemistry to be an intriguing subject because it mostly deals with abstract ideas that go beyond human experience and observation, making these things less intuitive (Cooper & Stowe, 2018). One of the main reasons for these problems in Turkey may be that mostly theoretical knowledge is included in the chemistry curriculum and great importance is attached to the teaching of this knowledge (Özden, 2007) and therefore chemistry education programs emphasize traditional and theoretical knowledge rather than associating this knowledge with daily life. A holistic understanding of chemistry plays an important role in individual and societal decision-making on chemistry-related issues and researchers have argued that both students and the public should achieve chemical literacy (Avargil et al., 2013; Dori et al., 2018). In this respect, it is important to determine the chemistry literacy levels of the students and consider their compatibility with the outcomes in the high school chemistry curriculum.

The definition of CL given by Shwartz et al. (2006) was based on a consensus view among chemists, educators, and high school teachers. The definition is based on the scientific literacy framework proposed by Bybee (1997), and there are four domains (components) of chemical literacy that high school graduates (freshmen university students) are expected to be familiar with (Shwartz et al., 2006).

Chemistry content knowledge: Students can understand general chemical facts, ideas, scientific research, generalization, and how to relate chemistry knowledge with other disciplines to find answers to scientific questions. Also, students should understand multiple representations in chemistry (macroscopic, sub-microscopic, and symbolic levels).

Chemistry in context: Students can use chemistry knowledge in order to explain daily life issues and make scientific and evidence-based decisions, and join in public debates about chemistry-related issues.

Higher-order thinking skills in chemistry: Students can ask questions about what observe or experience and also collect data, make inferences, and evaluate the multiple natures of the debates.

Affective aspects related to chemistry: Students can show interest in chemistry and chemistry-related issues in formal (chemistry education in school) and non-formal learning areas (e.g. social media, and news).

Various studies have been conducted to assess the chemistry literacy levels of students in chemistry education (Celik, 2014; Sadhu & Laksono, 2018; Shwartz et al., 2006; Thummathong & Thathong, 2016; Witte & Beers, 2003). Shwartz et al. (2006) investigated the chemical literacy levels of 10th-12th grade chemistry students. They aimed to assess students' ability to recognize chemical concepts (nominal literacy), describe key concepts in chemistry (functional literacy), and use chemistry understanding to explain everyday phenomena (conceptual literacy); and read materials (articles, advertisements, internet sources) and analyze information about chemistry given in the text (multi-dimensional literacy). They found that fundamental chemistry courses mostly contributed to nominal chemical literacy whereas only a small percentage of students achieved functional chemical literacy (the ability to define a concept correctly). Also, the majority of students did not give correct scientific explanations of daily phenomena. Using the same assessment tool, Celik (2014) determined Turkish pre-service teachers' levels of chemical literacy. The results showed that most students could relate their scientific understanding of chemical reactions, oxidation, diffusion, and mixtures to their daily lives. However, most of the students could not define chemistry concepts which were a sign of their low levels of functional chemical literacy.

Many countries aim to promote scientific literacy (e.g. England, Canada, Norway, the USA, Taiwan, and Australia) and chemistry curricula have been changed, in keeping with reforms of the other science content curricula in many countries to achieve the aim of chemical literacy (Herscovitz et al., 2012). The importance of scientific literacy as an aim of science education has been underlined in the last 20 years in Turkey. The aim of Turkish science teaching programs is to improve students' scientific literacy (Ministry of National Education of Turkey [MNE], 2013; 2018). Turkey is one of the countries which undergo major changes in education programs from time to time. Various revisions have been made in primary and secondary school programs to emphasize the relationship of knowledge with technology and society, as well as scientific concepts and content knowledge. The main goal of the new chemistry curriculum is to educate people to be chemically literate. In this context, the high school chemistry education curriculum helps students

- To have knowledge about the basic principles, concepts, theories, models, and laws of chemistry;
- To use chemistry knowledge and skills they have acquired course in explaining the phenomena related to daily life, environment, health, and industry;
- To understand and comprehend the role of chemistry in the continuity of life (mne, 2018).

Science teacher education programs focus on the development of literacy skills of pre-service teachers in discipline-specific areas (e.g. chemical literacy, health literacy, etc.). In particular, their ability to understand and explain current daily phenomena with theoretical chemistry knowledge (chemical explanations of everyday phenomena) will significantly affect the chemical literacy levels of their prospective students in the future to fulfil the aim of scientific literacy. In addition, the chemical explanations of first-year university students about daily phenomena mostly reflect their high school chemistry knowledge (Celik, 2014). In this direction, the examination of how chemistry concepts are included in the high curriculum is important in terms of explaining and making sense of the chemistry understanding of first-year students. Therefore, the aim of the present study is to determine freshmen pre-service science teachers' levels of chemical explanations of daily life phenomena. Also, it is aimed to investigate whether these examples are in accordance with the high school chemistry curriculum in Turkey. In light of this aim, the research questions are:

- How is pre-service science teachers' understanding of chemistry related to daily life phenomena?
- How are chemistry concepts in daily life phenomena included in the high school chemistry curriculum?

Materials and Method

This study was carried out with descriptive research methods. The descriptive design was used to examine and understand the phenomenon by getting information directly from the pre-service teachers involved in the teacher education program (Merriam, 1998). The study group was determined according to the convenience sampling method, one of the qualitative research sampling methods, and non-probability sampling (Patton, 2015). This sampling method allows the researchers to conduct the study practically since it is a type of non-probability sampling method (Yıldırım & Şimşek, 2013).

The participants of the study were 71 pre-service science teachers including 64 females and 7 males. They were freshmen students at the Department of Science Education in a state university in Turkey. In their first year of education, freshmen students usually take General Chemistry I-II and Chemistry Laboratory I-II courses as well as Biology and Physics courses. The data of the study were collected while the pre-service teachers were still taking their first semester courses (at the beginning of their first semester). Their ages were between 18-19 years and they all volunteered to be participants to join the study.

