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Application of the First Law of Thermodynamics to the Adiabatic Processes of an Ideal Gas: Physics Teacher Candidates' Opinions

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ABSTRACT: The present study was carried out with 46 teacher candidates taking the course of *Thermodynamics* in the Department of Physics Teaching. The purpose of the study was to determine the difficulties that teacher candidates experienced in explaining the heat, work and internal energy relationships in the processes of adiabatic compression and expansion of an ideal gas. By examining both the results the teacher candidates found and the related interpretations made by the teacher candidates, the difficulties they experienced in understanding the subject were determined. The difficulties determined were gathered under two categories: a) discriminating the concepts (heat, work, internal energy and temperature) and b) application of the first law of thermodynamics to the adiabatic processes. It was seen that most of the teacher candidates experienced difficulty in understanding the fact that there was no difference between the functions of the concepts of heat and work in the microscopic scale.

KEY WORDS: Physics education, thermodynamics, internal energy, heat, adiabatic process

INTRODUCTION

Thermodynamics allows an understanding of the overall physical features of a system in a microscopic dimension without focusing on the microscopic details of the behaviour of each component of the system. Thermodynamics also explains the relationships between such basic concepts as entropy, energy, heat capacity and temperature. In addition, it helps understand such various occasions as stable equilibrium, semi-stable equilibrium, reversible processes, irreversible processes and phase transitions based on classical theories. This field of physics deals with physical systems including such parameters as Helmholtz energy, Gibbs free energy, entropy and enthalpy as well as such thermodynamic parameters as temperature, pressure and volume. Thermodynamics

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education aims at developing the students' ability to reveal the relationships between the occasions and concepts mentioned above.

In previous studies, it is reported that there is little research on students' judgments regarding thermal physics and that there is a need for more information about students' ability to apply their background knowledge to new situations (Leinonen et al., 2011). Such vast and deep information not only helps students overcome the difficulty in learning but also helps teachers and teacher trainers design and develop thermal physics instruction. Both problem solving as a teaching method and making judgments as a thinking skill have an important place in teaching the science of physics. It is seen that in general, a majority of published studies have mentioned the concepts related to reasoning and problem solving (Bhaslar & Simon, 1977; Chi et al., 1982; Leonard et al., 1996). In literature, these concepts have not been defined clearly and are mostly used in related discussions without being defined first (Leonard et al., 1996; Mason and Singh, 2010). We can consider problem solving as a process in which the problem solver is active, makes research, obtains certain findings and benefits from his or her previous experiences and from the findings obtained (Dhillon, 1998). The most beneficial aspect of problem solving is that it provides the person with the opportunity to learn and to expand and organize his or her knowledge (Mason & Singh, 2010). In practice, there are various problem solving activities. Typical examples for these activities include use of different presentations and explanations as well as use of related concepts and qualitative analyses (Dhillon, 1998). Therefore, problem solving strategies constitute an important scheme of actions approved in problem solving. For example, these strategies may include using, producing and testing strategy analogies or dividing a problem into parts (Dhillon, 1998).

A detailed definition of the concept of reasoning was put forward by Walton (1990). According to Walton, reasoning is a tool used in problem solving. In addition, reasoning constitutes the basis of students' responses (McDermott & Residh, 1999). However, this is not a process that can easily be seen or revealed. It is quite rarely seen only in mathematical problem solving (McDermott, 1991). In a sense, as a part of problem solving, reasoning is regarded as a job that students are supposed to do to fulfil, confirm and evaluate their problem solving task. Although problem solving is sometimes considered to be a mechanical process, it is seemingly a complex process of reasoning. Since reasoning and problem solving are two interrelated concepts in practice, it is impossible to draw a clear-cut line between these two concepts. The example below demonstrates these relations in physics.

In studies comparing expert and novice problem solvers, it is reported that when experienced physics teachers encounter with a new phenomenon, they automatically use such basic principles as conservation of momentum and conservation of energy while making judgments (Chi et al., 1982). If they cannot find a solution via their first approaches, they always make effort to change this (Loverude et al., 2002). Especially when this principle is used once and approved, an expert problem solver solves the problem by using appropriate equations related to this principle. For a scientist, the most important phase is to find and choose the appropriate principle.

Although the principles constituting the basis of conceptual information and equations have been suggested by physics education researchers, these principles are rarely used (Leonard et al., 1996). Novice students tend to believe only one aspect of equations without understanding the limitations of these equations. Being aware of the limitations of an equation is an issue related to reasoning skills.

Reasoning skills are quite important both in problem solving and for future scientists and teachers (Redish et al., 1998). Students try to base their responses on the principles and laws of physics (Leonard et al., 1996). In addition, it is claimed that focusing on solving mathematical problems without any reasoning in physics teaching does not contribute efficiently to students' levels of conceptual understanding (McDermott, 1991).

