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Araştırma Makalesi/ Research Article

Evaluating Senior Pre-Service Chemistry Teachers' Foundational Understanding of Nuclear Reactions[1]

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Abstract: Nuclear chemistry plays a crucial role in various essential daily life applications; however, students often struggle with many of its concepts. These learning difficulties in teaching and understanding nuclear chemistry can largely be attributed to problems with misconceptions and perceptions regarding pre-requisite concepts. Among these, the concept of nuclear reactions serves as a fundamental prerequisite for comprehending other topics within nuclear chemistry. This study aims to determine the extent to which senior pre-service chemistry teachers (SPSCTs) regard nuclear reactions as a type of chemical reaction. It also aims to identify the reasons behind SPSCTs' classification. The study involved 158 SPSCTs enrolled in an education faculty. This research focused on analyzing responses to a specific research-related question within a Nuclear Chemistry Concept Test, which was composed of 10 open-ended questions developed as part of a larger project. The findings indicated that 64% of SPSCTs perceived nuclear reactions as a subset of chemical reactions. Upon examining the underlying reasons for this misconception, two primary factors emerged. First, although SPSCTs demonstrated an awareness of nuclear reactions, their understanding of the mechanisms underlying chemical reactions was either incomplete, leading them to categorize nuclear reactions as a type of chemical reaction. Second, they struggled to distinguish chemical and nuclear reactions in terms of reaction mechanisms, processes, and dynamics. Based on these findings, recommendations for addressing these misconceptions were provided.

Keywords: Nuclear reaction, chemical reaction, senior pre-service chemistry teachers

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INTRODUCTION

[1]This article was produced from the author's project titled "Determining the relationship between prospective chemistry teachers' knowledge, misconceptions and science literacy about nuclear chemistry".

All matter in nature undergoes changes over time, which can generally be classified as physical or chemical. Physical changes alter only the appearance or state of matter without affecting its identity, whereas chemical changes modify the composition and internal structure of matter, resulting in the formation of new substances. Students often struggle to distinguish between these two types of change, particularly in understanding that chemical changes occur at the atomic level (Nakiboğlu, 2023, 2024; Stavridou & Solomonidou, 1989). Moreover, comprehending chemical changes is fundamental to understanding chemical reactions, as these reactions systematically represent chemical transformations. Chemical reactions form the foundation of chemistry education, representing the fundamental processes that drive the transformation of matter and energy. This process, in which atoms are rearranged to produce new substances with distinct chemical properties, is known as a chemical reaction (Ahtee & Varjola, 1998). A solid grasp of chemical reactions is essential for students to develop a deeper understanding of more advanced concepts in chemistry and related scientific disciplines.

Studies have shown that students at various educational levels encounter difficulties in understanding the concept of chemical reactions (Ahtee & Varjola, 1998; Barker & Millar, 1999; Cervellati et al., 1984; Cheng, 2018; Hesse & Anderson, 1992; Øyehaug & Holt, 2013; Stavridou & Solomonidou, 1989, 1998; Yan & Talanquer, 2015). One of the key challenges in grasping chemical reactions is the difficulty in understanding that the atoms composing a substance are conserved during a reaction and that new substances are formed solely through their rearrangement. Anderson (1986) found that students often confuse the rearrangement of atoms with the type of change that occurs in a chemical reaction. Similarly, Hesse and Anderson (1992) also reported that although students frequently use the term 'reaction' when describing natural phenomena, they fail to recognize that chemical reactions specifically involve the reorganization of atoms.

