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PAPER

Pre-service primary science teachers' understandings of the effect of temperature and pressure on solid–liquid phase transition of water

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The aim of this study was to explore pre-service primary teachers' understandings of the effect of temperature and pressure on the solid–liquid phase transition of water. In the study a survey approach was used, and the sample consisted of one-hundred and three, third year pre-service primary science teachers. As a tool for data collection, a test composed of five open-ended questions was used. In addition, semi-structured interviews were conducted with four purposefully selected students. All interview records were transcribed and analyzed with respect to the students' misunderstandings. The results show that there were common misunderstandings in the students' written responses. The statistical analysis indicated that the chi square statistic calculated is significant at a level of 0.05, suggesting that the observed frequency differences among categories are not due to chance. It is believed that the results of the study carry valuable knowledge for researchers and teacher educators.

In the last three decades, science education research has made great progress. This research has shown that students consistently achieve algorithmic understanding of science concepts, especially chemistry concepts, more readily than the conceptual understanding we wish that they would also acquire (Nurrenbern and Pickering, 1987; Nakhleh and Mitchell, 1993; Gabel, 1999). Research on student understanding of scientific phenomena indicates that student explanations, also called *misconceptions*, are often inconsistent with, inferior to, and incapable of explaining observable phenomena compared to the scientifically accepted descriptions (Osborne and Cosgrove, 1983; Andersson, 1986). It is known that students of all ages widely misunderstand natural phenomena. Accordingly, students in introductory chemistry courses exhibit an extensive array of misunderstandings of chemical behavior (Mulford and Robinson, 2002). Reviews of common misunderstandings of chemistry concepts and chemical behaviour are available (Gabel and Bunce, 1994; Johnson, 1998a, b; Wandersee *et al*., 1994). Today, many high school and undergraduates have difficulties in understanding fundamental concepts and phenomena in chemistry. Among these phases, one of the central topics of chemistry curriculum, which includes concepts such as melting, freezing, evaporation, vapour pressure, state changes and phase diagrams, constitutes a fundamental part of high school and university courses. The literature review conducted on this topic showed that there were some studies probing students' understandings of phases and phase transitions (Osborne and Cosgrove, 1983; Azizoğlu *et al*., 2006; Canpolat, 2006; Bar and Travis 1991; Johnson, 1998a, b; Pinarbasi *et al*., 2006; Coştu *et al*., 2010; Chang, 1997; Paik *et al*., 2004; Stavy, 1990; Schmidt *et al*., 2009). Some studies investigating the subject are discussed below.

Bar and Travis (1991) investigated Children's (grades 1–9) views concerning phase changes. Oral and written questions concerning the phase change from liquid to gas was used as a data collection tool. Researchers investigated the development of student concepts from concrete to abstract ideas and found that children had difficulty with the application of abstractions and problem solving, even though they may have had the necessary level of knowledge. In this study the author argues that it is important to emphasize the importance of explaining specific situations and experiences using clear and relevant models suited to the discussion, and they made a great number of suggestions to minimize misunderstandings and enhance understanding.

In a study conducted by Osborne and Cosgrove (1983), clinical interviews and a written test were conducted in order to study the conceptual development of students between the ages of 8 and 17 years, concerning the changes of ice, water, and vapour. The findings show that students only have superficial understandings of terms like condensation, evaporation, melting, *etc*. The distribution of students' conceptions changes along with the age of students, but some non-scientific ideas are even more common among older students. Four commonly held views on the bubbles in boiling water are: the bubbles are made of heat; the bubbles are made of air; the bubbles are oxygen or hydrogen; and the bubbles consist of steam. In addition the research revealed that most of the students identified the visible mist coming away as 'steam', and, when steam was no longer visible, it changed into air; *i.e*., it had become air.

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Johnson (1998b) carried out a 3-year longitudinal study that explored secondary school students' ideas regarding evaporation at room temperature and condensation of atmospheric water vapour. The results reported in this investigation represent a substantial exploration of children's understanding of changes of state involving gasses across a number of related phenomena, on a number of occasions, and over an extended period of time. The author stated that, for most of the pupils, particle ideas provided the means for them to begin to accept that the bubbles in boiling water were when the water changed into the gas state. In the article, the importance of this, in terms of children's understanding of a sample of gas as a sample of a substance, was discussed. It was argued that boiling water must be seen to have a curriculum significance which goes far beyond its association with a defined temperature.