Consequently, it is suggested that students should make their judgments via their own words to understand physics (McDermott, 1991). According to Van Heuvelen (1991), before establishing the mathematical forms of problems in physics, students should be allowed to make transitions between different presentations and to discuss them in terms of their quality. Thanks to such activities, students can think in the way a physics expert does.

The research questions directed in the present study were as follows:

- Are teacher candidates able to explain questions directed towards adiabatic expansion and compression of an ideal gas by giving the logical reasons?
- Are teacher candidates able to apply the first law of thermodynamics to adiabatic processes?
- Do teacher candidates experience difficulty understanding the change in temperature in the process of adiabatic expansion and compression of an ideal gas?

LITERATURE REVIEW

The first study on students' learning of thermal physics concepts was carried out by Zemansky in 1970. This study was followed by many others in the field. For instance, the difficulties experienced by students regarding the concepts and terms of thermal physics have been discussed in various studies (Barbera and Wieman, 2009; Ineke et al., 1999; Meltzer, 2004; Van Roon et al., 1994). In addition, students' understanding of concepts related to the first law of thermodynamics was also investigated (Barbera and Wieman, 2009; Meltzer, 2004; Van Roon et al., 1994; Yeo and Zadnik, 2001). Most of these studies focused on the compression and expansion of an ideal gas (Kautz et al., 2005; Leinonen et al., 2009; Loverude et al., 2002; Meltzer, 2004).

Loverude et al. (2002) and Leinonen et al. (2009) determined and reported on the problem students encountered regarding the first law of thermodynamics. This observation made in the context of the adiabatic compression process revealed that the students tended to use inappropriate explanations rather than the first law of thermodynamics. As a result of this observation, it was reported that the students were not able to discriminate between such situational quantities as thermal energy and internal energy and such process quantities as work and heat (Loverude et al., 2002; Meltzer, 2004). In addition, it was also stated that the students did not apply the concepts scientifically, but used them in daily statements that require rather special language in the context (Loverude et al., 2002; Meltzer, 2004).

A more general problem is that the students do not remember or consider the important features related to various ideal gas processes. This situation is seen when students do not benefit from the concept of work while explaining the adiabatic operational processes (Loverude et al., 2002). If students cannot remember a concept, they will not know how and when to use that concept; as a result, they experience problems. Another problem observed by Kautz et al. (2005) is that students do not fully appreciate the relationships between the three thermodynamic quantities (temperature, pressure and volume). Therefore, students think that the pressure always increases if the volume decreases.

It is reported in many studies that students cannot discriminate between isothermal and adiabatic processes (Kautz et al., 2005; Leinonen et al., 2009; Meltzer, 2004). This is true when students take 'heat equal to zero' in isothermal processes (Meltzer, 2004) or when they take the 'temperature change equal to zero' in adiabatic processes (Leinonen et al., 2009; Loverude et al., 2002). Students frequently use the microscopic model incorrectly. Thus, they compare the temperature and the collision between particles and the pressure and speed of the particles or make an analogy between these concepts (Kautz et al., 2005; Leinonen et al., 2009; Loverude et al., 2002; Meltzer, 2004). In addition, students ignore the interactions of a system with its environment while making explanations at the micro level.

In one study, Meltzer (2004) determined a problem related to students' ability to apply different methods in problem solving. As a result of that study, it was found out that only a few students use the PV diagram in the process of an ideal gas cycle, although experts find this is the easiest way to the solution. In this process, various studies were conducted in the process to discover the possible reasons for students' misconceptions, or for the difficulties they experience in acquiring the concepts. Meltzer (2004) claims that this difficulty is likely to result from the difficulties that students experience in recognizing the difference between the important quantities in the first law of thermodynamics and the change in these quantities. It is also asserted that the difficulties experienced by students in mechanics (Loverude et al., 2002; Meltzer, 2004) are also likely to lead to problems together with the process quantities within the context of calorimetry (Meltzer, 2004). It is suggested that students face such problems in learning the microscopic model if it is introduced to them quite early in the instructional process (Leinonen et al., 2009; Loverude et al., 2002). In addition, very few of the previous studies mentioned discussions on the misconceptions and difficulties stated. Although different ideas were presented in the conclusion parts of only a few studies, the number of studies revealing the reasons is very limited[†].

Several studies carried out to prevent the learning difficulties that students experience have been introduced above. For example, teaching programs were designed to help acquire the concepts (Cochran, 2005) and to help apply the first law of thermodynamics (Barbera & Wieman, 2009; Kautz et al., 2005; Loverude et al., 2002). The difficulties mentioned and the materials introduced were activated to overcome students' misconceptions. It could be stated that most of students' misconceptions are due to lack of efficient reasoning skills. Various clues that support this view can be seen in the previous studies. For example, students tend to reach the present concepts by using the most familiar ideas without considering other options (Loverude et al., 2002) and experience difficulty recognizing the inconsistencies in their judgments (Loverude et al., 2002; Yeo and Zadnik, 2001). It is stated that students who do not have any scientific belief mostly resemble those who are not skilful (Lawson and Weser, 2006) and that students who have inefficient *reasoning skills* may not understand the abstractness of physics (Hammer, 1996). *Reasoning skills*, which are considered to be among the most important, are those we want our students to develop. When university students are asked to solve a secondary school level problem related to the adiabatic compression of an ideal gas, they will also need to have the knowledge about the content related to the problem (Leinonen et al., 2009). Students demonstrate inconsistencies in making appropriate explanations as well as in making judgments about events.

