

# 11<sup>th</sup> Grade Students' Understanding Level of Gases in terms of Some Chemical Variables and the Determination of Alternative Conceptions

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## ABSTRACT

For abstract concepts to be well understood, students need to be familiar with the concepts and able to associate them correctly. Students cannot make scientific explanations on the subject unless they can establish relationships. This study aimed to determine the understanding level of 11<sup>th</sup>-grade high school students on “gases” in terms of chemical variables and any alternative frameworks on the subject of gases. A methodology, including both qualitative and quantitative design, was used for this investigation. Open-ended questions and group discussion methods were used for data collection. The questions were applied to 87 11<sup>th</sup>-grade students from three public schools. Group discussions were conducted with nine students. The students' understanding level of gases was statistically presented based on the predetermined categories. Besides, alternative frameworks on gases were described with direct excerpts taken from the students' statements. According to the results of the study, it was concluded that the students' understanding level of gases was low. In addition, it was observed that students were often inadequate in explaining gas-related events and that there were numerous unscientific errors in their explanations. Active learning methods should be designed to minimize the alternative conceptions of high school students on gases and focus on the conceptual and scientific understanding of students.

**KEY WORDS:** science education; chemistry education research; scientific conceptions; alternative conceptions; gases

## INTRODUCTION

Science education aims to enable students to acquire the skills of problem-solving and scientific thinking using scientific concepts and definitions and to educate them as science-literate (Baird et al., 1991; de Boer, 2000; de Jong and Talanquer, 2015; Osborne and Freyberg, 1985). While the students are gaining knowledge, appropriate strategies should be developed for teaching the relationships between concepts and sub-dimensions of concepts. While developing these strategies, it is necessary to determine what the learning aspects of the students are, to have knowledge about how they understand the concepts, and how they relate them to one another (Lin et al., 2000; Mas et al., 1987). People have a structure of information in their brains that is similar to boxes containing meaningful information. The same experiences might be differently interpreted by each individual and therefore stored in different boxes. Students' knowledge sometimes leads them to develop concepts that do not conform to some scientific concepts (Jauhariyah et al., 2018). Educators need to develop strategies that help students develop a better conceptual understanding (de Boer, 2000; de Jong and Talanquer, 2015; Taylor and Lucas, 2000).

Constructivist learning theory explains learning as an active process where students create their knowledge by linking the

concepts. Students should be able to transfer the knowledge they have learned to any situation to make meaningful connections (Marx et al., 2004; National Research Council, 2005). When students encounter a new problem situation, meaningful and permanent information can be provided if they can compare and synthesize this new information with their previous knowledge (Airasian and Walsh, 1997; Driscoll, 2005).

Students sometimes perceive and explain basic concepts or events differently from scientists (Fleer, 1999; Nakhleh, 1992; Osborne, 1982). The fact that students think that their knowledge is scientifically true leads them to develop alternative concepts (Abraham et al., 1992; Driver et al., 1994; Gilbert et al., 1982; Nakhleh and Samarapungavan, 1999). From the scientific point of view, these ideas are reasonable and logical information embedded in the students' concept learning system. Incorrect ideas and explanations are referred in the literature to such terms as preconceptions (Driver and Easley, 1978; Nakhleh, 1992; Nicoll, 2001); children's science (Osborne et al., 1983); and alternative frameworks (Driver and Erickson, 1983; Hewson and Hewson, 1989). When these terms are examined in terms of similarities, they are almost the same. In this study, the term alternative framework is used to refer to any conceptual difficulties that are different and inconsistent with the accepted scientific definition. Guzzetti

(2000) states that alternative frameworks complicate the structuring of information and it is very difficult to reconstruct by changing this information when the underlying information is incorrect.

Teachers (Ebenezer and Erickson; 1996; Ebenezer and Gaskell, 1995; Ginns and Watters, 1995; Valanides, 2000; Jauhariyah et al., 2018), textbooks (de Berg, 1989; Jauhariyah et al., 2018; Nakiboglu and Yildirim, 2011), and students themselves (Jauhariyah et al., 2018) can be the reason for developing alternative frameworks. In a study conducted by de Berg (1989), 14 chemistry books were examined, and it was found that only five of the 80 questions regarding the pressure-volume relationship were of the type requiring conceptual explanation. The textbooks should contain questions that require explanation rather than mathematical operations (de Berg, 1995), different types of questions should be written (Nakiboglu and Yildirim, 2011), and the lessons should include questions such as analysis, synthesis, and evaluation. The lack of explanations in the textbooks, the choice of multiple-choice questions instead of open-ended questions, the inability of the students to change their study habits, the students' lack of focus on explaining the causes of events, and phenomena lead them to create an alternative idea. How can we expect the students to understand unless some explanations, different from the books, are made about how things are related (Lin et al., 2000).

In the studies conducted in the field of chemistry education, it is seen that the concepts of chemistry are not sufficiently understood by the students. (Abraham et al., 1992; Ayas, 2002; Ayyildiz and Tarhan, 2013; Bodner, 1991; Calik and Ayas, 2005; de Jong and Talanquer, 2015; Ebenezer and Erickson, 1996; Lin et al., 2000). The literature reveals that some students have difficulties conceptualizing "gas" (Mas et al., 1987; Novick and Nussbaum, 1978; Stavy, 1988), "physical and chemical change" (Abraham et al., 1992; Abraham et al., 1994; Andersson, 1990; Driver et al., 1994), and "dissolution" (Abraham et al., 1992; Abraham et al., 1994; Ebenezer and Erickson, 1996; Ebenezer and Gaskell, 1995; Lee et al., 1993; Osborne and Cosgrove; 1983; Valanides, 2000). The reasons for this situation include the facts that the concepts contain abstract information, students are biased to science subjects, the concepts are less related to daily life, and the hierarchical relationship between the concepts is not understood (Gabel Samuel and Hunn, 1987; Lee et al., 1993; Nakhleh, 1992; Novick and Nussbaum, 1978; Mas et al., 1987; Rollnick and Rutherford, 2011; Tsai, 1999). According to the literature, many of the concepts of chemistry that students have the most difficulty with are related to gases (Mas et al., 1987; Nelson et al., 1992).