Gopal *et al.* (2004), investigated tertiary students' understanding of evaporation, condensation, and vapour pressure. During individual interviews, they were questioned on three tasks related to these topics. The findings of the investigation indicated a range of conceptions in each area, including some misconceptions. A key underlying misconception was the belief that evaporation and condensation require a temperature gradient in order to take place.

Azizoğlu *et al.* (2006) used an eight-question concept test to determine fifty-nine pre-service teachers' understandings of concepts like equilibrium vapour pressure, phase diagrams, state changes, colligative properties and Rault's law. Their findings show that the undergraduates' understandings of the related concepts were quite weak and also they had some significant misunderstandings concerning the phase equilibrium.

Canpolat *et al.* (2006), revealed undergraduate students' misconceptions relating to evaporation and vapour pressure. Open-ended diagnostic questions and semi-structured interviews were conducted to determine students' understanding. The results of the study show that there were some significant misunderstandings. Several of the misunderstandings revealed in the study are below.

Vapour pressure is pressure exerted onto the surface of a liquid by the particles at vapour phase in a closed container.

Vapour pressure is pressure caused by particles at the vapour phase during boiling.

Vaporization starts with boiling (*a liquid has to be heated up to boiling point in order to vaporize*).

Pinarbasi *et al.* (2006) studied prospective chemistry teachers' misconceptions of colligative properties. Data was collected through a diagnostic test composed of four open-ended questions. Data analyzed descriptively indicated that participants hold some common misconceptions. In the research some common misconceptions were identified, such as "*Boiling temperature does not stay constant as density of water increases after boiling starts*", *and* "*Freezing temperature does not stay constant as the density of water increases during freezing*".

In a study conducted by Coştu *et al.* (2010), the effect of the PDEODE (Predict-Discuss-Explain-Observe-Discuss-Explain) teaching strategy on pre-service science teachers' understanding of the evaporation concept was studied. Data was gathered using a test with eight questions. The teaching strategy was designed on the basis of the students' preconceptions. Conceptual change in students' understanding was evaluated by administering the same test as pre-, post and delayed post-test. The test scores were analyzed. The analysis showed that there are statistically significant differences among pre-, post-, delayed post tests and total scores, suggesting that the strategy helped students to achieve a better conceptual understanding. Some of the misconceptions revealed in this study follow:

Heating is necessary for evaporation

Water in a system isolated thermally from its environment does not evaporate

Water evaporates due to the heat of the environment

The temperature does not remain the same during a changing of state

Vaporizing particles give heat to their environment during evaporation

Evaporation does not occur at 0 °C

Vaporization starts with boiling (*or evaporation does not occur unless boiling occurs*)

Chang (1997) investigated intermediate students' conceptions about evaporation, condensation and boiling, and to identity the key points in the students' learning of these concepts. An open-ended written test and multi-choice test containing the same tasks was administered to intermediate students in the Taipei area. The results show that students had better understanding of the evaporation concept than condensation concept. Furthermore, students were not able to differentiate the formation of tiny water drops in an open and closed system. Only 26.6% of the students responded that the matter inside the bubbles formed during boiling is water vapour, while 57.6% of the students completed the multi-choice test picked the correct response. Less than 10% of the students could point out that the white smoke coming out from the kettle were tiny water drops, while 70% of the students thought that it was water vapour.

Paik *et al.* (2004) investigated the various conceptions held by K-8th Korean grade students regarding the 'changes of state' and the 'conditions for changes of state'. The sample consisted of five kindergarteners, five second-grade students, five fourth-grade students, five sixth-grade students, and five eighth-grade students in South Korea. Researchers conducted interviews with the students. They found that while most kindergarteners and second-grade students were able to perceive the phenomena involving changes of state, they were unable to express conceptions related to the changes of state and the conditions under which the state changes. The upper-grade students, on the other hand, had some conception of the invisible gas state. Most of these students had proper understanding of the boiling water's change of state from liquid to gas, but few of them had proper understandings of the changes of state involving condensation. Most students understood heat and temperature as conditions of the changes of state, but only applied the heat concept to situations involving rising temperatures.