In addition to students not understanding the logic of chemical reaction mechanism at the particle level, another important situation is that they have difficulty understanding the differences between chemical reaction types (Çokadar, 2013; Sağır et al., 2012). The basis of this type of problem may be the lack of full understanding of what happens in reactions at the particle level. Not thinking about chemical reactions at the particle level and not understanding the function of electrons in chemical reactions may also negatively affect students' understanding of the differences between nuclear and chemical reactions at a later stage (Erçoklu, 2001; Nakiboğlu, 2003; Nakiboğlu & Bülbül, 2000; Nakiboğlu & Tekin, 2006; Şahin, 2008). In fact, Erçoklu (2001) determined in his study with high school students that students have a misconception that nuclear reactions occur via valence electrons. Şahin (2008) based the reason why students confuse chemical reactions with nuclear reactions on the fact that students try to explain the changes in nuclear reactions with the knowledge they have gained in chemical reactions. The differences between

chemical reactions and nuclear reactions lie in their mechanisms, energy changes, and effects on atomic structure. The students are expected to comprehend the difference between chemical reactions and nuclear reactions based on chemical reactions that occur through changes in the electron arrangements of atoms, while nuclear reactions occur through changes in the atomic nucleus. Another problem that students experience in distinguishing between chemical and nuclear reactions is that they think that mass is also conserved in nuclear reactions (Erçoklu, 2001; Nakiboğlu & Tekin, 2006; Şahin,2008).

Nuclear chemistry is important for many applications in the most important areas of daily life such as medicine, energy and archaeology. However, students have learning difficulties concerning many concepts of nuclear chemistry (Eijkelhof, 1990; Nakiboğlu, 2003; Nakiboğlu & Ölmez, 2021; Nakiboğlu & Tekin, 2006; Prather & Harrington, 2001; Tsaparlis et al., 2013). Prior knowledge plays a crucial role in shaping how new concepts are understood. Considering students' prior knowledge is particularly important when designing an effective instructional environment. Research has shown that students often bring misconceptions or alternative conceptions that hinder their understanding of nuclear chemistry topics (Nakiboğlu, 2003; Nakiboğlu & Bülbül, 2000;). These learning difficulties in teaching and understanding nuclear chemistry can largely be attributed to problems with misconceptions, ideas and perceptions regarding pre-requisite concepts. Among these, the concept of nuclear reactions serves as a fundamental prerequisite for comprehending other topics in nuclear chemistry.

A review of the literature revealed no studies that directly investigated whether students perceive nuclear reactions as chemical reactions. Therefore, this study aims to determine the extent to which senior pre-service chemistry teachers (SPSCTs) regard nuclear reactions-an essential concept in teaching nuclear chemistry-as a type of chemical reaction. Subsequently, the study also aims to identify the reasons behind SPSCTs' classification of nuclear reactions as a type of chemical reaction. For this purpose, the research questions of the study were given as follows.

1. What is the rate at which the SPSCTs who participated in the study thought of nuclear reactions as a type of chemical reaction?
2. Why do the SPSCTs think of nuclear reactions as a type of chemical reaction?
3. Why do the SPSCTs think of nuclear reactions as not being a type of chemical reaction?

METHOD

Model of the Study

This study employed a *descriptive research design*, which aims to determine and describe existing phenomena (Gay & Airasian, 2000). Specifically, it was conducted as a *longitudinal descriptive study*. Longitudinal surveys involve collecting data at multiple points in time, either from the same sample group or from different sample groups. In this study, all data were collected at different time intervals from different sample groups.

Working Group

In the selection of the study group, *convenience sampling*, one of the *purposive sampling methods*, was employed. This method, which enhances the speed and practicality of the research, allows the researcher to select a readily accessible and easily reachable group (Yıldırım & Şimşek, 2021). Although purposeful sampling allows participants to be selected in qualitative research in a way that provides in-depth information to understand a particular phenomenon (Patton, 2014), the method has some limitations. First of all, since convenience sampling usually focuses on a small and specific group, the generalizability of the findings obtained is limited (Creswell & Poth, 2018). Though the aim in qualitative research is generally not to make generalizations but to create in-depth meaning, this may limit the transferability of the findings to different contexts. Secondly, the subjectivity of the researcher in the sample selection process can lead to sampling bias (Maxwell, 2013). The researcher's personal interests, assumptions, and theoretical orientation can affect which participants are included. Therefore, it is important to explain the sampling process transparently and minimize possible biases. Therefore, how the sampling was done in the study was explained in detail. In addition, the researcher ensured that there was no influence caused by the researcher by including all of the teacher candidates who were in the classroom at that moment and those who volunteered to participate in the study while selecting the participants.