[†]Concept descriptions and students' misconceptions/ confusions/ misunderstanding about the thermodynamic processes is given in Table 1 [(adapted from Leinonen (2013)].

Table 1. Concept descriptions and students' misconceptions/confusions/ misunderstanding about the thermodynamic processes

Accurate concept descriptions related to heat, temperature and thermodynamic subjects	Students' misconceptions/misunderstanding and confusions	Researcher(s)
• Measured with a thermometer • A measure of the tendency to spontaneously give energy • A measure of the average kinetic energy of particles	• Paralleled with heat • Connection to thermal equilibrium is not understood • Related to density • Related to molecular collisions • Temperature as a property of a substance	• (Barbera & Wieman, 2009) • (Kautz, Heron, Loverude, & McDermott, 2005a)
• A measure of space occupied by the system	• Confused with the amount of gas • Incorrectly related to the molecular size of gases • Cooler gas takes less space • Incorrect microscopic models	• (Kautz, Heron, Loverude, & McDermott, 2005a)
• Energy in transfer due to the temperature difference	• Paralleled with temperature • Confused or paralleled with work/in thermal energy/thermal energy/enthalpy • Generated in interactions between particles • Considered as a substance	• (Barbera & Wieman, 2009) • (Kautz, Heron, Loverude, & McDermott, 2005a) • (Loverude, Kautz, & Heron, 2002) • (Meltzer, 2004) • (Van Roon, van Sprang, & Verdonk, 1994)

Table 1. (cont'd) Concept descriptions and students' misconceptions/confusions/ misunderstanding about the thermodynamic processes

• Energy in transfer not caused by temperature difference; an agent is required	• State quantities like thermal energy and in thermal energy are misunderstood • Direction of the work is misunderstood • Considered to be path independent	• (Loverude, Kautz, & Heron, 2002) • (Meltzer, 2004) • (van Roon, van Sprang, & Verdonk, 1994)
• The sum of microscopic kinetic and potential energies in a matter	• Confused with heat, work, enthalpy and mechanical energy • Can be changed via interactions within the system	• (Loverude, Kautz, & Heron, 2002) • (Van Roon, van Sprang, & Verdonk, 1994)
• Adiabatic and isothermal processes	• Confused with isothermal and adiabatic processes • Students' tendency to confuse adiabatic and isothermal processes • Students considered temperature change equal to zero in an adiabatic process	• (Kautz, Heron, Loverude, & McDermott, 2005a) • (Leinonen et al. 2009) • (Loverude, Kautz, & Heron, 2002)

Learning on reasoned basis without any inconsistencies is one of the most important issues that physics education focuses on. If students fail to see the harmonious structure in physics, they will also fail to determine the inconsistency in their own judgments (Redish et al., 1998).

The present study tried to present teacher candidates' responses to a pen-and-paper test and to present their ways of reasoning in an interview process. As the number of studies examining teacher candidates' levels of understanding the concepts in thermal physics (especially the first law of thermodynamics) is limited in number, the present study is thought to contribute to the related literature.

RESEARCH DESIGN

In the present study, the case study method was used. McMillan (2000) defines a case study as a method that allows thoroughly examining of one or more incidents, environments or social groups. In order to increase the reliability of a case study, Yin (1993) points out that data could be gathered from six different sources. These sources are documents, archive records, interviews, direct observation, participatory observation and physical effects (artistic works and other physical findings). The purpose here was to describe and evaluate students' skills in problem solving and reasoning in the present conditions. Such a case study was considered as the natural choice for research strategy (de Vaus, 2001; Yin, 2003).

Participants

This study was carried out at Dicle University, which is located in the Southeast of Turkey. The research sample was made up of 46 physics teacher candidates who took the 3rd-grade course of thermodynamics. All the teacher candidates also took such courses as mechanics, electric and magnetism during their university education. In addition, they also took the courses of Basic Chemistry and General Mathematics in their first two academic terms at university. The research sample included the teacher candidates who took the 4-credit course of Thermodynamics in the academic years of 2009-2010 and 2010-2011.

In the Turkish university system, most students attending the departments of physics teaching take courses related to science and mathematics in their secondary school education.

In order to support the research data on the basis of the students' responses to the pen-and-paper test, interviews were held with 4 students selected (Gilham, 2005). All the participants reported that they were taught the thermal physics subjects during their high school education.

Data Collection Tools

In this study, a pen-and-paper test and a semi-structured interview form were used as data collection tools. While preparing the questions found in the interview and in the pen-and-paper test, course books and scientific articles related to the subject were used (Young et al., 2008; Loverude et al., 2002; Leinonen et al., 2011).