In most of the studies conducted in science education, it is stated that students have difficulty in understanding the basic properties of gases. In these studies, it is argued that understanding levels and alternative frameworks for gases should be determined to identify the issues that students have difficulty in understanding (Aslan and Demircioglu, 2014;

Azizoglu and Geban, 2004; Benson et al., 1993; Clough and Driver, 1986; de Berg, 1992; 1995; Demircioglu and Yadigaroglu, 2013; Eskilsson and Helldén, 2003; Gilbert and Watts 1983; Griffiths and Preston 1992; Hwang, 1995; Hwang and Chiu, 2004; Jauhariyah et al., 2018; Jones and Anderson, 1998; Lin et al., 2000; Mas et al., 1987; Mayer, 2011; Niaz and Robinson, 1992; Novick and Nussbaum, 1978; Stavy, 1990). Although the issue of gases subject and its concepts are related to daily life, they are difficult to perceive because they are abstract. To minimize the students' alternative ideas on gases and other subjects of chemistry, alternative ideas should be taken into consideration in teaching and they should be seen as the starting point of teaching (Aslan and Demircioglu, 2014; Azizoglu and Geban, 2004; Benson et al., 1993; Jauhariyah et al., 2018; Lin et al., 2000; Mas et al., 1987; Stavy, 1988).

In the literature, students' thoughts about gases are as follows: gases have no volume and the volume of gases is as large as the size of particles (Hwang 1995); gas does not homogeneously distribute in the container (Hwang and Chiu 2004); heavy gases occupy more space than light ones (Aydeniz et al., 2012); gas particles are collected in the upper part of the container as they are lighter than the solid and liquid form (Chiu, 1993); the properties of gases are similar to those of liquids, gases expand to fill the container; and there is relatively little space between the gas particles (Benson et al., 1993). Furthermore, Stavy (1988; 1990) found in his studies that the students had such alternative thoughts as the gaseous state of matter is lighter than the liquid and solid-state of the substance and gases have no weight.

Chemistry subjects constitute integrity within themselves, and therefore it is not possible to construct information without understanding the basic knowledge of a concept area (Abrahami et al., 1992; Calik and Ayas, 2005). When students begin secondary education, they gain knowledge and ideas about many aspects of the natural world from their experiences both in primary school and out of school. These ideas can contribute to further learning as well as alternative ideas. When students' understanding is lacking, this lack of understanding leads to misunderstandings. It is considered that effective learning will not take place unless the students' perspectives are taken into consideration (Driver et al., 1994). It is important to determine the comprehension level and the inaccuracies of the students about gases subject to rearrange the educational environments. In the curriculums that are constantly developed and changed, the course of the alternative frameworks and the students' comprehension level on gases subject should be followed and the programs should be structured accordingly (Mas et al., 1987; Novick and Nussbaum, 1978; 1981; Stavy, 1988). How the students can explain the concepts related to gases in terms of chemical variables to improve their science teaching experiences makes the present study important. Although there have been many studies on alternative ideas, this should not be sufficient, and more studies should be conducted on whether alternative ideas persist and what they are. To overcome the misunderstandings by the students, it is necessary to examine the

reasons for the alternative ideas and determine what the students relate in forming these ideas. In addition to helping to develop teaching strategies, identifying alternative concepts are also a step forward in organizing workshops, guiding materials, and developing teaching strategies in education. When educators have an idea of the students' possible misconceptions, they consider these when planning the lessons. Students' perspectives should be defined and then teaching should be planned to facilitate conceptual learning (Jaunine, 2015).

There are a limited number of studies conducted with high school students on gas pressure in Turkey (Cermik, 2008; Cetin, 2009; Demirel, 2015; Demircioglu and Yadigaroglu, 2014; Demirci Celep, 2015). In this study, as in other science concepts, it was found that there were deficiencies in understanding the relationships between related concepts in gas pressure. All education levels are hierarchically related to each other. Since high school education is a transition education for the university, it increases the importance of conceptual learning for students. When students can structure information mentally correctly, they can process it with other information and make it meaningful.

To overcome the misconceptions that arise from students, it is necessary to examine the reasons for alternative ideas and to determine how students can relate to when creating these ideas. It is thought that the current study could provide ideas that teachers and educators can take into account in making their teaching plans and curriculum preparations. The purpose of this study is to determine the level of understanding of gases in terms of some chemical variables and the alternative frameworks of gases in 11<sup>th</sup>-grade high school students. In the present study, it was intended to determine the 11<sup>th</sup>-grade students' ability to explain the problems related to pressure and the factors affecting it and to what extent the students were able to reason concerning the subject.

## METHODS

In this study, since 11<sup>th</sup>-grade science students' understanding levels of gases and their alternative frameworks were aimed to be determined, the survey method was used. The survey method is used in studies where sample views on a topic or interest, skill, ability, etc., characteristics are determined (McMillan and Schumacher, 2010).

### Study Group

Compulsory education in Turkey has been divided into three levels and increased to 12 years since the 2012–2013 academic year. It was organized as 4 years of elementary school (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup>), 4 years middle school (5<sup>th</sup>, 6<sup>th</sup>, 7<sup>th</sup>, and 8<sup>th</sup>), and 4 years high school (9<sup>th</sup>, 10<sup>th</sup>, 11<sup>th</sup>, and 12<sup>th</sup>) (MONE, 2018). Grade 10 high school students in Turkey are supposed to choose to study either a science class or social class.

The sample of the study consists of 87 11<sup>th</sup> grade students studying in the science classes of three public schools in the central district of Erzurum Province. Erzurum is one of the largest cities in the east of Turkey. The schools where the study was carried out

were selected by convenience sampling method. These schools were easily accessible to the researcher. This sampling method provides the researcher with speed and practicality as, in this method, the researcher chooses a sample that is close and easy to access (McMillan and Schumacher, 2010). All students in the sample had taken science courses and were familiar with the concepts under investigation in this study. It was stated to the students that the data collected in the study would be used for scientific purposes. In addition, the study was carried out on the basis of the voluntary participation of the students.