Data Collection

The data of the study were collected with a Multiple-choice Questionnaire titled as the "Chemical Explanations of Daily Phenomena" Questionnaire developed by Shwartz et al. (2006). The original questionnaire was translated into Turkish and used in another study for investigating Turkish pre-service teachers' chemical literacy levels (Celik, 2014). The questionnaire aimed to assess students' chemical explanations about daily life/everyday phenomena (e.g. rusty nail/redox reactions, smelling perfume/diffusion of gases). This questionnaire aims to determine the levels of conceptual chemical literacy. A number of examples from daily life and some statements about these examples were given in the questionnaire. The pre-service teachers were asked to carefully read the statements and decide whether the statements about the given phenomena were correct or incorrect. If they don't know the answer, there was a third option; "I can't know how to determine". There were 11 different everyday phenomena in the original questionnaire consisting of two different versions (version A and version B). 7 of these phenomena were used for the current study. Since only 5 scenarios were used in the translated version of Celik's study (2014), 2 of the scenarios were translated into Turkish by the researcher. The final version of the questionnaire in Turkish was examined by an outside researcher who is an expert in the field of science and chemistry education. These phenomena were related to chemistry concepts below:

- Diffusion of gases: smelling a perfume;
- Heat and temperature: wooden chair and metal chair;
- Combustion reactions and the law of conservation of mass: burning of a candle;
- Isotopes: heavy water;
- Reaction rate: acid rain;
- Redox reactions: rusting of iron;
- Mixtures and solutions: oil and water.

In line with the purpose of the study, the researcher investigated how these phenomena in the questionnaire are included in the chemistry curriculum. For this reason, the learning outcomes in the high school chemistry curriculum were examined. The latest version of the chemistry curriculum was revised and renewed in 2018 (MNE, 2018). According to the suggestions and demands of chemistry teachers and different stakeholders, some chemistry concepts and theories have been excluded from the curriculum; therefore the curriculum has been simplified compared to the earlier version. In addition, the learning outcomes were restructured to reflect higher-order thinking skills and daily life examples (Elmas et al., 2020). The learning outcomes in the curriculum were examined whether the daily phenomena and chemical concepts in the questionnaire are included (whether they are related to the chemistry topics in the questionnaire). If the statements in the questionnaire are not emphasized by the learning outcomes, students probably will not be

Table 1. Keywords Used for Search in the High School Chemistry Curriculum (MNE, 2018).

Daily Life Phenomenon	Keywords (searching words for curriculum)
Diffusion (Gases)	Diffusion, gas (gases), smell, smelling, perfume, odor
Temperature	Temperature, heat transfer, specific heat capacity
Combustion reactions (Burning candle)	Candle, wax, combustion reaction(s), the law of conservation of mass (conservation of mass)
Isotopes (Heavy water)	Heavy water, isotope(s), deuterium, radioactivity
Limestone reacting with acid	Limestone, acid(s), reaction rate, acid reaction (alternative keyword: acid-base reactions)
Redox reactions (Rusty nail)	Redox reaction, oxidation, nail, chemical bond, iron
Water and oil mixture	Mixture, heterogeneous mixture, oil-water (water-oil), hydrophobic

able to answer these statements correctly or they can probably only give answers based on guesses and interpretations of other knowledge sources. In the study, the aim was specifically to address this issue.

Data Analysis

The answers given by the pre-service teachers to each statement in the "Chemical Explanations of Daily Phenomena" Questionnaire were analyzed in three categories: correct answer, wrong answer and don't know/can't determine. The responses of the pre-service teachers to each statement in the questionnaire were analyzed by the researcher. The frequencies and percentages of the data obtained from the questionnaire were determined and presented in tables.

Also, document analysis was utilized and the learning outcomes in the chemistry curriculum were examined to answer the second research question. There are five steps to follow in document analysis "(1) accessing the relevant documents, (2) checking the authenticity of documents (accessing through official sources), (3) understanding documents (analyzing documents in a certain system and comparatively with each other), (4) analyzing data, and (5) using data to illustrate what the document refers to". In this study, five steps suggested by Yıldırım and Şimşek (2013) were followed to perform the analysis. The researcher first accessed the current chemistry curriculum (Secondary Education Chemistry Curriculum (MNE, 2018) via the official web page of MNE. This procedure is the first two steps in document analysis. For the third step, the researcher analyzed the learning outcomes which are related to the daily life examples in the questionnaire. For example, the first question is about the diffusion of gases, and the researcher searched for learning outcomes with the keywords such as gases, gas, diffusion, and smelling. The keywords searched in the curriculum within the scope of each question and statements in the questionnaire are presented in **Table 1**. Once the learning outcomes with these keywords were identified, they were examined for their correspondence with each statement in the daily life phenomena. Finally, the learning outcomes associated with each phenomenon are presented with direct quotations and/or examples. If a statement in the phenomena is not related to learning outcomes, this is also explained. This analysis was conducted by the researcher at two different times. After that, the outcomes were also examined by an expert chemistry teacher with a master's degree and a university professor in the science education department. All of the experts and the researcher reached a consensus on the analysis.

Results

In this section, the findings showing the chemical literacy levels of pre-service science teachers' chemistry knowledge of daily life phenomena are presented, and then the inclusion of chemistry concepts in daily life phenomena in the high school chemistry curriculum is examined. The findings are presented under seven sub-headings related to the daily life phenomena in the questionnaire. Each of these subheadings (Daily Life Phenomenon …) is presented in ***bold italics*** type. The quotations of the learning outcomes are given in italics type in the text.

Pre-service teachers' levels of conceptual chemical literacy were determined with questions asking about daily life-related phenomena. For each phenomenon, there were some statements that were evaluated as a correct or incorrect statement. For a third option, if the pre-service teachers didn't understand the statement nor had no knowledge about it, then they could choose to answer as "I can't determine/don't know. Scientifically correct statements are shown in normal font, and the incorrect statements are written in italic font in the following tables. Frequency (f) and percentage (%) values of each category are presented in the relevant tables.

Daily Life Phenomenon 1: Diffusion

Pre-service science teachers' conceptual understandings of diffusion are presented in **Table 2**. In this question, Statements 1A, 1C, 1D, and 1E (written in normal font) are the correct statements), whereas 1B and 1F (written in italics) are incorrect. The pre-service teachers mostly had a correct understanding of diffusion in statements 1A, 1C, and 1D. However, 39.44% of the participants had a misconception about the relationship between boiling point and evaporation (Statement 1B). Half of the participants answered statement 1E about smelling correct. However, as can be seen from the other

Table 2. Pre-Service Teachers' Conceptual Understanding of Diffusion.

"When a bottle of perfume is left open in a room - after a while, people can smell the perfume across the room. Below there are several statements pertaining to this phenomenon."

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
1A	Some of the perfume molecules pass from a fluid aggregate state to a gaseous aggregate state.	69	97.18%	2	2.82%	-	-
1B	*Transition to the gaseous state will take place only if the boiling point of the perfume is lower than the temperature of the room.*	28	39.44%	27	38.02%	16	22.53%
1C	The perfume molecules spread throughout the room through clashing with other molecules in the air.	68	95.77%	3	4.23%	-	-
1D	The higher the temperature in the room becomes the faster will be the evaporation.	58	81.69%	8	11.27%	5	7.04%
1E	A weak chemical bond forms between the perfume molecules and special sensors found in our noses.	36	50.70%	15	21.13%	20	28.17%
1F	*The connection between the perfume molecules and the smell sensors in the nose is not a chemical connection but rather a biological connection.*	41	57.75%	13	18.31%	17	23.94%

related statement 1F, most of the pre-service teachers did not fully grasp the chemistry of smell. Smelling odor is a chemical process but 57.75% of them thought that it is a biological process.