Pen-and-Paper Test

In the pen-and-paper test, one question addressed adiabatic processes of an ideal gas. The teacher candidates were asked to solve this problem and to discuss the results they obtained (Appendix A). The purpose of this question was to allow teacher candidates to put forward both the results they obtained and their justifications. Use of open-ended questions in data collection is an effective way of collecting a sufficient amount of descriptive data from very small samples (Munn & Drever, 2004).

The arrangement of the data and the fulfilment of several reading cycles were all carried out by the researcher (Huberman & Miles, 1994). Categories were obtained from the data (Munn & Drever, 2004; Strauss & Corbin, 1990). These categories and their appropriateness to the data decoded were checked by field experts to increase the value of the data (Munn & Drever, 2004). In line with the suggestions of the field experts, the categories were clarified and simplified.

Interviews

The second part of the data included the semi-structured interviews held with the selected participants (teacher candidates) (Gilham, 2005). In order to collect multifaceted and detailed data, participants who gave good, moderate and weak responses to the pen-and-paper test were selected (Stake, 1995; Weiss, 1994). The length of the responses given to the test was taken as a criterion in selecting the participants who would be interviewed. The reason for this criterion was that students who write little are thought to be reserved. Considering the possibility that some of the participants selected might give up in the interview, at least three representative students who were good, moderate and weak were required. Therefore, 4 teacher candidates who volunteered to participate in the interview were selected. The responses of all the teacher candidates who gave responses appropriate to the purpose of the study were examined.

The purpose of the interview questions was to determine not only the teacher candidates' understanding and views but also their self-confidence. The participants were shown their test papers to allow them to check their responses to the pen-and-paper test. Following this, they were asked to explain their thoughts supporting their responses. In addition, in order to obtain detailed information about their conceptual understanding and about their explanations, a series of questions were asked to the participants. Sample interview questions are given in Appendix B. During the interviews, an audio-recorder was used to record the explanations made.

FINDINGS

In this part, first, the participants' solutions to and explanations about the problem asked were examined. Following this, the focus was on the results obtained from the participants interviewed.

Pen-and-Paper Test Results

The participants' responses were grouped based on the results they obtained and on the explanations they made. According to the explanations made by the participants, the distribution with respect to the groups is presented in Table 2. The participants' explanations regarding the adiabatic processes were divided into four groups. The grouping was made depending on various explanations the students made in their judgments. The analysis conducted did not focus on the correctness of the results. The primary purpose of the present study was not to see the results obtained by the participants but to reveal how they explained their responses. As the grouping was made according the participants' responses to the question, it was possible that one person could belong to two or even three groups. The distribution of the participants according to the groups is presented in Table 2 and Table 3. Those who made explanations on the basis of the first law of thermodynamics were placed in Group A.

Table 2. Grouping of the participants' explanations regarding the adiabatic processes of an ideal gas

Groups based on the explanations made	Number of participants in each group
A: Students Applying the 1st Law of Thermodynamics	4
B: Students Applying the Microscopic Model	17
C: Students Applying the Ideal Gas Law	22
D: Students Establishing Wrong Relationship between Thermodynamic Quantities	24

Table 2 was prepared considering the groups the participants' explanations belonged to. In addition, Table 3 demonstrates that the participants who were found in a main group could also be placed in other groups depending on their explanations. Therefore, all the groups had intersections among them.

Only one of the students in Group A solved the problem taking the first law of thermodynamics as a basis, while another student tried to solve the problem by using the ideal gas law besides the first law of thermodynamics. One of the participants started solving the problem with the first law of thermodynamics, yet failed to find the correct answer as the student established wrong relationships between the quantities of thermodynamics.

Table 3. Distribution of the participants to the groups according to the explanations made

Explanations	Participants found in the groups
A:Students Applying the 1st Law of Thermodynamics	P_1, P_5, P_6, P_{13}
B:Students Applying the Microscopic Model	P_3, P_8, P_9, P_{10}, P_{13}, P_{19}, P_{22}, P_{24}, P_{29}, P_{31}, P_{34}, P_{35}, P_{37}, P_{38},P_{43}, P_{45}, P_{46}
C:Students Applying the Ideal Gas Law	P_4, P_5, P_{11}, P_{12}, P_{14}, P_{16}, P_{19}, P_{20}, P_{21}, P_{24}, P_{26}, P_{29}, P_{30}, P_{32}, P_{33}, P_{36}, P_{37}, P_{39}, P_{41}, P_{42}, P_{44}, P_{45}
D:Students Establishing Wrong Relationship between Thermodynamic Quantities	P_2, P_3, P_6, P_7, P_{10}, P_{15}, P_{17},P_{18}, P_{20}, P_{21},P_{22}, P_{23}, P_{25}, P_{26}, P_{27}, P_{28}, P_{33},P_{36}, P_{39}, P_{40}, P_{41}, P_{42}, P_{43}, P_{46}

* *The codes of P_1, P_2, P_3,……,P_{46} represent 46 participants in the study, respectively.*

According to the participant who tried to find the solution by using the ideal gas law, the temperature of the gas increases; the work is done by the piston; and this causes an increase in the energy of the isolated system. This process increases the temperature. The work done on the isolated system increases the temperature of the ideal gas [Participant P11]. As can be seen, this student did not mention the concept of internal energy in his or her explanations.