158 SPSCTs who are continuing their final year of chemistry teaching participated in the study. The age of the study group ranged from 21 to 23. All of the SPSCTs had completed General Chemistry I and II, Analytical Chemistry I and II, Inorganic Chemistry I and II, Physical Chemistry I and II, and Organic Chemistry I and II courses. They were 4th year students continuing in the same faculty of education in different periods. The faculty of education has four-year teacher training programs. The purpose of the chemistry teacher training program is to educate teacher candidates for chemistry teaching in high schools.

The entire study group participated in the study voluntarily and were free to write their names on the test. Ethical permission for the study was obtained from the Balıkesir University Science and Engineering Ethics Committee.

Data Gathering

The nuclear chemistry conception test was used to evaluate the knowledge of preservice chemistry teachers for different purposes within the scope of a project. In this study, only the findings of the analysis of a question consisting of two parts were included in order to determine to what extent the preservice chemistry teachers can differentiate nuclear reactions from chemical reactions.

The first version of the Nuclear Chemistry Concept Test was designed to assess the preparedness of prospective chemistry teachers regarding fundamental concepts prior to undertaking the nuclear chemistry course. This initial version of test comprised 10 questions covering topics such as nucleons, isotopes, atomic number, mass number, nuclides, radioactivity, models explaining the structure of the atomic nucleus, the types of reactions substances undergo, the classification of chemical reactions, and the definition of a nuclear reaction. Based on the analysis of the test results, a revised second version was developed. The evaluation of responses to the open-ended questions indicated that three questions related to nuclear reactions should be merged into a single question. Consequently, the new question was formulated as: "Are nuclear reactions a type of chemical reaction?" While six of the remaining seven questions were retained, the question "Which models explain the structure of the atomic nucleus?" was removed. During the analysis, it was deemed appropriate to add a question on isotopes due to their strong relevance to nuclear reactions. Additionally, two new questions were introduced to address nuclear stability and the concept of energy. Following the application and analysis of the second version of the test, it was decided to remove the newly added question on energy, as it did not yield correct responses and failed to contribute to understanding the relationships between concepts. Similarly, the question on isotopes was eliminated for the same reasons. The analysis of the question on radioactivity in both the third and final versions of the test indicated the need for an additional question addressing the concept of "radiation." Furthermore, a conceptual question exploring the concept of "quark" was incorporated. A part was added in which participants were asked to explain the reasoning behind their answers to the question "Are nuclear reactions a type of chemical reaction?" in the final version of the Nuclear Chemistry Concept Test.

The test was finalized following the administration and analysis among pre-service chemistry teachers at various grade levels. This study specifically presents the analysis findings related to the question on nuclear reactions as a type of chemical reaction and previous analyses indicated that this question warranted separate examination from the other conceptual questions. The author of the study is a chemistry education expert with extensive experience in teaching nuclear chemistry and conducting research in the field. Consequently, she meticulously reviewed each stage of the test development process and determined the fundamental concepts of nuclear chemistry, as well as the relationships

between these concepts. An additional opinion was sought from another faculty member solely to evaluate the appropriateness of the basic atomic concepts included in the test.

Analysis of the Data

In the analysis of the first part of the question, the answers given as yes, no or differently were counted one by one and tabulated. The data gathered from the second part of the question were analyzed with the content analysis method by the researcher of the study. For content analysis, explanations for yes and no answers were analyzed separately. For this purpose, themes were created firstly during the analysis of the answers. Then, these themes were collected under certain categories and tables were created. The qualitative data obtained were digitized and presented in a quantitative format. Yıldırım and Şimşek (2011), state that "it is possible to reduce qualitative data to numbers" (p. 242). They further emphasize that "quantifying qualitative data to a certain extent may allow comparisons to be made between themes or categories that emerge as a result of data analysis" (p. 243).

To obtain intra-judge reliability of the analysis, the researcher analyzed the data for the second time 3 months after the first analysis and checked the themes and categorizes (Gay & Airasion, 2000, p. 175). Minor discrepancies between the findings of the two analyzes were reviewed and finalized.