Literature reviews outlined above suggest that there are a number of studies about students' understandings of the effect of temperature and pressure on phase transition of pure water and its solutions at various age and levels. The majority of the studies have focused on probing concepts, such as evaporation, condensation, vapour pressure, melting point depression and boiling point elevation by using the same questions, particularly those that use systems with at least two phases in equilibrium with each other, particularly such as the liquid–vapour or liquid–solid equilibrium. But there exist no current studies using the illustrated questions about how temperature and pressure affect phase transitions of only liquid or solid in a container, therefore, the research question in this study was: What are the pre-service primary teachers' understandings of effects of temperature and pressure on solid–liquid phase transition of water?

Method

Research design

In this study, survey method as research approach was used. Surveys are used to learn about people's attitudes, beliefs, values, demographics, behavior, opinions, desires, ideas, and other types of information. This method is very popular in education, primarily for three reasons: versatility, efficiency and generalizability (Mcmillan and Shumacher, 2006, p. 233).

The sample

The sample consisted of one-hundred three third year pre-service primary science teachers (aged 20–22 and 63% male, 37% female with middle socio-economic level) enrolled in the Science Teacher Training Department in Bayburt University, Turkey.

The subject

The students took General Chemistry-I and -II in the first year, General Chemistry-III and -IV in the second year and General Chemistry laboratory—I and II. The related main titles covered in the general chemistry courses -II and -III related to the topic of phases were phase equilibrium (evaporation, condensation and vapour pressure), energetics of phase changes, temperature dependence of vapour pressure, and phase diagrams. In chemistry laboratory courses, in some experiments work with phases was conducted, such as determining melting and boiling points, and determining reaction heat. In all courses, the traditional teacher-centered instruction approach was used.

Data collection tools

In order to reveal student understanding of how temperature and pressure affect the solid–liquid phase transition of water, a test composed of five illustrated questions was developed by the researcher (Appendix A). Using a similar group at the same level, all questions were piloted and required modifications were made prior to the administration of the test. The content validity of the test questions was assessed by the researcher and one other lecturer. During the administration, it was observed that the students took the test seriously. Moreover, the semi-structured interviews of 30–40 min including the same questions in the written test were conducted with the four individuals selected purposefully among students with common misunderstandings considering their responses to the written test. Interviews were planned to explore in depth the student teachers' misunderstandings identified from their responses to the questions. Previously, the interview protocol was prepared. All the interviews were conducted according to the protocol consisting of the three sections such as, introduction, questions and closing. Before the interview, the list of key and possible probing questions and approximate interview duration were predetermined. During the interview, following the thanks for their participation in the interview, they were informed about the aim of the interview. It was guaranteed that their interview records would never be shared with anybody and a relaxed, confidential interview environment was created. All participants were interviewed separately. The predetermined key questions were asked of the participants in the same order as appeared on the Appendix A and are followed with appropriate probing questions, such as, *Why do you think so*?, *How does temperature change in this situation*?

Analysis of data

The students' written responses were read individually by the researcher and two other chemistry lecturers, categorized (see Table 1) according to the scheme developed by Haidar and Abraham (1991). The reading of students' written responses by the three persons aimed to check the reliability of the study beside the interview results. The similarity of the findings from the analyses individually conducted by the author and other two chemistry lecturers suggested the consistence of the analysis process. All interview records were transcribed and individually analyzed. In the analysis of interviews conducted separately by the author and the chemistry lecturer, it was adopted content analysis method. Considering the sentences the analysis unit, transcripts from four students were individually classified according to the misunderstanding they included. The findings, which are originally Turkish, were translated into English. The excerpts supporting the results from the written responses were discussed in detail. Moreover, chi squared analysis was performed on data to determine whether the differences in the number of responses observed for each category result from chance or random effects.