Diffusion in the chemistry curriculum: Diffusion is a key concept in the "Gases" unit at the Grade 11 level. In the chapter, there are two learning outcomes related to the derivation of Graham's Diffusion law and an experiment on the diffusion of gases as seen below:

"The Graham Law of Diffusion and Effusion is derived using the basic assumptions of kinetic theory." L.O. 11.2.3.1.b

"Diffusion experiment is performed; explained by using information technologies (animation, simulation, video, etc.)." L.O. 11.2.3.1.c

In addition to this, in the Gases unit, there is a learning outcome related to establishing a daily life relationship (e.g. "*Explains the partial pressures of gas mixtures with examples from daily life"-L.O. 11.2.4.1. Grade level 11*), however, the outcome is not related to the concept of diffusion. Also, the learning outcomes that may be related to the question in the questionnaire were searched with different keywords such as smell, smelling, and perfume. There are no outcomes related to smell and the process of smelling.

Table 3. Pre-Service Teachers' Conceptual Understanding of Temperature.

"A wooden chair and a metal chair are held in the same room for an extended period. Then, the temperatures of both chairs are measured. There are different statements below related to the temperature of the metal chair and the wooden chair."

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
2A	Transfer of energy will take place between the particles/molecules of each chair and the molecules in the air in the room to the point of equilibrium of energy between the air in the room and the chairs.	44	61.97%	20	28.17%	7	9.86%
2B	Transfer of energy will take place between the particles/molecules of each chair and the molecules in the air in the room to the point of equilibrium of temperatures between the room and the chairs.	54	76.06%	10	14.08%	7	9.86%
2C	When equilibrium in temperature between the two chairs in the room is reached - the particles building the two chairs will have the same kinetic energy as the molecules in the air.	28	39.44%	29	40.85%	14	19.72%
2D	*There will be a difference in temperatures of the two chairs. The metal one will heat up more if the room is hot and will cool off more if the room is cold.*	50	70.42%	15	21.13%	6	8.45%
2E	*The proof that the temperature of the two chairs is different is how we feel when we sit on them.*	26	36.62%	31	43.66%	14	19.72%
2F	*The final temperature of each chair depends on the melting point of the material it is built of.*	22	30.99%	32	45.07%	17	23.94%

In addition, the learning outcome related to perfume only includes an explanation of the harmful chemicals it may contain (grade level 10) which is not related to diffusion. In this respect, it can be said that students do not have curricular chemistry knowledge that may enable them to answer the questions in 1E and 1F.

Daily Life Phenomenon 2: Temperature

Pre-service science teachers' understanding of temperature is presented in **Table 3**. Most of the pre-service teachers gave correct answers for statements 2A and 2B (61.97%-76.06%). However, it is seen that they had various misconceptions in many of the other statements, especially in 2D. 70.42% of them thought that the metal chair would more heat up than the wooden chair in a hot environment, or cool off more in a cold environment, incorrectly. The most important misconception seen in this section is that they think that different substances made of different materials in the same environment (waiting for a while) can have different temperatures. This might show that their understanding of heat transfer is problematic and/or they don't take into account the specific heat capacity of the material that the chair is made of.

Table 4. Pre-Service Teachers' Conceptions of Burning Candle.

"When a candle burns it seems that the wax (wax is a solid mixture of carbohydrates) disappears. Following are various statements explaining what happens to wax when the candle burns/burning the candle."

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
3A	*In the course of burning the volume of the wax lessens mainly because air trapped within the wax during its production is released.*	41	57.75%	9	12.68%	21	29.58%
3B	*A candle burning is just only a change in the state of aggregation of the wax that the candle is made of - first it melts and after it evaporates.*	45	63.38%	22	30.99%	4	5.63%
3C	The burning of a candle is a reaction between the wax and oxygen in the air.	61	85.92%	6	8.45%	4	5.63%
3D	*The law of conservation of mass exists in states of combustion reaction only if it occurs in a closed vessel.*	48	67.61%	11	15.49%	12	16.90%
3E	*The law of conservation of mass exists in states of combustion reaction only if complete combustion takes place.*	24	33.80%	30	42.25%	17	23.94%

Temperature in the chemistry curriculum: The concept of temperature is covered in the high school chemistry curriculum within the scope of different topics such as gases, liquids and viscosity, solubility, and reaction rate. However, the statements in the questionnaire ask about the role of temperature in heat transfer. For this reason, after searching with temperature as a keyword, keywords such as heat transfer, and specific heat capacity were investigated in the curriculum. However, it is seen that these topics are not addressed in the high school chemistry curriculum. Although it is not included in the scope of the study, it was determined that the content related to this phenomenon in the questionnaire was actually covered in the high school physics curriculum.

Daily Life Phenomenon 3: Burning Candle

Pre-service science teachers' understanding of burning candle is presented in **Table 4**. The question on the burning of candle was aimed at identifying participants' conceptual understandings of combustion reactions and also the law of conservation of mass. Even though most of the students (85.92%) had a correct understanding of the reaction between the wax and oxygen (statement 3C), most of them had a misunderstanding about the chemical reaction of the wax (3A). 57.75% of the pre-service teachers incorrectly thought that there was air trapped in the wax and it was released during burning. In addition, there are some important misconceptions about the law of conservation of mass. Most of the pre-service teachers (67.61%) thought that conservation of mass can only occur in a closed vessel. Similarly, some students (33.80%) also thought that *"The law of conservation of mass exists in states of combustion reaction only if complete combustion takes place" which is an incorrect statement.*

Burning of Candle in the Chemistry Curriculum: Keywords related to the phenomenon such as candle, wax, combustion reaction(s), and the law of conservation of mass were searched in the chemistry curriculum. Among the learning outcomes related to candles and wax, there is a learning outcome on esters at the 12*th*-grade level: "*Wax is given as an example of natural substances containing esters- L.O. 12.3.7.1. Grade level 12*". However, this learning outcome does not contain any related information about combustion reactions. Among the learning outcomes related to the law of conservation of mass is the following excerpt in the "*Fundamental Laws of Chemistry and Chemical Calculations*" unit at the 10th-grade level. In this outcome, the relationship with daily life is not emphasized.