FINDINGS

The findings of the study are presented separately to answer each research question.

The First Research Question

The first research question aimed to determine the rate at which the SPSCTs participating in the study thought of nuclear reactions as a type of chemical reaction. For this purpose, the answers given by the SPSCTs in the study group to the first part of the question "Are nuclear reactions a type of chemical reaction?" as "yes, nuclear reactions are a chemical reaction/no, they are not" or if there were different answers, these answers were counted one by one and Table 1 was created, which includes frequencies and percentages.

Table 1

Findings regarding the answers to SPSCTs about the type of nuclear reactions

Answers	f	%
Nuclear reaction is a chemical reaction type.	101	64
Nuclear reaction is not a chemical reaction type.	33	21

Nuclear reaction is both physical and chemical reaction.	2	1
Nuclear reaction is physical reaction.	2	1
I do not know.	5	3
No answer	15	10
Total	158	100

When Table 1 is examined, it is determined that 64% of the SPSCTs stated that nuclear reaction is a type of chemical reaction, and 21% stated that nuclear reaction is not a type of chemical reaction. Apart from these two answers, it was determined that two of the SPSCTs stated that nuclear reaction is both a chemical and physical reaction, and two different SPSCTs stated that nuclear reaction is a physical reaction. 3% of the SPSCTs stated that they did not know, while 10% did not answer this question.

The Second Research Question

The second research question explored why SPSCTs think of nuclear reactions as a type of chemical reaction. For this purpose, the explanations of 101 SPSCTs that answered yes to nuclear reactions are a type of chemical reaction were analyzed. The findings obtained as a result of the analysis are given in Table 2.

Table 2

Findings from SPSCT explanations of why nuclear reactions are chemical reactions

Category	Theme	Sample Statement	f		%
Perception of reaction mechanism and process	Change in the Nucleus	It is a chemical reaction because there is a change in the nucleus of the atom. The changes that may occur in the nucleus are a chemical reaction because the nucleus may become radioactive as a result of the nuclear reaction.	12	30	29
	Decomposition or change of the atom	Because in the nucleus, another atom is obtained from an atom. A chemical reaction takes place here. Since it takes place in the nucleus of the atom, it destroys the structure of the atom.	5		
	Occurring in the atom/in the nucleus	Nuclear reactions are a chemical reaction. Because reactions also occur in the nucleus of the atom. When a chemical reaction occurs, it is a type of reaction	6		

		because the reaction also occurs in the nucleus.			
	Reaction of protons and neutrons	There are protons and neutrons in the nucleus, and the chemical reaction is due to their reaction. There are protons and neutrons in the nucleus. These react. To be stable.*" 119	3		
	Fission and fusion processes	Because fusion and fission events occur here. Nuclear reactions are a type of chemical reaction. For example; fission and fusion reactions.	2		
	Change in structure of matter	Because nuclear reactions change the structure of matter	2		
Perception of the reaction dynamics	Energy release or energy requirement	Because the element that has undergone a nuclear reaction cannot return to its former state.	4	11	11
	Irreversibility	Nuclear reactions are a type of chemical reaction because the changes that occur in the nucleus as a result of the reaction are different, that is, it cannot return to its previous state.	3		
	Nuclear stability	It is a type of chemical reaction because the nucleus is kept stable. There are protons and neutrons in the nucleus. These react. To be stable.*	2		
	Spontaneous reaction	Reactions are chemical reactions because they happen spontaneously.	1		
	Interaction	I think it is a type of chemical reaction. Because I guess there are reactions that are in a state of interaction.	1		
Perception based on results and products of reaction	A new event/chemical event occurs	It is a type of chemical reaction because a new event can occur with nuclear reactions.	3	7	7
	Reactant and product are change/product formation	Nuclear reactions are a type of chemical reaction because the substance entering and the substance leaving are different.	2		
	A chemical change occurs	It is a chemical reaction, not just a physical change, but also a chemical change.	2		
Perception based on reaction observations	Radiation	It is a chemical reaction because radiation occurs in the environment as a result of the reactions.	2	2	2
Relating nuclear	Nuclear reactions as a part of chemistry	The nuclear reaction is a chemical reaction because it is	1	1	1

reactions to the discipline of chemistry		a type of reaction that can be considered the basis of chemistry.			
General or Vague responses	Yes or repeated statement		51	51	50
Total				102	100

* This statement was evaluated in two categories. Therefore, although the explanations of 101 SPSCTs were analyzed, the total number was given as 102, considering the number of analyzed statements.