Microscopic Model:

The participants in Group B used the microscopic model while making their judgments. Naturally, microscopic models can be used in explaining the phenomenon. However, in this context, according to researchers, it is quite difficult for participants to use the microscopic model in a scientific case (Loverude et al., 2002; Meltzer, 2004). Six participants made correct statements regarding the kinetic energy of the particles and thus regarding their speed, while two of them used incorrect statements in explaining the reason for the change in the kinetic energies of the particles. One of the participants interviewed (P34) mentioned the momentum of the particles with an acceptable approach. All the other students mentioned collision or interactions between the particles while responding to the question. A sample response of a participant was as follows:

> *The temperature of the gas increases. The atoms of the gas collide with each other. When the piston is pressed, the atoms collide with each other as fast as possible. This also leads to the heat [Participant P34].*

This response demonstrates that the participant believed that the increase in temperature resulted from the heat.

The Ideal Gas Law:

The participants in Group C used the ideal gas law in their answers. Although this law is not efficient in explaining the phenomenon, it produces a reasonable solution. It was seen that most of the participants applied the ideal gas law without understanding the limitations regarding the situation. Three participants stated in the discussion that the temperature would remain stable. Only one of these participants had any hesitation in his or her answer when he or she recognized that the volume was not stable. The explanation below demonstrates the answer given by a participant found in this class.

> *For an ideal gas, the equation of state is* $P_1V_1 / m_1T_1 = P_2V_2 / m_2T_2$*. If the amount of the gas and the temperature are constant and the volume decreases, then the pressure increases [Participant P20].*

Establishing wrong relationships between thermodynamic quantities or ignoring certain quantities:

The participants in Group D put forward wrong claims while establishing relationships between the thermodynamic quantities. The students in this group completely ignored certain quantities and tried to establish relationships between unrelated quantities (for example, a higher level of density increases the temperature). One participant claimed that the temperature would decrease when the pressure decreased [Participant P36]. As mentioned before, the groups did not differ completely from one another. Thus, all the groups had intersections with each other (Table 3).

Here, the attention was drawn onto the overlaps that provided information.

The ideal gas law and some of the related explanations were used incorrectly by the students. The biggest overlap was seen in the intersections of (6 participants) Group C (ideal gas law) and Group D (wrong relationships between thermodynamic quantities). These participants used the ideal gas law and incorrectly acknowledged that one of the quantities remained constant. In their explanations, the participants completely ignored the volume and claimed that the increase in the pressure was the cause of the increase in the temperature. An example for this situation is as follows:

> *The temperature of the gas increases because the increasing pressure in the system leads to an increase in the temperature. PV/T=constant (Participant P16).*

All the participants in this group stated that an ideal gas did its work during the adiabatic free expansion. The participants' claim that the work was done in the adiabatic free expansion demonstrated that they were not knowledgeable about free expansion. It was seen that the participants in this group claimed the work was done and that most of them did not mention the relationship between the work done and the internal energy.

Ideal gas law and microscopic model:

Another important overlap was found in the intersections of groups B and C. Four participants here used the ideal gas law in explaining the phenomenon and tried to make clearer explanations appropriate to the microscopic model. However, these participants wrongly pointed out that the increase in the temperature resulted from the collisions between the particles. One of the participants in this group emphasized the kinetic energy of the particles, yet the reason the participant put forward for the increase in the kinetic energy was wrong. The explanation below is an example for this group.

> *The reason was that the amount of the gas sample and the gas constant do not change. The temperature increases, and the kinetic energy of the particles increases because the particles quite frequently collide with each other. The collisions between the particles cause the pressure to increase [Participant P37].*

The approach expected and inappropriate explanations:

One of the four participants used the first law of thermodynamics while explaining the phenomenon. One participant (P13) who was interviewed and had an answer in the intersections of the groups mentioned the average kinetic energy of the particles during the discussion related to the temperature. Another participant who was in the intersection of the groups A and C tried to explain the ideal gas law verbally as a support to his or her own answer. Another participant (P6) found in the intersection of the groups A and D stated that an increase in the pressure causes the temperature to increase. However, the participant did not establish a relationship between the kinetic energy of the piston and the increase in the temperature of the gas. It was seen that four participants used the first law of thermodynamics in explaining the phenomenon. In fact, it is important to use the first law of thermodynamics in explaining the phenomenon. However, it was also seen that there were students who made inappropriate explanations although they mentioned this law. One of the important findings in the study was that the teacher candidates commonly made incorrect connections between the quantities and that they tried to solve each phenomenon based on the ideal gas law.