"Explains the basic laws of chemistry and makes calculations about conservation of mass" (L.O. 10.1.1.a)

The learning outcomes related to combustion reactions are included in the unit of "*Fundamental Laws of Chemistry and Chemical Calculations*" at the Grade 10 level. Combustion reactions are key concepts in this unit. The learning outcome in this unit is given in the following excerpt below. Although it is stated in the learning outcome that combustion reactions will be explained with various examples, the relevance of these examples to daily life is not specified.

"Combustion, synthesis (formation), analysis (decomposition), acid-base, dissolution-precipitation reactions are explained with examples." L.O. 10.1.3.1.b

Daily Life Phenomenon 4: Isotopes

Pre-service science teachers' understanding of heavy water and isotopes is presented in **Table 5**. The majority of the pre-service teachers could not give correct answers to the statements in this question. Most of the pre-service teachers were able to give a correct answer only to statement 4E (57.75%). Also, in this section, some of the pre-service teachers (29.58%-36.62%) stated that they did not know the answer.

Isotopes in the chemistry curriculum: The learning outcomes were searched with keywords such as heavy water, deuterium and isotope, and radioactivity. It is seen that there is no content or learning outcome related to heavy water, deuterium, and radioactivity in the high school chemistry cur-

Table 5. Pre-Service Teachers' Conceptual Understanding of Isotopes.

"You will certainly have heard the term heavy water somewhere. What kind of water is this? What differences would you expect to find between regular water and 'heavy water?"

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
4A	*Heavy water is distilled water.*	30	42.25%	18	25.35%	23	32.39%
4B	*Heavy water is water in which the molecules contain only hydrogen, e.g., deuterium.*	32	45.07%	13	18.31%	26	36.62%
4C	*The difference between a regular hydrogen atom and a deuterium atom is in the number of protons in the nucleus.*	34	47.89%	16	22.53%	21	29.58%
4D	*Water molecules containing heavy isotopes cannot be found in nature.*	19	26.76%	26	36.62%	26	36.62%
4E	*There is no difference in density between 'regular' water and 'heavy' water.*	8	11.27%	41	57.75%	22	30.99%

Table 6. Pre-service teachers' conceptual understanding of limestone reacting with acid.

"To examine the effect of acid rain on buildings and sculptures built of limestone the following experiments were conducted: In the first experiment a small block of limestone rock whose mass was 1 gram was put into an acid solution. The block reacted (to the point of its complete disappearance) and gas was discharged, was collected and its amount was measured precisely. In the second experiment 1 gram of limestone dust was put into an identical amount and identical concentration of acid. Both experiments were carried out at exactly the same temperature. Following are various statements pertaining to the two experiments:"

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
5A	*The solid limestone changed aggregation state; in the course of the reaction it turned into liquid and after to gas.*	34	47.89%	25	35.21%	12	16.90%
5B	*Only the temperature influences the rate of reaction.*	12	16.90%	56	78.87%	3	4.23%
5C	*Since the identical temperature was maintained in both the experiments - the reaction occurred at exactly the same rate.*	17	23.94%	50	70.42%	4	5.63%
5D	Exactly the same volume of gas was obtained in the two experiments.	52	73.24%	10	14.08%	9	12.68%
5E	The gas discharged in the reaction is carbon-dioxide.	61	85.92%	3	4.23%	7	9.86%
5F	The reaction was faster in the second experiment because of a larger interface between the acid and the limestone.	55	77.46%	13	18.31%	3	4.23%
5G	A change in the acid concentration could also change the reaction rate.	66	92.96%	5	7.04%	-	-

riculum. However, the concept of an isotope is included as a key concept in "the Atom and Periodic System" unit at the 9th-grade level and there is a learning outcome about isotopes in the unit as shown below:

"The concepts of the electron, proton, neutron, atomic number, mass number, isotope, isotone, isobar, and isoelectronics are introduced." L.O. 9.2.2.1.a

However, the relationship with daily life (such as heavy water and isotopes) is not covered in the curriculum. In addition, at the Grade 10 level, the concept of isotope and the reason why the molar masses of some elements are not integers are explained in the unit; "Fundamental Laws of Chemistry and Chemical Calculations" (L.O. 10.1.2.1.c).

Daily Life Phenomenon 5: Limestone Reacting with Acid

Pre-service science teachers' conceptual understanding of "limestone reacting with acid" is presented in **Table 6**. Most of the pre-service teachers answered the statements given in this daily life phenomenon correctly (5B, 5C, 5D, 5E, 5F, 5G). The percentages of those who answered the questions correctly ranged between 70.42% and 92.96% except for one item; 5A. Only 35.21% of the pre-service teachers were able to answer item 5A correctly whereas 47.89% answered incorrectly.

The phenomenon "Limestone reacting with acid" in the chemistry curriculum: The learning outcomes were searched with limestone, acid, reaction rate, and acidic reactions. The Unit; "Reaction Rates" is at the 11th-grade level and "the Factors Affecting the Rate of Reaction (e.g. temperature, particle size)" are explained among the outcomes. The relevant outcome is given in the excerpt below:

"Explains the factors affecting the reaction rate. The effect of substance type, concentration, temperature, catalyst (not enzymes), and contact surface on the reaction rate is emphasized." L. O. 11.5.2.1

The learning outcomes related to acidic reactions are included in the unit "the Fundamental Laws of Chemistry and Chemical Calculations" at the Grade 10 level. The acid reaction is a key concept in this unit. The learning outcome in this unit is given in the following excerpt below:

Table 7. Pre-Service Teachers' Conceptions of Redox Reactions.

"A nail made of iron rusted after being in an environment in which it was exposed both to air and to moisture. The nail looks as if the iron was "eaten" and disappeared, but when weighing the iron and the rust that formed on it, it became clear that the mass was higher than the original mass of the nail, before it rusted. Following are statements relating to this phenomenon:"

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
6A	*The nail's mass increased only because the water molecules that were absorbed on the surface of the metal and molecules of the material are different than the air that was absorbed on the surface of the metal.*	14	19.72%	46	64.79%	11	15.49%
6B	The mass of the nail increased because the iron reacts with the oxygen.	70	98.59%	-	-	1	1.41%
6C	During a reaction between a metal and oxygen, there is a transfer of electrons from the metal to the oxygen.	43	60.56%	12	16.90%	16	22.53%
6D	*During a reaction between metal and oxygen a covalent bond forms between the metal atoms and the oxygen atoms.*	29	40.85%	33	46.48%	9	12.68%
6E	Various metals differ from each other in their tendency to be oxidized.	67	94.37%	-	-	4	5.63%
6F	Iron is a metal that has the highest tendency to be oxidized.	60	84.51%	4	5.63%	7	9.86%

"Combustion, synthesis (formation), analysis (decomposition), acid-base, dissolution-precipitation reactions are explained with examples." L.O. 10.1.3.1.b

In addition, "the Acids, Bases, and Salts" unit in Grade 10 includes detailed learning outcomes related to this phenomenon. Also, daily life example in the questionnaire is included in the curriculum on acids and bases in our lives (L.O. 10.3.3.1). The related learning outcomes are presented in the excerpts:

"Teacher explains important reactions of acids and bases in terms of daily life." L.O. 10.3.2.2.