When Table 2 is examined, it is seen that the reasons why SPSCTs think that nuclear reactions are a type of chemical reaction are gathered in six categories. The last category shown in Table 2 is actually a group where specific answers are gathered rather than a category, since it only includes repeated answers or answers of "yes" without any explanation. As can be seen from Table 2, almost half of the SPSCTs who answered yes could not write an explanation about why they think that nuclear reactions are a type of chemical reaction. It is seen that the explanations made are gathered in five categories and these are *perception of reaction mechanism and process, perception of the reaction dynamics, perception based on results and products of reaction, perception based on reaction observations* and *relating nuclear reactions to the discipline of chemistry*.

The Third Research Question

The third research question explored why SPSCTs do not think of nuclear reactions as a type of chemical reaction. For this purpose, the explanations of 32 SPSCTs that answered no to nuclear reactions are not a type of chemical reaction were analyzed. The findings obtained as a result of the analysis are given in Table 3.

Table 3

Findings from SPSCT explanations of why nuclear reactions are not chemical reactions

Category	Theme	Sample Statement	f		%
Perception of reaction mechanism and process	Change in the Nucleus	The change is not in the nuclei or the electrons.	4	12	34
		If we divide the concept of reaction into two branches, one of them is chemical reactions and the other is nuclear reactions. While chemical reactions occur between at least two particles and via electrons, nuclear reactions occur in the atomic nucleus of radioactive elements.			
	Bond breaking	Nuclear reactions are not a type of chemical reaction because there is no bond breaking.	1		
	Decomposition or change of the atom	They are different reactions. In chemical reactions, the structure of the atom is not destroyed, in nuclear reactions, the atom may be broken apart or a new environment may be formed.	2		

	Change in the numbers of protons and neutrons	Nuclear reactions are a radioactive reaction. They occur when the number of protons and neutrons in the nucleus changes.*	1		
	Fission and fusion processes	In nuclear reactions, electron transfer does not occur. Fission or fusion events occur.	2		
	Change in structure of matter	Combustion, neutralization, redox etc. are chemical reactions. Chemical reactions change in structure, not so in the nucleus.	2		
Perception of radioactive reaction		" It is a radioactive reaction and not a chemical reaction. The amount of energy released is greater than the chemical reaction*. Nuclear reactions are a radioactive reaction. They occur when the number of protons and neutrons in the nucleus changes*. It is a type of radioactive reaction.	5	5	14
Perception of the reaction dynamics	Energy amount	It is a radioactive reaction and not a chemical reaction. The amount of energy released is greater than the chemical reaction.*	1	2	6
	Different Interaction	I think that the reactions that take place in the nucleus react in a different way without entering into chemical interactions, so they are both different.	1		
Perception based on reaction observations	Radiation	Nuclear reactions are not chemical reactions. Nuclear reactions are based on particles and radiation in the nucleus.	1	1	3
Failure to comply with fundamental laws of chemistry		Because the fundamental laws of chemistry were definitely not sought in nuclear reactions. It was a separate type of reaction.	1	1	3
Perception based on results and products of reaction	Reactant and product are change/product formation	As a result of the reaction, the atoms or compounds that initially reacted do not form a substance with a new chemical matter.	1	1	3
General or Vague responses	No or repeated statement		13	13	37
Total				35	100

* These two statements were evaluated in two categories. Therefore, although the explanations of 33 SPSCTs were analyzed, the total number was given as 35, considering the number of analyzed statements.