### Data Collection

Data were collected through a paper-pencil test and a group discussion. Six open-ended questions were collected from the questions in the university exam (examination system used to place students in universities in Turkey), 11<sup>th</sup>-grade books and 11<sup>th</sup>-grade curriculum related to gases subject. Before the data collection tool was developed, content limits related to gases were defined, and the instructional objectives were determined. 11<sup>th</sup> class gases subject description in Turkey includes identifying key features of the general properties of the gases and to examine the relationships among the pressure, temperature, volume, and the number of gases (Ministry of Education, 2018). While selecting the questions, the studies of different researchers were examined (Novick and Nussbaum, 1981; Gilbert et al., 1982; Gabel et al., 1987; Mas et al., 1987; Stavy, 1988; 1990). The missing and incomprehensible aspects of the questions were corrected by applying the questions to the students in a different school. In addition, opinions of two chemistry teachers and two academics about the data collection tool were obtained. Teachers and academicians reviewed the appropriateness of the content of the questions in the data collection tool to the sampling, cognitive field taxonomy, and educational objectives. As a result of this arrangement, four open-ended questions were used as the data collection tool.

The language of education in the school where the study was conducted is Turkish, so the test was applied in Turkish. However, since the questions will be presented in the study, they have been translated into English with the support of two translators. After Turkish questions were translated into English, different translators were asked to write their counterparts in Turkish without showing the Turkish questions. Information about the questions in the data collection tool (Appendix A) and the content of the questions are given in Table 1.

**Table 1: The content of the open-ended questions in the data collection tool**

Questions	Content
1	The effect of gas pressure released by the reaction between metal and acid $\text{Mg(s)} + 2\text{HCl(aq)} \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq}) + \text{H}_2(\text{g})$
2	Pressure, temperature, volume relationship in gases
3	Pressure, temperature, expansion, kinetic energy relationship in gases
4	The effect of temperature, pressure, and state change in gases on intermolecular distance

The test was completed in 30 min. The sample was encouraged to answer all questions to the best of their ability since their written explanations were very important to identify alternative conceptions. After the test was administered, group discussion was used for an in-depth investigation of students' conceptions and validated the results of the paper-pencil test. This also provided data for triangulation (Harrison and Treagust, 2001).

In the study, three students were selected from each school and three groups were formed and interviews were

conducted with nine students in total. The students in the same group were educated at the same school. Interviews were conducted in three separate groups (Group A, Group B, and Group C). The students were randomly selected on voluntarily and regardless of their level of achievement. During the interview, students were assured that their views would be used within the scope of this study. In the group discussions, questions were asked about the answers of the students. "Can you explain the answer you wrote? Can you explain the situation that makes you think like that?" The group discussions were tape-recorded. Each group discussion took about 30 min.

**Table 2: The open-ended questions were analyzed using the following categories (Calik and Ayas, 2005. p. 642)**

Understanding levels	Criteria
Sound understanding	Responses that included all components of the validated response
Partial understanding	Responses that included at least one of the components of the validated response, but not all the components
Partial understanding with specific alternative conceptions	Responses that showed an understanding of the concept, but also made statement which demonstrated a misunderstanding
Specific alternative conceptions	Responses that included illogical or incorrect information
No understanding	Repeats question; irrelevant or unclear response; blank

### Data Analysis

The data obtained from the study were analyzed using content analysis and descriptive statistics. While analyzing the data, the answers given by the students were categorized under no response, no understanding, partial understanding with specific alternative conceptions, partial understanding, and sound understanding. In the literature, studies are using such categories in the analysis of open-ended questions (Akdeniz et al., 2000; Calik et al., 2006; Marek, 1986). The categories and contents used to analyze the answers given by the students are shown in Table 2. Besides, as each question was different from one another, the expressions that are appropriate for categories are shown in Table 3.

**Table 3: Expressions that are appropriate for categories**

Categories	Question 1	Question 2	Question 3	Question 4
			II and III (correct answer and correct explanation)	II and III (correct answer and correct explanation)
			I false: When the balloon is taken to a cooler environment at the same pressure, the volume of the balloon will decrease as the temperature will decrease. So the balloon will shrink rather than inflate. Its volume will decrease.	I False: if the temperature increases, the molecules become distant from each other and the distance between them increases.
			II true: If the balloon is taken to a place with higher elevation at the same temperature, the volume of the balloon will increase. Because the external pressure decreases as you go higher.	II true: If the pressure increases at a constant temperature, the molecules become more likely to get closer and the distance between them decreases.
Sound understanding	$Mg(s)+2HCl(aq) \rightarrow Mg^{2+}(aq)+ 2Cl^{-}(aq) + H_2(g)$ Mg metal and HCl acid solution react. As a result of this reaction, H <sub>2</sub> gas is formed. This gas causes the rubber stopper to eject.	As the tires heat up due to friction, the kinetic energy of the gases in the tire increases. This increases the speed and the collision severity of gases.	III true: In an air drained environment with the same temperature, the volume of the balloon will increase because there is no external effect.	III true: When completely liquefied, the intermolecular distance decreases. Liquids are more regular than gases.
Partial understanding	As a result of the release of H <sub>2</sub> gas, the rubber stopper pops out. Since the internal pressure and external pressure difference is formed, the rubber stopper pops out.	Responses that included at least one of the components of the validated response, but not all the components.	II and III (giving correct answers and making incomplete explanations without wrong concepts)	
Partial understanding with specific alternative conception				Responses that showed an understanding of the concept but also made a statement which demonstrated a misunderstanding.
Specific alternative conceptions				Responses that included illogical or incorrect information

To analyze the data, a data set was created by analyzing the written documents of 87 students for each question. The created data set was presented to the opinion of five science education experts, together with the researcher. Five experts in science education analyzed the data. The experts were asked to examine the data first and to classify the answers according to the categories listed in Table 2. Then, the evaluations of the experts were compared and the agreements and disagreements between the classifications were determined. Finally, the answers of the students were placed in the mostly agreed category. The formula reliability = consensus/(consensus + difference of opinion) was used for consistency between coders (Miles and Huberman, 1994). For the current study, this value was 80%.