"Teacher explains the benefits and harms of acids and bases. The formation of acid rain and its effects on the environment and historical artefacts are mentioned." L.O. 10.3.3.1

Daily Life Phenomenon 6: Redox Reactions

Pre-service science teachers' understanding of "rusty nail-reduction-oxidation" is presented in **Table 7**. It is seen that pre-service teachers gave a high percentage of correct answers, especially to statements 6B, 6E, and 6F (84.51%- 94.37%). Similarly, most of the participants gave correct answers to items 6A and 6C. Only about half of them answered the question about the type of chemical bond in 6D correctly.

Redox reactions in the chemistry curriculum: The learning outcomes were searched with redox reaction, oxidation, corrosion, nail, and chemical bond. Redox reactions are included in "the Chemistry and Electricity" unit at the Grade 12 level. In addition, learning outcomes related to the concept of corrosion are also included in the same unit. Within the scope of this unit, students:

> *"Recognize redox reactions. a. The concepts of oxidation and reduction are emphasized. Redox reactions are equated and common oxidants (O2) and reductants are introduced." L. O. 12.1.1.1*
> *"Explain the electrochemical basis of corrosion prevention methods. a. The concept of corrosion is explained." L.O. 12.1.6.1.*

In addition, ionic bonds and covalent bonds are included in detail among the high school chemistry curriculum learning outcomes at the 9^{th}-grade level.

Daily Life Phenomenon 7: Water and Oil Mixtures

Pre-service science teachers' understanding of water and oil mixture is presented in **Table 8**. Most of the pre-service teachers possessed an adequate understanding of this phenomenon. The percentages of correct answers were more than fifty percent for each statement. Statement 7B (*water and oil do not mix because they have different specific gravity*), is the one with the lowest percentage of correct answers in this section (25.35%).

Mixtures in the chemistry curriculum: In order to determine the learning outcomes regarding this phenomenon, the curriculum was searched with the keywords; mixture, heterogeneous mixture, oil-water, water-oil, and hydrophobic. In the 10th-grade level "Mixtures" unit, there are learning outcomes related to heterogeneous mixtures and homogeneous mixtures as can be seen below:

> *"Student classifies mixtures according to their qualities." L.O. 10.2.1.1.*

> *"Explains the properties that are decisive in distinguishing homogeneous and heterogeneous mixtures." L.O. 10.2.1.1.a*

Table 8. Pre-Service Teachers' Conceptions of Water and Oil.

"If we put water and oil in a test tube we will discern that they don't mix with each other. Following are various statements that are related to this phenomenon."

		Correct statement (f-%)		Incorrect statement (f-%)		I can't determine (f-%)	
7A	Water and oil are a mixture	66	92.96%	4	5.63%	1	1.41%
7B	*Water and oil do not mix because the two materials each have a different specific gravity.*	18	25.35%	41	57.75%	12	16.90%
7C	The term hydrophobic relates to material whose molecules do not bond with water molecules	66	92.96%	2	2.82%	3	4.23%
7D	Molecules of hydrophobic material are non-polarized molecules	48	67.60%	12	16.90%	11	15.49%
7E	There are molecules that are capable of bonding with both water molecules and molecules of oily materials.	45	63.38%	9	12.68%	17	23.94%
7F	Most creams for cosmetic use are a uniform mixture of a watery solution and some kind of oily material.	58	81.69%	3	4.23%	10	14.08%

"It is emphasized that homogeneous mixtures are called solutions and examples of solutions from daily life are given." L.O. 10.2.1.1.b

"Heterogeneous mixtures are classified according to the physical state of the dispersing substance and the dispersing medium." L.O. 10.2.1.1.c

In addition, the unit also includes learning outcomes on the separation and purification techniques of mixtures. There is also an outcome of conducting experiments to separate mixtures, but it is not emphasized which mixtures are meant here. Finally, there were no learning outcomes including the term, hydrophobic in the chemistry curriculum.

Discussion and Conclusion

The aim of this study is to determine freshmen pre-service science teachers' levels of chemical explanations of various daily life phenomena. Also, it is aimed to investigate whether these daily life examples are in accordance with the high school chemistry curriculum in Turkey. The findings of the study are presented under 7 headings regarding the daily life examples included in the questionnaire. After presenting the students' chemical understanding of each daily life phenomenon, how the daily life phenomena and theoretical explanations are covered in the high school chemistry curriculum is analyzed.

The findings showed that the majority of pre-service teachers have a generally correct understanding of diffusion and could partially relate their chemical understanding of diffusion to daily life. However, many of them answered incorrectly or could not answer the statement "*Transition to the gaseous state will take place only if the boiling point of the perfume is lower than the temperature of the room*". Similarly, most of the students who participated in Celik's (2014) study incorrectly thought that the changing state of the perfume could only take place if the boiling point of the perfume is lower than the temperature of the environment. Also, most of the pre-service teachers could not give a correct answer about the chemical process of smell ("*The connection between the perfume molecules and the smell sensors in the nose is not a chemical connection but rather a biological connection*"). This finding regarding smell might be related to the learning outcomes in the curriculum. As a matter of fact, there is no learning outcome that will enable participants to interpret whether the smelling process is chemical or biological. When the learning outcomes related to diffusion are examined holistically, it is seen that there are no learning outcomes that emphasize the relationship between diffusion and daily life. It was determined that there are different misconceptions about the diffusion of gases in the literature. Among these misconceptions are "*The diffusion rate of gases increases as their molecular weight increases", "The diffusion rate of a gas is directly proportional to its molecular weight" and "The molar mass is directly proportional to the diffusion rate of gases*" (Meşin et al., 2019). In addition to these misconceptions, the findings of this study revealed that students had the misconception "*Transition to the gaseous state will take place only if the boiling point of the perfume is lower than the temperature of the room*". This misconception also shows that students cannot relate chemistry knowledge to their daily experiences (for example, feeling the smell of perfume sprayed from a distance even in cold weather).