When Table 3 is examined, it is seen that SPSCTs' explanations for why nuclear reactions are not types of chemical reactions are gathered in seven categories. The last category shown in Table 3 is actually a group where specific answers are gathered rather than a category, since it only includes repeated answers or answers of "no" or writing "nuclear reactions are not chemical reactions." without any explanation. As can be seen from Table 3, 37% of the SPSCTs who answered no could not write an explanation about why they

think that nuclear reactions are not a type of chemical reaction. It is seen that the explanations made are gathered in six categories and these are *perception of reaction mechanism and process, perception of radioactive reaction perception of the reaction dynamics, perception based on reaction observations, failure to comply with fundamental laws of chemistry* and *perception based on results and products of reaction*.

RESULTS AND DISCUSSION

The present study, which investigated the extent to which the SPSCTs know the fundamental differences between chemical and nuclear reactions and why they think of nuclear reactions as a type of chemical reaction, reached the following conclusions.

In the first research question, it was concluded that 65% of the SPSCTs who participated in the study thought that nuclear reactions were a type of chemical reaction and 20% off them stated that nuclear reaction is not a type of chemical reaction. It was also determined that two of the SPSCTs indicated that nuclear reaction is both a chemical and physical reaction, and two different SPSCTs identified that nuclear reaction is a physical reaction.

When the reasons for this circumstances were investigated in the second research question, it was determined that the most of the SPSCTs did not understand the formation mechanisms and dynamic processes of chemical reactions. This situation is consistent with the findings of studies conducted in the literature on the difficulties of understanding the concept of chemical reaction among students at different levels (Ahtee & Varjola, 1998; Barker & Millar, 1999; Cervellati et al., 1984; Cheng, 2018; Hesse & Anderson, 1992; Øyehaug & Holt, 2013; Stavridou & Solomonidou, 1989, 1998; Yan & Talanquer, 2015). Çokakadar (2013), determined that students had some problems in his study on the classification of chemical reactions with teacher candidates. He also stated that when students classified some given reactions incorrectly, the reaction classification in the textbook used could have an effect. It is not surprising that students who still have difficulty distinguishing even the types of chemical reactions also have problems distinguishing nuclear and chemical reactions. These findings are consistent with the results of Şahin (2008), who attributed students' confusion between chemical and nuclear reactions to their tendency to explain changes in nuclear reactions using the knowledge they have acquired about chemical reactions.

The reasons why PSCTs consider nuclear reactions as a type of chemical reaction found are grouped under five headings. The two most important headings were that students had problems in the perception of reaction mechanism and process category and the perception of reaction dynamics category, and they were unable to distinguish between nuclear and chemical reactions and the conditions affecting the formation and reaction.

Although the perception of reaction mechanism and process category and the perception of reaction dynamics categories contain similar aspects in terms of students' understanding of reactions, they are fundamentally based on different conceptual frameworks. The perception of reaction mechanism and process category is related to students' understanding of which particles the reaction takes place between, which processes it involves, and how the process proceeds. The perception of reaction dynamics focuses on students' understanding of the conditions and variables necessary for reactions to occur. Therefore, the perception of reaction mechanism and process is related to reaction mechanisms, the interaction of subatomic particles, the process of formation of products, while the perception of reaction dynamics is related to thermodynamics, reaction kinetics, energy change, and irreversibility. There are five themes under the perception of reaction mechanism and process category, and these themes are change in the nucleus, decomposition or change of the atom, occurring in the atom/in the nucleus, reaction of protons and neutrons, and fission and fusion processes. When the explanations in the change in the nucleus theme are examined, it includes student responses that express the belief that a change at the nuclear level is related to chemical reactions. Students emphasize that a change at the nuclear level is a fundamental element of a chemical reaction. The decomposition or change of the atom theme includes statements indicating that changes or deterioration in the atomic structure constitute chemical reactions. The occurring in the atom/in the nucleus theme includes statements suggesting that chemical reactions occur inside the atom and nuclear reactions are a chemical process. Students classify all reactions that occur inside the atom as chemical and evaluate nuclear reactions within this scope. The reaction of protons and neutrons theme consists of student responses expressing the understanding that the reaction of protons and neutrons is related to a chemical reaction. The reaction of protons and neutrons is likened to chemical reactions that occur with the exchange of electrons. The fact that changes at the nuclear level are seen as one of the fundamental components of chemical reactions constitutes the reason why these students evaluate nuclear reactions as chemical. The statements in the theme of fission and fusion processes show that processes such as fission and fusion are based on the same principles as chemical reactions.