## RESULTS

### Findings of Determining Understanding Levels

The data obtained from the study were analyzed separately for four questions and are presented in Table 4:

When the table is examined, it is seen that the rate of sound understanding category for the first question was 25.28% and the rate of the partial understanding category was 50.57%. In terms of partial understanding with specific alternative conception category, specific alternative conceptions, and no understanding, the rates were 12.64%, 9.19%, and 2.29%, respectively. Half of the students gave answers that included one aspect of the answer to this question but did not include all aspects (partial understanding).

For the second question, the table shows that the rates of sound understanding and partial understanding were equal (22.9%). In terms of partial understanding with specific alternative conception category, specific alternative conceptions, and no understanding categories, the rates were 26.43%, 18.39%, and 9.19%, respectively. Most of the students (26.43%) answered this question in a way that showed the concept was partly understood but included an alternative concept at the same time (partial understanding with specific alternative conceptions) (Table 4).

As can be seen in the table, the rate of sound understanding category for the third question was 20.6% and the rate of the partial understanding category 48.27%. In terms of partial understanding with specific alternative conception category, specific alternative conceptions and no understanding categories, the rates were 14.94%, 9.19%, and 6.89%,

respectively. Most of the students (48.27%) gave answers that included one aspect of the answer to this question but did not include all aspects (partial understanding) (Table 4).

For the fourth question, it is seen that the rate of the sound understanding category was 55.17% and the rate of the partial understanding category 10.34%. In terms of partial understanding with specific alternative conception, specific alternative conceptions, and no understanding categories, the rates were 25.28%, 8.04%, and 1.14%, respectively. Most of the students (55.17%) gave answers that included all aspects of the answer (sound understanding) (Table 4).

In addition, when the answers containing alternative conceptions and no understanding category were evaluated together, it is seen that the answers given by the students to the second question (26%, 18%) were higher than the other questions in the same categories (44%). When sound and partial understanding categories were evaluated together (25%, 50%), the answers of the students to the first question (75%) were higher than the other questions in the same categories. It is observed that the students mostly did not answer the second question (9%) (Table 4).

### Findings of Determining Alternative Conceptions

#### *Alternative conceptions for the first question*

When Table 5 is examined, the students attributed the cause of the rubber stopper's popping out to the volume insufficiency in the tube, the increase in the number of moles as a result of the reaction, the volatility of H<sup>+</sup> ions, and the gas density. They also stated that the reaction would take place and air would be released because of the reaction.

Results obtained from Group A discussions: When Mg metal was added to the HCl solution, the students attributed the reason for the jump into the rubber stopper to increase the amount of matter. They stated that when two substances come together, the total amount of matter would increase and therefore, the rubber stopper would blow off. Besides, students discussed their ideas to reach an agreement; they thought that the air would be formed as a result of the metal dissolving in acid and that the air on the tube would increase. In the discussion, they did not mention the reaction between metal and acid and the release of hydrogen gas.

Results obtained from Group B discussions: The students thought there was a chemical reaction between HCl and Mg, but their description was quite different. One student stated that

**Table 4: The rate of answers to questions by categories**

Questions	Sound understanding		Partial understanding		Partial understanding with specific alternative conception		Specific alternative conceptions		No understanding	
	n	%	n	%	n	%	n	%	n	%
1	22	25.28	44	50.57	11	12.64	8	9.19	2	2.29
2	20	22.9	20	22.9	23	26.43	16	18.39	8	9.19
3	18	20.6	42	48.27	13	14.94	8	9.19	6	6.89
4	48	55.17	9	10.34	22	25.28	7	8.04	1	1.14

**Table 5: The students' statements for the first question, including alternative conceptions**

Categories	Students' statements
Sound understanding	<p>A reaction between the metal and the acid occurred. As a result of this reaction, H<sub>2</sub> gas was released. The gas must have thrown the rubber stopper.</p> $\text{Mg(s)} + 2\text{HCl(aq)} \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq}) + \text{H}_2(\text{g})$ <p>H<sub>2</sub> gas was released as a result of the reaction between a metal and a strong acid. As a result of the pressure made by the gas, the stopper popped out.</p>
Partial understanding	<p>Because of the reaction of acid and metal, the pressure was applied to the stopper and the stopper popped out.</p> <p>As a result of the Mg and HCl reaction, the rubber stopper popped out as the volume was insufficient.</p> <p>Mg metal was dissolved in HCl.</p> <p>Since HCl is a strong acid, a strong effect occurs in a closed container.</p> <p>When Mg and HCl combine, there occurs a swell.</p> <p>Due to the difference between internal pressure and external pressure, the rubber stopper popped out.</p>
Partial understanding with specific alternative conception	<p>Air is released by the acid metal reaction.</p> <p>HCl and Mg metal reacted and the number of moles increased.</p> <p>Since Mg and HCl react, there occurs a gas density.</p> <p>Since Mg and HCl react, heat is produced. This situation forces the stopper as the temperature increases the pressure.</p> <p>Mg and HCl have a reaction and pressure difference occurs. External pressure decreases and internal pressure increases.</p>
Specific alternative conceptions	<p>Mg metal pressurizes the HCl acid solution.</p> <p>With the H<sup>+</sup> ions flying in gaseous form, the rubber stopper pops out.</p> <p>The reduction of O<sub>2</sub> content and increased CO<sub>2</sub> content creates pressure inside.</p> <p>When Mg is removed, a neutralization reaction occurs and H<sup>+</sup> ion is released.</p> <p>When the H<sup>+</sup> ions decompose and fly as a gas, the stopper pops out.</p> <p>The energy inside the tube fills the tube.</p>

the pressure increased due to the reaction and that the rubber stopper was forced out. This answer is the kind of answer that will be considered partially correct. Two other students stated that a solution was formed inside the tube, the dissolved gases mixed into with the air, the amount of air on the tube increased, and the rubber stopper popped out (was ejected) for these reasons. They did not give any explanation for the formation of hydrogen gas or the difference in internal pressure and external pressure, considering that the rubber stopper popped out because the amount of air in the tube increased.