The findings related to the temperature showed that most of the pre-service teachers had incorrect answers or could not give any answer to most of the statements. Most of them gave incorrect answers, especially to the statement; *"There will be a difference in temperatures of the two chairs. The metal one will heat up more if the room is hot and will cool off more if the room is cold*". Previous literature studies on thermal energy and related concepts in everyday contexts (e.g. Chu et al., 2012; Harrison et al., 1999) showed that students had alternative conceptions about thermal equilibrium (*"The temperature of different objects is different even though they have been placed in the same environment over an extended period of time"*). Also, the temperature in the context of heat transfer and specific heat capacity is not covered in the high school chemistry curriculum. This might also explain their low levels of understanding.

The findings related to the burning of a candle showed that most of the participants had a correct understanding of the reaction between the wax and oxygen. The findings also revealed their understanding of combustion reactions and the law of conservation of mass. However, they had incorrect answers, especially about the law of conservation of mass and combustion reactions in open and closed systems. Although the relationship between the burning of wax and combustion reactions is not included in the chemistry curriculum, scientific explanations (definitions) of combustion reactions and the law of conservation of matter are among the learning outcomes. Similar misconceptions regarding the conservation of mass during combustion reactions are also found in the literature. Boujaoude's (1991) study at the middle school level showed that most of the students thought there would be no change when a candle burned in a closed vessel. Also, Haidar (1997) found that pre-service chemistry teachers did not develop an appropriate conceptual understanding of the conservation of matter and related concepts.

Students' conceptual understanding of heavy water and isotopes showed that they had a very limited understanding in general. Many of the participants thought that heavy water is distilled water, or they could not answer the question. Heavy water is a form of water that contains only deuterium rather than the common hydrogen-1 isotope (Britannica the Editors of Encyclopedia, 2022) whereas distilled water is pure water, produced with the distillation of plain water (containing hydrogen-1). Also, nearly half of them thought that *"The difference between a regular hydrogen atom and a deuterium atom is in the number of protons in the nucleus"* which is an incorrect statement. In the study of Molu et al. (2016), 68% of the pre-service teachers were able to explain the concepts of isotope and radioisotope correctly. However, in this study, the percentage of correct answers was found to be 22.53%. In Tsaparlis et al.'s (2013) study with Turkish and Greek participants, an average of 20% of Greek pre-service teachers and 11% of Turkish pre-service teachers gave acceptable or partially acceptable answers, while a large number (on average about 50% of Greek students and 27% of Turkish students) avoided answering the questions. Similar to the finding of this study, Tsaparlis et al. (2013) found that the most common misconception was the confusion of "mass number" with "atomic number". The current chemistry curriculum does not include any learning outcomes related to heavy water and deuterium, but only one learning outcome that includes the definition of the concept of the isotope. This may be one of the reasons why the participants gave incorrect answers or did not give answers to the questions on isotopes and heavy water.

Participants' responses about "limestone reacting with acid" showed that this phenomenon is one of the daily life phenomena with the highest number of correct answers. One of the reasons for this may be that the learning outcomes in the curriculum directly include the effects of acid rain on nature and historical structures. The findings showed that the lowest percentage of the correct responses was on the aggregation state of limestone *"The solid limestone changed aggregation state; in the course of the reaction it turned into liquid and after to gas"*. A similar finding regarding the statement was obtained from Celik's (2014) study, as well. This may indicate that the participants only interpreted the reaction as far as they could observe it (at a macroscopic level), as they were informed in the questionnaire that the limestone rock or dust completely disappeared when the reaction was completed. Therefore, it can be interpreted that they lacked the ability to think about the reaction at the sub-molecular level. The pre-service teacher in this study had adequate understanding related to reaction rate, acid-base reactions, and the related daily life phenomena; acid rain. However, there are various studies that reveal that students have misconceptions about these concepts (Cakmakci et al., 2005; Pabuçcu, 2016; Karslı & Ayas, 2014; Kolomuç & Tekin, 2011). For example, Pabuçcu's (2016) study showed that first-year pre-service teachers did not have sufficient knowledge about how acid rain occurred and its effects on the environment. Cakmakci et al. (2005) found that even after instruction, many students use conceptions that are not consistent with a scientific perspective, and have difficulties in understanding the relationships between concentration and reaction rate. However, the findings of the current study demonstrate that most of the participants had a correct understanding of the factors influencing reaction rate (particle size, temperature, concentration).

Pre-service science teachers' understanding of redox reactions (rusty nail example) showed that this phenomenon is also one of the daily life phenomena with a higher number of correct answers. One of the reasons for this might be the inclusion of topics such as redox reactions and corrosion in the chemistry curriculum. However, this daily life example in the questionnaire shows that pre-service teachers (40.85%) have some misconceptions about the type of chemical bond formed (ionic bond) during redox reactions. (*"During a reaction between metal and oxygen a covalent bond forms between the metal atoms and the oxygen atoms"*). Treagust et al. (2014) state that redox reactions, in particular, are regarded by students as one of the most difficult topics as they involve multiple levels of chemical representation (e.g. macroscopic, sub-microscopic, symbolic) and there are four models, named the oxygen model, the hydrogen model, the electron model, and the oxidation numbers model, that can explain the complex nature of redox reactions. For this reason, in a question/topic related to redox reactions, students may focus only on reduction and oxidation and may not think in detail about the type of bond formed. Nakhleh (1992) asked students' views on what happens when iron rusts and found that they had some misconceptions such as *"Displacement hm one physical location to another occurs", "The material is modified (another form of the original material)", 'Transmutation occurs"*. Even if it is not the case in this present study, pre-service teachers could not make the connection between electron exchange and ionic bonding.

Most of the pre-service teachers possessed an adequate understanding of water and oil mixtures. The percentages of correct answers were more than fifty percent for each statement. One of the interesting findings of the study is that the students answered the questions correctly, especially the questions involving the concept of hydrophobic particles (parts), which is not included in the high school curriculum. The reason for this may be that they have heard this term in daily life or in different courses, although it is not included in the curriculum.

In this study, the "Chemical Explanations of Daily Phenomena" Questionnaire developed by Shwartz et al. (2006) was used. Shwartz et al. (2006) also developed and used different questionnaires to determine the various levels of chemical literacy. One of the limitations of the present study is that only the students' ability to relate chemistry to daily life was examined and aspects such as the multi-dimensional level were not identified. The multi-dimensional level focuses on students' ability to understand a chemistry-related text or to recognize chemistry-related aspects in content such as a newspaper article. Therefore, through different texts and current global and local events (e.g. vaccines, nanotechnology, alternative energy resources, sustainability, carbon footprint, global environmental problems, etc.), students' multi-dimensional chemical literacy level can be identified and their awareness of socioscientific issues can be enhanced.