Based on these results, it can be said that the students did not understand that the fundamental differences between chemical reactions and nuclear reactions are based on the mechanisms of the reactions, energy changes, and effects on atomic structure. An analysis of students' explanations within all themes under *the perception of reaction mechanism and process* category revealed that 30% correctly understood that changes in nuclear reactions occur within the atomic nucleus. However, their responses also indicated difficulties in comprehending *the mechanisms and processes* underlying chemical reactions. This finding aligns with the second category*, perception of reaction dynamics*.

While students generally recognized the necessary conditions for both types of reactions, they struggled to differentiate between them. For instance, they acknowledged that "energy change" occurs in both reaction types but failed to distinguish the magnitude of energy involved. In chemical reactions, energy is released or absorbed in relatively small amounts, typically in the range of kilojoules per mole (kJ/mol), whereas in nuclear reactions, energy changes are millions of times greater, measured in mega-electronvolts (MeV). A result supporting this situation is also seen in the study of Taber (1996). Taber (1996), investigated what new A-level students understood about the background knowledge of a subject at the beginning of a chemistry course. One of the topics he researched was energy, and in his question on this subject, the student determined that bond formation was defined by a "radioactive reaction". Student "*If certain chemical bond together they will be unstable + cause a nuclear explosion* (p. 8)".

Additionally, certain misconceptions emerged in students' reasoning. For example, a statement that is accurate for chemical reactions but incorrect for nuclear reactions was frequently observed: "It is a type of chemical reaction because the nucleus is kept stable." Similarly, some students classified nuclear reactions as chemical reactions while providing explanations that were valid for nuclear reactions but incorrect for chemical ones, such as: "There are protons and neutrons in the nucleus. These react. To be stable."

The third research question explored why SPSCTs do not think of nuclear reactions as a type of chemical reaction. When the explanations of these students were examined, although 37% of SPSCTs did not write an explanation about why nuclear reactions are not a type of chemical reaction, it was concluded that the majority of the remaining students understood the difference between chemical and nuclear reactions from their explanations. It was understood that they were especially aware of the difference in the amount of energy between the two reactions, the interactions related to electrons in chemical reactions and the arrangements in chemical bonds.

SUGGESTIONS

Although both chemical and nuclear reactions play an important role in nature and technology, they differ greatly in their mechanisms, energy levels, and outcomes. Chemical reactions occur through the rearrangement of electrons in atoms, while nuclear reactions are characterized by changes in the atomic nucleus. However, as the findings suggest, the primary issue lies in students' incomplete understanding of the mechanisms and processes involved in chemical reaction formation. Therefore, the most crucial recommendation is to ensure that students acquire an accurate, particle-level comprehension of both the

mechanisms underlying chemical reactions and the formation of different types of chemical reactions. This recommendation has also been emphasized in several studies in the literature. Godfrey et al. (1991), highlighted that nuclear reactions are analogous to chemical reactions and that students should first develop a solid understanding of chemical reactions before being introduced to nuclear reactions. However, they also emphasized a crucial distinction: nuclear reactions, unlike chemical reactions, involve the transformation of elements. They argued that this fundamental difference should be explicitly stressed to help students clearly distinguish between chemical and nuclear reactions. Nakiboğlu and Tekin (2006), investigated students' misconceptions about the basic concepts of nuclear chemistry at the secondary school level and determined that there were significant misconceptions among students. When their suggestions on how to teach nuclear chemistry were examined at the end of the study, they stated that firstly, teachers should make sure that students have a solid knowledge base about the concepts of atomic number, mass number, nucleons, isotopes and nucleoids before starting to teach nuclear chemistry-related topics. Secondly, they suggested that teachers should emphasize the distinction between chemical and nuclear reactions using examples. A similar suggestion can be made at the end of this study. The distinction between chemical and nuclear reactions should be made first at the particle size as suggested above and then the distinction should be shown by presenting different examples of the reactions.