Results obtained from Group C discussions: They began to argue based on the idea that there was a hydrogen element in the HCl acid solution. They stated that when the hydrogen element and Mg metal reacted, the pressure increased, and the rubber stopper popped out as the pressure increased. They strongly claimed that pressure difference may occur due to the hydrogen element that occurs when the Mg metal dissolves within the acid. The students described hydrogen gas as the hydrogen element and continued these claims.

### *Alternative frameworks for the second question*

When Table 6 is examined, students generally attributed the increase in tire pressure to the change in outdoor pressure and the change in elevation. They also attributed the cause of pressure increase to volume decrease and the cause of volume decrease to heat increase. It was also mentioned that the pressure on the accelerator pedal increased the gas pressure on the wheels.

Results obtained from Group A discussions: The students started the discussion based on the ideal gas equation and the

pressure-volume relationship in the gases. They stated that as the temperature increased, the gas pressure would increase. They explained that the wheel was constantly active due to friction and that the increased temperature would cause an increase in gas pressure. Besides, some students noted that due to friction, the temperature increased, but the volume decreased. The students came up with the idea that the volume would decrease from the reverse ratio between the pressure and volume of a gas. They concluded that the volume should decrease because of the pressure in the tire increases.

Results obtained from Group B discussions: The students noted that there would be an increase in heat due to friction and movement, which would increase the energy of gas molecules. They stated that there was a direct ratio between the acceleration of gas molecules and the increase in tire pressure. Furthermore, one of the students asked if they could say that if the pressure was increasing, then the volume was decreasing. Other students stated that there was the opposite ratio between the pressure and volume of the gases, and the other decreased when one increased. However, one of the students said it would not be right to mention the case of volume increase or decrease for this question. Others said that if gas was mentioned, the relationship between volume and pressure would not be ignored. There was a disagreement among the students.

Results obtained from Group C discussions: They expressed that energy was formed due to friction and this energy is kinetic. They stated that the tires need to be rested to reduce energy growth. The students explained the answer with energy and stated that they did not want to mention other issues

**Table 6: The students' statements for the second question, including alternative conceptions**

Categories	Students' statements
Sound understanding	<p>Due to friction in the tires, the temperature increases, kinetic energy increases, gas pressure increases due to temperature. The temperature increases due to friction. According to the ideal gas equation (<math>PV=nRT</math>), temperature increase causes pressure increase.</p> <p>The kinetic energy of the gas molecules in the tire increases. The temperature of the substance increases as the kinetic energy of the gas molecules increases. Temperature causes an increase in pressure.</p> <p>The car tire heats up and expands due to friction. The air particles in the tire move faster. Therefore, the pressure increases.</p>
Partial understanding	<p>The pressure increases as the wheels heat up (<math>PV=nRT</math>)</p> <p>Pressure increases due to friction.</p> <p>When the gas pressure increases, the tire explodes.</p> <p>The temperature increases due to friction.</p> <p>Increased kinetic energy increases the temperature.</p> <p>The pressure increases with the increase of kinetic energy.</p>
Partial understanding with specific alternative conception	<p>Heat increases due to friction, volume decreases with heat increase, gas pressure increases when volume decreases. The ideal gas equation can be reached from this conclusion (<math>PV=nRT</math>).</p> <p>As the tire comes into contact with the ground, it heats up, increasing the temperature, reducing the volume, and increasing the pressure because there is friction.</p> <p>As a result of friction, the heat is revealed. This increases the intermolecular distance, which leads to an increase in pressure. At high pressure, road holding decreases.</p> <p>Friction happens, volume decreases gradually.</p> <p>As the tires move, the gases inside apply kinetic energy to each other, so the pressure increases.</p> <p>When the tires turn for a long time, the air inside them gets compressed.</p>
Specific alternative conception	<p>Increasing the volume of the tire makes driving difficult.</p> <p>Pressure from the accelerator pedal increases the gas pressure on the wheels.</p> <p>Gas molecules apply energy to each other.</p>

in order not to answer incorrectly. When asked what other issues were, they stated that they could not fully express the relationship among the variables in the ideal gas equation.

### *Alternative frameworks for the third question*

When Table 7 is examined, the students explained the volume change of the balloon in the conditions given in the question as follows: The volume increases with the pressure increase above the sea level, the volume increases as the elevation increases, and the air expands when the pressure decreases.

Results obtained from Group A discussions: The students in group A made the right statement thinking that the volume of the balloon would decrease so that the molecules would get closer in the colder environment at the same pressure. As you go higher, the pressure increased and they made an incorrect explanation input, thinking that this pressure change would increase the volume of the balloon. In other words, they were unable to correctly associate the change in balloon volume with the pressure change that occurs as you rise to high levels. In the deflated environment, they stated that the volume of the balloon would not increase but would decrease. They noted that the air was the main cause of the increase in the volume of the balloon. They claimed that the volume of the balloon would not change because there was no air and no oxygen, that is, no external effect on the balloon. Concerning these explanations, the students stated that only in the second case, the volume of the balloon would increase.

Results obtained from Group B discussions: In the first case, the students started to argue that the substances would expand in a cold environment at the same pressure, that is, their volumes would increase. One student noted that electrical wires crumpled in the cold and expanded in the heat. Later, they changed the expression "substances expand in a cold environment" and stated that the substance would expand when heated. In this case, by changing their first statements, they concluded that the volume of the balloon would decrease in the first case. In the second case, they said that as the pressure increased, the volume of the balloon would decrease as the pressure decreased. In the third case, they stated that they certainly did not expect the volume of the balloon to increase in the deflated environment. "Isn't the deflated environment neutral environment? So does the volume of the balloon not change?" they claimed. As a result, they stated there was nothing that would cause the volume of the balloon to change.