The findings also showed that students' answers regarding the topics that were not sufficiently covered in the high school curriculum were generally incorrect. The 2018 chemistry curriculum was simplified compared to the previous curriculum, but concepts such as radioactivity, heat transfer, and specific heat capacity were not included. Although some of these concepts are included in the curricula of other disciplines such as physics, they are considered to be important topics for high school chemistry. It is suggested that these topics should be integrated into the curriculum in future revision.

Some limitations of the study should be mentioned. The study was conducted with pre-service science teachers who were first-year students and new entrants to the university. Examining only the chemical literacy levels of pre-service teachers may be partially insufficient in interpreting the findings. In addition, the number of pre-service teachers participating in the study was 71. It would be more appropriate to interpret chemical literacy levels with a larger group of participants. Due to these limitations, some suggestions can be made for future research. It is recommended to examine the views of high school students as well as pre-service teachers and thus increase the sample size. Also, conducting longitudinal studies involving different grade levels are recommended for future researchers. In addition, open-ended questions and interviews can further explore participants' chemical understandings and explanations of daily life phenomena. Therefore, future studies could focus on developing open-ended questionnaires about chemistry-related topics in daily life.

References

Avargil, S., Herscovitz, O., & Dori, Y. J. (2013). Challenges in the transition to large-scale reform in chemical education. *Thinking Skills and Creativity*, 10:189-207. DOI: https://doi.org/10.1016/j.tsc.2013.07.008

Bond, D. (1989). In pursuit of chemical literacy: A place for chemical reactions. *Journal of Chemical Education*, 66(2):157. DOI: http://dx.doi.org/10.1021/ed066p157

BouJaoude, S. B. (1991). A study of the nature of students' understandings about the concept of burning. *Journal of Research in Science Teaching*, 28(8):689-704. DOI: https://doi.org/10.1002/tea.3660280806

Britannica, The Editors of Encyclopedia (2022). Heavy Water. Encyclopedia Britannica, December 23, 2022. Available at: https://www.britannica.com/science/heavy-water

Bybee, R. W. (1997). Achieving Scientific Literacy: From Purposes to Practices. Heinemann. ISBN: ISBN-0-435-07134-3

Bybee, R. W. (2012). Scientific literacy in environmental and health education. In A. Zeyer, & R. Kyburz-Graber (Eds.), Science|Environment|Health (pp. 49-67). Springer. DOI: https://doi.org/10.1007/978-90-481-3949-1_4

Cakmakci, G., Donnelly, J., & Leach, J. (2005). A Cross-sectional study of the understanding of the relationships between concentration and reaction rate among Turkish secondary and undergraduate students. In K. Boersma, M. Goedhart, O. de Jong, & H. Eijkelhof (Eds.), Research and the quality of science education (pp. 483–497). Springer. DOI: https://doi.org/10.1007/1-4020-3673-6_38

Celik, S. (2014). Chemical literacy levels of science and mathematics teacher candidates. *Australian Journal of Teacher Education*, 39(1):1-15. DOI: https://doi.org/10.14221/ajte.2014v39n1.5

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education*, 34(10):1509-1534. DOI: https://doi.org/10.1080/09500693.2012.657714

Cigdemoglu, C., & Geban, O. (2015). Improving students' chemical literacy levels on thermochemical and thermodynamics concepts through a context-based approach. *Chemistry Education Research and Practice*, 16(2):302-317. DOI: https://doi.org/10.1039/C5RP00007F

Cooper, M. M., & Stowe, R. L. (2018). Chemistry education research-From personal empiricism to evidence, theory, and informed practice. *Chemical Reviews*, 118(12):6053-6087. DOI: https://doi.org/10.1021/acs.chemrev.8b00020

Dori, Y. J., Avargil, S., Kohen, Z., & Saar, L. (2018). Context-based learning and metacognitive prompts for enhancing scientific text comprehension. *International Journal of Science Education*, 40(10):1198-1220. DOI: https://doi.org/10.1080/09500693.2018.1470351

Elmas, R., Rusek, M., Lindell, A., Nieminen, P., Kasapoğlu, K., & Bílek, M. (2020). The intellectual demands of the intended chemistry curriculum in Czechia, Finland, and Turkey: a comparative analysis based on the revised Bloom's taxonomy. *Chemistry Education Research and Practice*, 21(3):839-851. DOI: https://doi.org/10.1039/D0RP00058B

Gilbert, J. K., & Treagust, D. (2009). Macro, submicro and symbolic representations and the relationship between them: Key models in chemical education. In E. Gilbert, J. K. Gilbert, & D. Treagust (Eds.), Multiple representations in chemical education (pp. 1-8). Springer. DOI: https://doi.org/10.1007/978-1-4020-8872-8_1

Haidar, A. H. (1997). Prospective chemistry teachers' conceptions of the conservation of matter and related concepts. *Journal of Research in Science Teaching*, 34(2):181-197. DOI: https://doi.org/10.1002/(SICI)1098-2736(199702)34:2<181::AID-TEA5>3.0.CO;2-P

Harrison, A.G., Grayson, D.J., & Treagust, D.F. (1999). Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, 36(1):55–87. DOI: https://doi.org/10.1002/(SICI)1098-2736(199901)36:1<55::AID-TEA5>3.0.CO;2-P

Herscovitz, O., Kaberman, Z., Saar, L., & Dori, Y.J. (2012). The relationship between metacognition and the ability to pose questions in chemical education. In A. Zohar, & Y. Dori (Eds.), Metacognition in science education. Contemporary trends and issues in science education vol 40. (pp.165-195). Springer. DOI: https://doi.org/10.1007/978-94-007-2132-6_8

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education—a pedagogical justification and the state-of-the-art in Israel, Germany, and the USA. *International Journal of Science and Mathematics Education*, 9(6):1459-1483. DOI: https://doi.org/10.1007/s10763-010-9273-9

Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. *International Journal of Environmental and Science Education*, 4(3):275-288. Available at: https://eric.ed.gov/?id=ej884397

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7(2):75-83. DOI: https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Karsli, F., & Ayas, A. (2014). Developing a laboratory activity by using 5E learning model on student learning of factors affecting the reaction rate and improving scientific process skills. *Procedia-Social and Behavioral Sciences*, 143:663-668. DOI: https://doi.org/10.1016/j.sbspro.2014.07.460

Kohen, Z., Herscovitz, O., & Dori, Y. J. (2020). How to promote chemical literacy? Online question posing and communicating with scientists. *Chemistry Education Research and Practice*, 21(1):250-266. DOI: https://doi.org/10.1039/C9RP00134D

Kolomuç, A., & Tekin, S. (2011). Chemistry teachers' misconceptions concerning concept of chemical reaction rate. *International Journal of Physics and Chemistry Education*, 3(2):84-101. DOI: https://doi.org/10.51724/ijpce.v3i2.194

Merriam, S. B. (1998). Qualitative Research and Case Study Applications in Education. Jossey-Bass Publishers. ISBN: 9780787910099.