A correct understanding of how to write nuclear reaction equations will also aid in distinguishing between chemical and nuclear reactions, as well as comprehending the distinct properties of nuclear reactions that will be introduced later. Therefore, it is essential to first verify whether students recognize the concept of "nuclide" in nuclear reactions and whether they can correctly represent it in written form. Based on this, it may be advisable to begin instruction with an explanation of this fundamental concept before delving into the broader topic.

Chantharanuwong et al. (2012), investigated the metacognition of secondary school students in Thailand regarding nuclear energy topics, including the concept of nuclear reactions. The study concluded that students generally lacked declarative knowledge about concepts related to nuclear energy and the metacognition of nuclear reactions. Metacognition is defined as the ability to reflect on, understand, and regulate one's thinking, learning, and actions. As a result, the authors recommended incorporating activities that promote the development of metacognitive skills into science classes. Specifically, activities that encourage reflective and intentional thinking on topics of interest, particularly cooperative learning and group work, could significantly enhance students' understanding of nuclear chemistry concepts.

Conflict of Interest Declaration

The author has not declared a potential conflict of interest during the research, authorship, and publishing of this article.

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Ethical Committee Decision / Permission

For this research, an ethical permission / a permission was granted by Balikesir University Science and Engineering Sciences Ethics Committee

Son Sınıf Kimya Öğretmen Adaylarının Nükleer Reaksiyonlara İlişkin Kavrayışlarının Değerlendirilmesi[2]

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Özet: Nükleer kimya, günlük yaşamın çeşitli temel uygulamalarında önemli bir rol oynar; ancak öğrenciler genellikle nükleer kimya ile ilgili kavramlarının önemli bir kısmı ile ilgili sorunlar yaşamaktadır. Nükleer kimyayı öğretme ve anlamadaki bu öğrenme güçlükleri büyük ölçüde ön koşul kavramlarıyla ilgili yanlış anlamalar, algılar ve fikirlerle ilgili sorunlara bağlanabilir. Bunlar arasında nükleer tepkime kavramı, nükleer kimyadaki diğer konuları anlamak için temel bir ön koşul görevi görür. Bu çalışma, öncelikle son sınıf kimya öğretmen adaylarının nükleer tepkimeleri kimyasal tepkime türü olarak görme düzeyini belirlemeyi amaçlamaktadır. Ayrıca kimya öğretmen adaylarının, nükleer tepkimeleri bir kimyasal tepkime türü olarak sınıflandırmalarının nedenlerinin belirlemesi amaçlanmıştır. Çalışmaya bir eğitim fakültesinin son sınıfına devam eden 158 kimya öğretmen adayı katılmıştır. Çalışmada bir proje kapsamında hazırlanan veri toplama aracının çalışma ile ilgili sorusunun analizine yer verilmiştir. Çalışma sonunda öğretmen adaylarının %64'ünün nükleer tepkimelerin bir kimyasal tepkime türü olduğunu düşündüğü ortaya çıkarılmıştır. Öğretmen adaylarının bu düşüncelerinin nedenlerinin analizi sonucunda, ilk olarak öğretmen adaylarının nükleer tepkimelerin ne olduğunun farkında olsalar da kimyasal tepkimelerin nasıl oluştuğuna yönelik yanlış kavrama veya eksik bilgileri nedeniyle nükleer tepkimeleri kimyasal tepkime türü olarak düşündükleri belirlenmiştir. İkinci olarak kimyasal ve nükleer tepkimeler arasındaki farkları tepkime oluşum, süreç ve dinamiği açısından anlamlandıramadıkları sonucuna ulaşılmıştır. Çalışma sonunda önerilere yer verilmiştir.

Anahtar kelimeler: Nükleer tepkime, kimyasal tepkime, kimya öğretmen adayı

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