Interviews:

The interviews held with the participants were examined in two phases. The first phase presents the inappropriate words used by the participants in their statements, and the second phase presents sample judgments they made.

Participant: P13

The explanation made by P13 in the pen-and-paper test was one which belonged to the expected approach group and which included statements appropriate to the microscopic model. Consequently, the teacher candidate's answer was in the intersection of the groups A and B.

According to P13, the temperature of the gas increases. When the gas is compressed, the work is done on the gas. This increases the pressure of the gas, and the increasing pressure increases the speed of the particles. As a result, the temperature of the gas increases.

P13 used the first law scientifically while mentioning the concept of job yet emphasized the average kinetic energy of the particles while mentioning the temperature. During the interview, P13 made detailed explanations for his answer in the test. According to P13, when the gas was compressed, the speed of the particles increased in proportion to the distance covered by the piston.

This participant believed that the speed of the particles would inevitably increase as the cylinder containing the gas was isolated and that this situation would cause the temperature to increase. Depending on the examples above, it could be stated that P13 understood the content of the first law even though he/she used the concepts relatively wrongly while making his/her judgment. In addition, it was seen that at the end of the interview, P13 had some inconsistencies in his/her explanations which were based on the microscopic model (for example, the average kinetic energy of all the molecules are the same even while the piston moves).

> *Interviewer: What do you want to say about the temperature?*
>
> *P13: Yes, it is the movement of the particles; well, I think so. I thought about "what would happen when the piston was pushed inwards?" Accordingly, when the piston is pushed inwards, the number of the collisions will increase.*

It was seen that P13, who tried to relate the temperature with the speed of the particles, made explanations which included statements inconsistent with the mental model. Despite the low number of mistakes P13 made while using the concepts, he/she made acceptable explanations related to the adiabatic processes of an ideal gas depending on his/her knowledge of thermal physics.

Participant: P34

The answer given by P34 was found in the category of the microscopic model (Group B). According to P34, the temperature remains stable as the net momentum of the atoms found in the environment does not change. The fact that P34 pointed out the net momentum of atoms and that he/she established a relationship between the kinetic energy and momentum could be considered to be a correct explanation. The reason is that like the kinetic energy, momentum is a function of the mass and the speed and that it is a qualitatively acceptable explanation. However, in his/her explanations, P34 used incorrect statements regarding the temperature. To state it more clearly, he/she did not establish a correct connection between the temperature and the changes in the speeds of the particles and thus in their kinetic energy.

> *P34: I always made equal the motion and the temperature or the momentum of all the particles or something like that. Therefore, the pressure of the gas possibly increases, and the temperature does not probably change.*
>
> *Interviewer: What is your support in saying that the temperature does not change? Do you have any evidence?*
>
> *P34: Yes.*
>
> *Interviewer: While reaching this solution, which quantities and concepts did you need?*
>
> *P34: Let me explain: I thought it was necessary to use the pressure, and I thought about how the particles would move there. Depending on these thoughts, like the speeds of the particles, their average kinetic energy changes as well.*

First, P34 simply approved his/her own answer, yet the expression of "or something like that" demonstrates that he/she was not certainly sure about his/her answer. His/her explanation was not efficient as he/she did not take the energy transfer into account. In addition, this answer was worth considering. To sum up, the model used by P34, who emphasized the movement of the particles, was reasonable although it did not lead to the correct result.

Participant: P6

As the answer given by P6 included statements from the groups D (establishing wrong relationships between thermodynamic variables) and A (expected approach), it was an answer found in the intersection of these two groups. According to P6, the gas pressure increases. When the pressure increases, the temperature of the system increases, too. In this case, the kinetic energy of the piston is somehow transferred into the thermal energy of the gas. The first part of the answer given to the question demonstrates that P6 considered the pressure and the temperature to be in direct proportion to each other. This answer given by P6 was not correct. On the other hand, P6 used the concept of work in the second part of his/her answer. This situation shows that in a sense, she/he managed to apply the first law of thermodynamics. When compared to her/his written answer, it could be stated that P6 explained the phenomenon better during the interview. One of the important findings obtained in the present study was that interviews could help reveal teacher candidates' thoughts about a phenomenon better.

> *Interviewer: As for the second part, what did you mean when you said "the kinetic energy is transferred"? Could you please clarify this statement?*
>
> *P6: Okay, the work was done by the piston. As a result, force appears. When the piston is pushed forward, I thought the kinetic energy is transferred to the gas. Accordingly, this energy is stored in one place because the system is isolated. This is an ideal situation. As the energy cannot pass there, it is transferred into the gas as thermal energy. At least, I think the energy cannot go somewhere else.*

Although she/he was not asked, P6 used the concept of work to confirm her/his answer scientifically. During the interview, she/he made other explanations regarding the phenomenon.