Results obtained from Group C discussions: The students claimed there would be no pressure in the deflated environment, so they thought there would be a tendency to spread in gases. They emphasized that the volume of the balloon could increase due to its tendency to spread. When asked about the reason for this situation, they stated that as you go higher, the pressure increase and the balloon would be explosive. They stated that the volume of air particles would decrease in cold weather, and this reduction would directly affect the volume of the balloon. As a result, they stated that the volume of the balloon in the

**Table 7: The students' statements for the third question, including alternative conceptions**

Categories	Students' statements
Sound understanding	<p>II and III</p> <p>I. If the temperature decreases, the volume decreases</p> <p>II. As you go to high altitudes, open-air pressure decreases, the volume of the balloon increases</p> <p>III. There is no external pressure in the air-drained environment, the volume increases.</p>
Partial understanding	<p>As you go higher, the volume of the balloon increases.</p> <p>Only in the second case, as you go higher, the pressure decrease. Pressure and volume are inversely proportional.</p> <p>Only in the third case, the volume increases.</p> <p>The volume of the balloon increases because there is no external pressure in the air-drained environment.</p> <p>Pressure and volume are inversely proportional.</p> <p>In places with high elevation, the pressure is low. According to the ideal gas equation, the volume is inversely proportional to pressure, if the pressure is low, the volume increases and the balloon swells.</p>
Partial understanding with specific alternative conception	<p>As the balloon goes up, its volume increases, and it explodes.</p> <p>If there is no external pressure, the balloon explodes.</p> <p>I and II</p> <p>Gases expand in the cold environment. As you go higher, the pressure decreases, so the volume increases. In an air-drained environment, the volume of the balloon decreases.</p>
Specific alternative conceptions	<p>No expansion occurs when the air is deflated.</p> <p>The gas condenses in the cold.</p> <p>As the pressure decreases, the air expands.</p> <p>As you go higher, the pressure becomes higher. Pressure and volume are inversely proportional.</p> <p>The volume of the balloon is fixed as you go higher.</p> <p>Gases expand in the cold environment.</p> <p>The volume of air particles increases in the hot environment.</p> <p>If the temperature decreases, the volume increases. <math>PV=nRT</math></p> <p>Since the pressure increases as you go above the sea level, the volume of the balloon decreases.</p>

cold would decrease, but the explanation was not necessarily a true explanation.

#### *Alternative conceptions for the fourth question*

When Table 8 is examined, the students stated that the distance between gaseous matter according to the conditions stated in the question is related to high pressure and the increase in pressure causes volume decrease. They also explained the matter with varying intermolecular distance in the solid, liquid, and gaseous states.

Results obtained from Group A discussions: The students claimed that when the temperature increased, intermolecular interaction and distance would decrease. In the case of increasing the pressure at a constant temperature, they made an accurate discussion entry by stating that gases would be compressed. They then stressed that this compression would cause the gas to liquefy and the distance between the gas molecules would decrease. They stated that the intermolecular distance would decrease from gases to liquid. Therefore, when gas substances were liquefied, their molecules would get closer together and the distance between them would decrease.

Results obtained from Group B discussions: Students first began to explain the third condition. They stated that if gaseous substances were liquefied, the molecules would move closer together. They emphasized that the intermolecular distance in the gaseous state of matter was the most. They argued that if we increased the temperature in constant

volume, intermolecular interaction and vibration would increase, but this would not change the distance between molecules. They concluded their discussion by stating that when pressure was applied to the molecules, the molecules would move closer together and the intermolecular distance would increase.

Results obtained from Group C discussions: In the first case, they argued that when the temperature of the gaseous substance at a constant volume was increased, the intermolecular distance would decrease as the intermolecular bond was weakened. They said the intermolecular distance would not change without the intermolecular bonds being extended and severed. They linked that temperature increased the number of collisions and associated this with the weakening of the intermolecular bond. In the second case, one of the students commented on the formula  $PV=nRT$ . "If the pressure of the gas increases, the volume increases; if the volume increases, the intermolecular distance increases," he said. He also stated that as the pressure increased, there would be more matter between the molecules. Other students opposed these ideas. They stated that when the pressure increased, the volume would decrease, and they should reconsider it in line with this idea. In the third case, they claimed that the intermolecular distance decreased because the volume decreased. One of the students stated that the intermolecular distance from the gas to the solid would increase, while the others argued that it should be the opposite.

**Table 8: The students' statements for the fourth question, including alternative conceptions**

Categories	Students' statements
Sound understanding	According to the formula $PV=nRT$ , I. If the temperature increases, the intermolecular distance increases. II. If the pressure increases, the intermolecular distance decreases III. - Intermolecular distance decreases. I. The most irregular state of matter, that is, the state where the distance between the molecules is the highest, is the state of the gas. When the temperature of matter increases, the distance between the molecules increases. II. According to $PV = nRT$ , if the pressure at constant temperature increases, the volume decreases, and the intermolecular distance decreases. III. Since the intermolecular distance is gas > liquid > solid, the intermolecular distance decreases.
Partial understanding	I. If the pressure increases, the gases will approach each other. II. When the gases are liquefied, it becomes more regular than gases. I. If the temperature increases, the molecules accelerate, and the distance between the molecules increases as a result of accelerations
Partial understanding with specific alternative conceptions	If the pressure increases at a constant temperature, the volume decreases, and if the volume decreases, the distance increases. II and III in both cases, reduce the volume. I. If the temperature increases in constant volume, the kinetic energy of the gases increases. Therefore, the distance between molecules is reduced. According to $PV=nRT$ formula, I. If the pressure increases, the volume decreases, and the distance decreases II. If the pressure increases at a constant temperature, the volume decreases, and the distance increases
Specific alternative conceptions	If the temperature increases, the pressure decreases, and the volume decrease. Intermolecular distance does not change. If gases are liquefied, intermolecular distance increases As you move from gas to solid, the intermolecular distance increases. Increased pressure results in more substances between molecules. If the temperature increases at a constant volume, the intermolecular bond weakens. If the temperature increases, the pressure decreases, and the distance between molecules decreases. At high pressure, the volume decreases, and the intermolecular distance decreases. If the temperature increases, the pressure decreases. Intermolecular distance increases. According to the formula $PV=nRT$ , if the pressure increases, the volume increases and if the volume increases, the intermolecular distance increases. If the temperature increases, the intermolecular interaction decreases. If the pressure increases, the interaction between the matters, and the intermolecular distance increases. If the gaseous material liquefies, it becomes bulky. If the pressure increases at a constant temperature, it solidifies. To have a gravitational force between the molecules, the pressure difference must be created.