Meşin, M. Z., Koçak, N., Koçak, A., & Şahin, M. (2019). 2007-2017 yılları arasında Türkiye'de gazlar konusunda kavram yanılgıları ile ilgili yapılan çalışmalar: Bir içerik analizi [Studies on misconceptions about gases conducted in Turkey between 2007-2017: A content analysis]. *Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi*, 13(2):620-650. DOI: https://doi.org/10.17522/balikesirnef.512765

Ministry of National Education of Turkey (MNE) (2013). Chemistry Education Curriculum for Secondary Grades (9, 10, 11, and 12th Grades), Ministry of National Education, Board of Education.

Ministry of National Education of Turkey (MNE) (2018). Chemistry Education Curriculum for Secondary Grades (9, 10, 11, and 12th Grades), Ministry of National Education, Board of Education.

Molu, Z. , Kahyaoğlu, H., & Köksal, E. A. (2016). Fen bilgisi öğretmen adaylarının radyoaktiflikle ilgili bilgi düzeyleri [Knowledge levels of pre-service science teachers on radioactivity]. *Journal of the Turkish Chemical Society Section C: Chemical Education*, 1(1):165-190. Available at: https://dergipark.org.tr/en/pub/jotcsc/issue/30533/330317

Mozeika, D., & Bilbokaite, R. (2010). Teaching and learning method for enhancing 15-16 years old students' knowledge as one of scientific literacy aspect in chemistry: Results based on research and approbation. *International Journal of Educational Researchers*, 1(3):1-16. Available at: https://dergipark.org.tr/en/pub/ijers/issue/8489/105626

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education*, 69(3):191. DOI: https://doi.org/10.1021/ed069p191

National Research Council [NRC] (1996). National Science Education Standards. National Academy Press. ISBN: 978-0-309-05326-6.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, 87(2):224-240. DOI: https://doi.org/10.1002/sce.10066

Özden, M. (2007). Problems with science and technology education in Turkey. Eurasia Journal of Mathematics, *Science and Technology Education*, 3(2):157-161. DOI: https://doi.org/10.12973/ejmste/75391

Pabuçcu, A. (2016). Öğretmen adaylarının asit yağmurlarıyla ilgili bilgilerinin kimya okur-yazarlığı açısından incelenmesi [Investigating pre-service science teachers' knowledge of acid rain in terms of chemical literacy]. Abant İzzet Baysal Üniversitesi Eğitim Fakültesi Dergisi, 16(3):961-976. Available at: https://dergipark.org.tr/en/pub/aibuefd/issue/24917/263023

Papageorgiou, G., Markos, A., & Zarkadis, N. (2016). Understanding the Atom and Relevant Misconceptions: Students' Profiles in Relation to Three Cognitive Variables. *Science Education International*, 27(4):464-488. Available at: https://eric.ed.gov/?id=EJ1131138

Patton, M.Q. (2015). Qualitative Research and Evaluation Methods (4th ed.). Sage Publishing. ISBN: 9781412972123.

Petrucci, R. H., Herring, F. G., Bissonnette, C., & Madura, J. D. (2010). General Chemistry: Principles and Modern Applications. Pearson Canada. ISBN: 9780136121497

Roberts, D.A. (2007). Scientific literacy/science literacy. In S.K. Abell, & N.G. Lederman (Eds.), Handbook of research on science education (pp. 729-780). Lawrence Erlbaum Associates.

Sadhu, S., & Laksono, E. W. (2018). Development and validation of an integrated assessment for measuring critical thinking and chemical literacy in chemical equilibrium. *International Journal of Instruction*, 11(3):557-572. DOI: https://doi.org/10.12973/iji.2018.11338a

Shwartz, Y., Ben-Zvi, R., & Hofstein, A. (2006). The use of scientific literacy taxonomy for assessing the development of chemical literacy among high-school students. *Chemistry Education Research and Practice*, 7(4):203-225. DOI: https://doi.org/10.1039/B6RP90011A

Shwartz Y., Dori Y. J., & Treagust D., (2013), How to justify formal chemistry education, to outline its objectives and to assess them. In I. Eilks, & A. Hofstein, (Eds.), Teaching chemistry-a studybook: A practical guide and textbook for student teachers, teacher trainees and teacher (pp. 37–66.) Sense Publishers.

Suwono, H., Pratiwi, H. E., Susanto, H., & Susilo, H. (2017). Enhancement of students' biological literacy and critical thinking of biology through socio-biological case-based learning. *Journal Pendidikan IPA Indonesia*, 6(2):213-220. Available at: https://journal.unnes.ac.id/nju/index.php/jpii/article/view/9622

Thummathong, R., & Thathong, K. (2016). Construction of a chemical literacy test for engineering students. *Journal of Turkish Science Education*, 13(3):185-198. Available at: https://www.tused.org/index.php/tused/article/view/649

Treagust, D.F., Mthembu, Z., & Chandrasegaran, A.L. (2014). Evaluation of the predict-observe-explain instructional strategy to enhance students' understanding of redox reactions. In I. Devetak, & S. Glažar (Eds.), Learning with understanding in the chemistry classroom (pp. 265-286). Springer. DOI: https://doi.org/10.1007/978-94-007-4366-3_14

Tsaparlis, G. (2000). The states-of-matter approach (SOMA) to introductory chemistry.

Chemistry Education Research and Practice, 1(1):161-168. DOI: https://doi.org/10.1039/A9RP90017A

Tsaparlis, G., Hartzavalos, S., & Nakiboğlu, C. (2013). Students' knowledge of nuclear science and its connection with civic scientific literacy in two European contexts: The case of newspaper articles. *Science & Education*, 22:1963-1991. DOI: https://doi.org/10.1007/s11191-013-9578-5

Witte, D., & Beers, K. (2003). Testing of chemical literacy (Chemistry in context in the Dutch national examinations). *Chemical Education International*, 4(1):1-3. Available at: https://publications.iupac.org/cei/vol4/0401x0an3.pdf

Yadigaroglu, M., Agyan, Z., & Demircioglu, G. (2021). High school students' levels of relating the chemistry knowledge to daily life: Acid-base example. *Journal of Turkish Science Education*, 18(3):512-524. DOI: https://doi.org/10.36681/tused.2021.87

Yıldırım, A., & Şimşek, H. (2013). Sosyal Bilimlerde Nitel Araştırma Yöntemleri [Qualitative Research Methods in Social Sciences]. (9. Ed.). Seçkin. ISBN: 9789750239991.

Received: 02 February 2023
Revised: 12 February 2023
Accepted: 24 February 2023