> *Interviewer: While solving the problem, what quantities and concepts did you need?*
>
> *P6: First of all, the ideal gas equation came into my mind. The volume, pressure and temperature of a gas are interrelated. Based on this fact, I think the pressure will increase when the volume decreases.*

When asked about the use of the concepts, the interesting answer given by P6 demonstrated that she/he first thought about the ideal gas law and later sought for alternative ways.

The interviewer reported that P6 was able to explain the process taking the movements of the particles into consideration. Thus, P6 made quite an interesting judgment.

> *P6: I thought the gas was not dense, and there was little interaction between the gas molecules. When the volume is decreased, the distance between the molecules decreases as well. Therefore, the molecules come closer to each other, and more collisions occur. Therefore, I thought the heat is partly produced and the collisions occur when the particles come close to each other. Okay, when the piston is pushed and the particles are moved, does the piston produce kinetic energy?*

P6's thought that the distance between the molecules would decrease via compression is reasonable. However, the number of collisions and the increasing interactions do not always explain the increase in the temperature. P6 first stated that these changes were due to the collision between the particles, yet later, she/he tried to explain this phenomenon with the concept of heat.

To sum up our findings, P6 made both correct and incorrect explanations while explaining the phenomenon. The explanations obtained during the interview provided better data than the pen-and-paper test did.

Participant: P38

P38 gave an answer that could be placed in Group B. According to P38, since the gas molecules start to collide more with each other, the heat increases. The reason is that as the volume which contains the gas becomes smaller, the collisions increase. Energy occurs as a result of the collisions in this process.

> *P38: When one mole of gas is compressed in a volume, the particles collide. When they collide, they produce energy. When they collide with an increasing frequency, more energy occurs or spreads as heat.*

The fact that P38 mentioned collisions rather than the kinetic energy and speed of particles clearly indicates that his microscopic model was wrong. In addition, it was not scientifically true that P38 considered heat and kinetic energy to be equal.

> *P38: If I had remembered it correctly, I would have thought that the temperature would be stable.*
>
> *Interviewer: For what reasons do you think so?*

P38: I do not remember it precisely, but in any case, I think the temperature does not change if there is no energy occurring. As the energy mostly increases, the particles simply move and collide, but now I really cannot remember, but is there anything else that I thought about?

When asked if there are other possible solutions, P38 started to talk about a piston which goes in a cylinder. She/he seemed to think about the energy to make judgment regarding the context. In addition, it was apparent that as he thought that the temperature was stable, he/she did not understand that the work was a method of transferring the energy. Later, when asked about heat isolation, he/she made an explanation about energy and heat. As a result, it was seen that P38 had a vague and weak idea about the first law and that he failed to apply it to the special situation desired.

Interviewer: What does the thermal isolation mentioned above mean?

P38: Isolation does not abandon the cylinder as everything remains in the cylinder like the energy and heat. This refers to isolation.

Although his microscopic model was wrong, P38 was able to explain thermal isolation correctly. In addition, as there was no transfer of heat, it was quite surprising that he/she stated the temperature could remain stable.

The interviews held with the teacher candidates revealed new data regarding their reasoning and problem solving skills. Generally, the participants seemed to have various ideas for explaining the work concept. However, they did not make efficient judgments about their ideas. The fact that the students did not make any self-evaluation during the application process could be a result of their unawareness of the contradictions and inconsistencies in their answers.

DISCUSSION AND CONCLUSION

In this study, physics teacher candidates' explanations and their conceptual reasoning regarding the adiabatic compression and expansion processes of an ideal gas were evaluated. The teacher candidates were asked to apply their physics knowledge in a new context. As a result of these applications, it was seen that the teacher candidates had difficulties applying their knowledge they gained in their previous education and that they thus made non-functional explanations. The teacher candidates aimed at giving detailed answers to the questions directed, yet they made inefficient evaluations regarding the correctness of their explanations. In addition, it is reported by Tatar and Oktay (2011) that students experience difficulty understanding the first law of thermodynamics or have misconceptions regarding this law. Only a few students used the expected approach (first law of thermodynamics) in explaining the phenomena that occurred in the adiabatic processes (Leionen et al., 2009; Loverude et al., 2002). For the teacher candidates who benefitted from the first law of thermodynamics, one of the possible reasons could be the presentation of these laws in books as a mathematical formula. A similar situation is also true in course books used in Turkey. In course books, there is no efficient explanation for the laws related to the relationships between physical quantities. For this reason, it takes quite a long time for students to learn a special part of the content.