## DISCUSSION AND CONCLUSION

### The Results of the Understanding Level

According to the findings obtained from the study, it was observed that the students answered the fourth question at the level of sound understanding, where the effect of temperature, pressure, and state change on the intermolecular distance in gases was examined.

This might be because the events occurring in the change of state are more readily understood by the students than the other specific issues about gases (Table 4). Learning the nature of matter for teaching chemical concepts and subjects is important for the transition to other subjects (Barker, 1995; Benson et al., 1993; Griffiths and Preston, 1992; Hwang, 1995; Kruger and Summers, 1989; Lin et al., 2000; Osborne and Cosgrove, 1983; Stavy, 1990). The subject of the nature of the matter concerning gases includes the subjects of the states of matter and the

variation of the distance between particles when the matter changes state. The fact that these subjects are frequently seen by the students might positively contribute to the learning of the students (Azizoglu and Geban, 2004; Demirhan et al., 2017; Jauhariyah et al., 2018; Lin et al., 2000; Mayer, 2011; Ozmen et al., 2002). Since the subject of state changes is frequently included in the 9<sup>th</sup>- and 10<sup>th</sup>-grade curriculum, students could be expected to have this information.

The question with the least number of correct explanations was the third question that examined the relationship between pressure, temperature, expansion, and kinetic energy in gases (Table 4). This question is more related to daily life than other questions. The relationship between external pressure change, temperature, and pressure as you go higher are events related to daily life. Besides, students in the sample should know the relationship between the chemical variables such as pressure, temperature, and expansion and they should be expected to

be able to reason on how the variables affect each other. The least number of correct explanations might be because students cannot sufficiently relate to the issue of gases to daily life. In the literature, there are studies similar to the present study finding that students cannot associate their knowledge with current daily life events (Azizoglu and Geban, 2004; Demirhan et al., 2017; Jauhariyah et al., 2018; Lin et al., 2000; Mayer, 2011; Ozmen et al., 2002).

### The Results of Alternative Conceptions

In the first question that examines the effect of gas pressure released as a result of the reaction between metal and acid, students were expected to respond that the rubber stopper would pop out when the internal pressure was too high, that is, the  $H_2$  gas pressure in the container was greater than the open-air pressure. However, the students said the reason for the rubber stopper to pop out was that HCl acid was strong,  $H^+$  ions fluctuated, the number of moles as a result of the reaction increased, the amount of  $O_2$  decreased, the amount of  $CO_2$  increased, and the air released. As it is understood from the answers, the difference between  $H_2$  gas and  $H^+$  ion was not known by the students (Table 5). They could not fully reason the difference between internal pressure and external pressure. Therefore, to avoid such an alternative framework, the information should be given about different ideas on different subjects (Abraham et al., 1992; Bodner, 1991; Dori and Hameiri, 2003; Goodwin, 2002) and the terms “ion,” “atom,” and “molecule” should be defined with their exact similarities and differences (Calik and Ayas, 2005; Ebenezer and Erickson, 1996; Mas et al., 1987). Dori and Hameiri (2003) emphasized that without a thorough understanding of the symbol, macro, micro, and process, the levels and transformations between them cannot be accurately classified.

In the second question that examined the relationship between pressure, temperature, and volume in gases, the students were expected to explain the reason for the increase of gas pressure in the tire with the increase in the average velocity of the gas molecules in the tire, the increase in the impact force of the gas particles on the inner surface of the tire, and the increase in the number of impacts of the gas particles on the inner wall of the tire per unit time. Although the question did not indicate an elevation or descent above sea level, the students attributed the reason for the increase in tire gas pressure to the change in elevation. Besides, the change of open-air pressure and the energy applications of gas molecules to each other were among the alternative conceptions. They stated that the temperature increased due to friction and that temperature increase caused volume decrease and pressure increase. As the students knew that  $PV = nRT$  pressure is inversely proportional to the ideal gas equation, they interpreted that the volume decreased if the pressure increased (Table 6). Similar to the findings of the present study, it was stated that although students had memorized the formula, they did not know the meaning of the formula and could not correctly use it (Bodner, 1991; Demirhan et al., 2017; Lin et al., 2000). Students should be taught exactly and accurately of symbolically expressed concepts and gas

laws (Demircioglu and Yadigaroglu, 2013; Jauhariyah et al., 2018; Lin et al., 2000; Nakiboglu and Yildirim, 2011).