A comprehensive study on the questions found in the (secondary school) chemistry books covering the ideal gas laws was carried out in Turkey by Nakiboğlu and Yıldırır (2011). The researchers reported that the questions related to the behavior and characteristics of ideal gases were mostly in algorithmic style and did not encourage students to understand. It could also be stated that similar deficiencies exist in university-level books. As there is no part for discussion in books, students generally tend to prefer formula that they can more easily recall and thus use these formulas to solve the problems. This claim is also supported by the teacher candidates' statements they made while answering the questions and interpreting the results. It is also reported by a number of researchers that students frequently use the microscopic model and the ideal gas laws instead of the first law of thermodynamics while explaining the behavior of ideal gases (Kautz et al., 2005; Loverude et al., 2002; Leinonen et al., 2009; Meltzer, 2004). Our observations and experiences in teaching demonstrate that students generally tend to use the ideal gas law to solve the problems related to gases. One important reason for this tendency of students is that almost all students taking education in science-related fields learn these laws during their previous education. Secondary school students choosing science in Turkey frequently use the ideal gas laws in solving the problems in both physics and chemistry courses.

It is a common situation for students that they establish incorrect connections between concepts in their explanations or ignore certain important elements (Kautz et al., 2005; Loverude et al., 2002). It could be stated that the tendency in such a context is related to the ideal gas model. The most important phase in solving a given problem is to discover the phenomenon and the most important related factors. To observe this, a cylinder containing gas is isolated, and the work is done on the gas. Such activities could help problem solvers reach the correct solution and establish the appropriate principle needed. Certainly, students prefer familiar principles and laws related to the variables in order to find a solution to the problem. However, if the principles and laws considered by the students are wrong, they may fail to solve the problem even though they are willing to change the approach (Loverude et al., 2002). They are supposed to know and define the problem in all aspects to solve the problem.

It is seen that the explanations made by the students regarding the work done on the gas considering the characteristics of the phenomenon contradict with the basic principles of physics. This situation also demonstrates how novice teachers focus on the solution in problem solving (Chi et al., 1982; Hardiman et al., 1989; Leonard et al., 1996). Their explanations mostly depend on handling an equation (like the ideal gas law). Regarding this situation, if students' tendency is ignored or not applied, there occurs an important limitation.

The interrogations during interviews made clearer the inconsistencies in students' knowledge structures. In this process, students make various explanations without considering that they have made a mistake (Chi et al., 1982). P13, a successful teacher candidate interviewed, used contradictory statements in his explanations without being aware of his mistakes. Another sample inconsistency which was not recognized can be seen in P6's answer in her microscopic-level explanation: P6 stated that the particles gained kinetic energy via the piston and that the interactions between the particles produced heat. These statements make it evident that there were contradictions in P6's explanations. The interviews revealed that it is an important problem that students do not correct their non-scientific explanations. This situation has been mentioned by other researchers as well (Johnson-Laird et al., 2004). In order to encourage students to revise their thoughts, the question of "Is there anything you want to change in your answer?" was directed to the students. Despite this question, the students did not make any effort to overcome their inconsistencies.

The results obtained in the present study demonstrated that in general, physics teacher candidates do not completely comprehend the basis of the laws of thermodynamics. Learning the principles that constitute the basis of the models used in explaining physical phenomena helps students understand the hierarchical structure of physics (Halloun, 2004). Students should be encouraged to learn the basic principles of physics as they base their answers on principles and laws, whether useful or not, while solving problems (Leonard et al., 1996). In addition, teachers should not only be encouraged to use clear examples of the situations in which the models do not work and but also be invited to indicate the limitations of these models clearly. The findings of this study also demonstrated that the physics teacher candidates did not have the necessary meta-conceptual reasoning skills at a sufficient level. In order to facilitate metacognitive awareness, students are supposed to interrogate their own thoughts and to suspect their mental structures (Asikainen and Hirvonen, 2009).

With applications carried out during lessons, students' inconsistencies should be investigated; these inconsistencies should be overcome to reach their hierarchical knowledge structure; and in this way, they could gain more consistent reasoning skills (Johnson-Laird et al., 2004). In order to achieve this, open interviews should be held with couples of teachers and students (Vosniadou and loannides, 1998). It is thought that interviews held with teachers and students could be beneficial in revealing these skills. In this way, students could evaluate both their own and their friends' skills. Teachers have important duties in helping students become good problem solvers. For this, teachers should be trained as good problem solvers during their pre-service education. In this respect, teacher training institutions and teacher trainers have important responsibilities.

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APPENDICES

Appendix A.

Of an ideal gas put in an isolated cylinder, the initial volume is 4 liters; the pressure is 3 atmospheres; and the temperature is 20 0C. This gas has been exposed to adiabatic transformations until:

1. The volume decreases to 2 liters,
2. The volume increases to 8 liters,
3. The pressure decreases to 1 atmosphere,
4. The pressure increases to 6 atmospheres. For each of these transformations, find the final pressure, the final temperature, the work done and the internal energy change? Interpret the results you have obtained.

Appendix B.

A few sample interview questions:

1. Explain what “Adiabatic heating” and “adiabatic cooling” mean.

2. Does an ideal gas expand without doing work in the adiabatic process? Explain your thoughts.
3. The pressure has been observed to decrease in the adiabatic process of an ideal gas. Explain how the internal energy of the gas changes in this process?
4. Using the first law of thermodynamics, explain that the energy of an isolated system will always be preserved.