In the third question, where the effect of external pressure and temperature change on the volume of elastic balloon was examined, the answers that the students should give were as follows: the volume of the balloon becomes smaller when the temperature of the balloon decreases (Premise I is false); the internal pressure must be increased or the external pressure must be decreased to increase the volume of the elastic balloon; as you go higher the volume of the balloon increases due to the decrease in external pressure (Premise II is true); the volume of the balloon increases as the external pressure decreases (Premise III is true). The students stated that the pressure would increase and the volume will decrease as the sea level goes up. The students who gave answers with alternative concepts could not distinguish the difference between the external pressure and gas pressure. Some students stated that the external pressure would decrease as the elevation increased in group discussions, but they thought the volume of the balloon was inversely proportional to the external pressure. Therefore, they failed to use the  $PV = nRT$  formula correctly. They tried to relate the pressure and volume relationship in the ideal gas equation to the answer to the question (Table 7). The prior knowledge about gases of the students adversely affects the interpretation and understanding of gases and leads them directly to the formula (Lin et al., 2000; Mayer, 2011). While the students were learning through formulas, they could not fully internalize the meaning of the parameters in the gas equation (Bodner, 1991; Lin et al., 2000). Since atmospheric pressure and gases are an abstract topic, studies are indicating that students may have difficulty in learning if the students are not taught effectively (Mas et al., 1987; Nelson et al., 1992). Since generally, students cannot learn by reasoning about gases, they have alternative conceptions about the properties of gases (Aydeniz et al., 2012). It is seen that the students interpreted the subject of the expansion of the gases in a wrong way as they presented such statements as “gases expand in the cold environment,” “no expansion occurs when air is deflated,” “air expands when pressure decreases,” and “volume increases if temperature decreases.” This statement could be interpreted that students did not understand the relationship between the pressure and volume of gas within a balloon. It could also be inferred that students knew that when the pressure outside of the balloon decreased, the air within the balloon expanded.

Expansion can be observed as the air in the balloon expands the volume of the balloon. Responses such as the matter that increases its temperature expands and the matter that decreases its temperature shrinks might be considered scientifically correct. The fact that the students have the idea “the volume of air particles increases in the hot environment” might be due to their attempt to explain the reason for the expansion by the increasing or decreasing volume of the particles instead of the distance between the particles. From these answers, it can be concluded that students could not correctly construct the concept of the gap. Hwang (1995) identified the alternative

conceptions of gases have no volume and the volume of gas is as large as the size of its particles. The misconception of as you go up, the pressure increases due to the increasing amount of gas was found in various studies (Aron et al., 1994; Aydeniz et al., 2012; Nelson et al., 1992; Pabuccu, 2016; Sahin and Cepni, 2012; Yalcinkaya and Boz, 2015).

In the fourth question, where the change in intermolecular distance was examined, the answers that the students were expected to give should be as follows: The distance between the particles of gases depends on the ratio of the number of moles to the volume  $n/V$ ; if this ratio increases, the distance between particles decreases; accordingly, the ideal gas equation is arranged as  $n/V = P/(R.T)$ . If the temperature increases at a constant volume, the  $n/V$  ratio does not change, as it will increase the pressure at the same rate (Premise I is not appropriate). If the external pressure increases at a constant temperature, the  $n/V$  ratio must increase (Premise II is appropriate). If a gaseous material is completely liquefied, the particles approach each other. (Premise III is appropriate). When the answers of the students and group discussion results were examined, it was seen that they misinterpreted the ideal gas equation like other questions and they could not reason that the distance between gas particles is  $n/V$  dependent (Table 8). Despite memorizing the formula, they could not use the formula appropriately (Lin et al., 2000). The students could not explain how gas pressure was affected and how the distance between particles changed when two variables changed in the gas equation. Similar to the findings of the present study, studies are indicating that it is difficult to understand the effect on gas pressure when two variables in the ideal gas equation change together (Basca and Grotzer, 2001; Taylor and Lucas 2000).

In the present study, the students used the expressions “the gaseous matter becomes bulk if it becomes liquefied,” “the distance increases if the gaseous materials get liquefied,” and “the intermolecular distance increases as the gas changes to solid.” These statements might be due to their inability to reason that the most irregular state of the matter is gas and the distance between particles is the most. In addition, the students attempted to explain the increase or decrease of intermolecular distance by intermolecular bonds. By explaining the distribution properties of gases, they could not clearly describe the relationship between concepts.

According to the results stated in the present study, alternative conceptions of students should be taken into consideration while designing teaching and it should be aimed to overcome misunderstandings (Mayer, 2011). In this direction, student-centered active learning methods should be designed, strategies should be developed by making correct learning in line with the reasoning difficulties of the students and the conceptual learning of the students should be supported (Ayyildiz and Tarhan, 2013; Yoshikawa and Koga, 2016). Two challenges facing science teachers are identifying misperceptions about how students work in the world and overcoming these

misunderstandings. Previous concepts of students often contradict the content that educators and science-textbook writers try to teach. They need to define the perspectives of students and then design guideline materials that should be designed to facilitate conceptual learning (Fouché, 2015).

### Limitations

The data obtained from the study are based on the responses of the students to the data collection tools. The answers reflect the perspectives of the students. The results of this study were found through written documents of 87 students from three public schools. Besides, the results were limited to the answers of nine volunteer students to interview questions. The number of samples can be increased by working with many schools in further studies. In future studies, long-term observations can be made and student perceptions can be supported by observation data.

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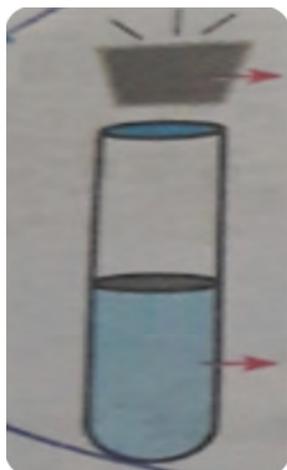
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## APPENDIX A

### Question 1:



Rubber stopper

Mg metal is thrown into a tube containing HCl acid solution and immediately sealed with a rubber stopper. After a while, the rubber stopper pops out.

HCl acid solution

Could you explain the reason for this?

### Question 2:

It is necessary to take a break every 2 h and relax on long journeys. One of the reasons for this is to prevent accidents due to the increased gas pressure in the car tire during the journey.

How do you explain the reason for this gas pressure increase?

### Question 3:

An elastic balloon that is slightly inflated through blowing and tied with rope is taken from its location and put in the following places:

- I. Colder at the same external pressure
- II. A higher place at the same temperature
- III. At the same temperature and deflated

Which of the environments is expected to increase the volume of the balloon? Please explain.

### Question 4:

A certain amount of gaseous matter is present,

- I. Increasing the temperature in a constant volume
- II. Increasing the external pressure at a constant temperature
- III. Liquefaction of all

Which of the processes is expected to decrease the intermolecular distance of that substance? Please explain.