Findings and discussion

In this section, the results from analysis of student written responses and statistical findings are given. Initially, from chi square analysis performed in order to explore whether the observed responses' variable for each category are statistically

Table 1 The scheme developed by Haidar and Abraham (1991) to categorize student responses

Code	The criteria used to classify the responses
R1	No response or no explanation
R2	No understanding: irrelevant explanations or answers such as "I do not know", "I have no idea" or "I do not understand"
R3	Misunderstanding: explanations that attempt to describe the target concept but do not match the scientific conception
R4	Partial understanding: incomplete but correct explanation
R5	Sound understanding: explanation that include all components of the science concept

significant, it was found that minimum expected value is 103.0. There is no cell with an expected frequency less than 5. The same analysis indicated that the chi square statistic calculated is significant at a level of 0.05 ($\chi^2(4) = 265.2$, $p = 0.00$). It suggests that the observed frequencies differences among categories are not due to chance; that is, the high frequency observed in code R3 could not be attributed to various random effects. The results from the analysis of the student interview showed no new or different misunderstandings apart from the written document analysis, thus they were used to support the misunderstanding identified from written documents and increase their validity.

As exhibited in Table 2, the analysis of student responses to the first question showed that pre-service teachers' misunderstandings about the effect of external pressure on phase transition of water are rather pervasive (54 students). It is apparent from the same tables that while in total 20 students are at the "no response" and "no understanding" levels, only 29 students exhibit partial or sound understanding. The expected correct response from students was "no evaporation takes place since the external pressure is much higher than the vapour pressure of water in given conditions, 17.5 mm Hg for 20 °C". From the analysis of student responses, three distinct misunderstandings (in Table 3), which have prevalence of 16.5%, 17.5% and 18.4%, respectively, were identified. Findings of the analysis showed that 17 of the students hold the idea that vaporization is a function of only temperature, independent of external pressure. 18 of them thought that in a closed container only water molecules in vapour phase exert pressure on the inner walls of its container, and that therefore liquid water exerts no pressure on the walls of its container. The remaining 19 students stated that phase transition would be only possible at 100 °C, since liquid water would just vaporize at 100 °C, the normal boiling point.

In question 2, although the expected response was that temperature increase would lead to the evaporation of some amount of liquid water, but not all liquid water due to the rising vapour pressure exerted on the liquid water with the temperature. The amount of the vapour in the container would increase with increasing temperature and the increased pressure on the liquid phase would cause the closed system to reach a new equilibrium state at new temperature. Thus, the system, while moving from 50 °C to 100 °C, would pass through a number of equilibrium states. The results found "no response" and "no understanding levels" among a total of 22 subjects, with only 32 of them demonstrating partial and sound understanding levels. It appears that most students

Table 2 Distribution of student responses ranging from no response to sound understanding ($N = 103$)

	R1[b]	R2	R3	R4	R5
Question 1	11[a]	9	54	21	8
Question 2	14	8	49	26	6
Question 3	13	8	51	24	7
Question 4	12	7	50	25	9
Question 5	16	11	30	38	8
Total	66	43	234	134	38
Mean	13.2	8.6	46.8	26.8	7.6
%	12.8[c]	8.3	45.4	26.0	7.4

[a] The number of students. [b] The codes corresponding to the classification in Table 1. [c] % = mean/the total number of students × 100.

(49 subjects) have two misunderstandings: "*In the system in equilibrium with its vapour in a closed container at a constant volume, temperature increase has no influence on the amount of liquid or vapour*"(*27 students*) and "*If the temperature of liquid water in equilibrium with vapour in a closed container without a movable piston is raised, all liquid water vaporizes*" (22 students).

When the analysis results of question 3 are examined, it seems that the number of students with sound understandings is rather low. However, the responses of 21 pre-service teachers were coded as "no response" and "no understanding", and the majority of them (31) have partial and sound understanding. Actually, a scientifically acceptable answer was that all liquid water would vaporize when external pressure is lowered from 760 mm Hg to zero. It is obvious from the table that the majority of students (49.5%) exhibited a misunderstanding: *State transition of water is only a function of temperature*. The analysis results regarding fourth question, in which an expected answer would approximate "*ice would vaporize when external pressure is lowered from* 760 mm Hg *to zero*" demonstrated that 12 and 7 students were classified as "no response" and "no understanding" levels, respectively, which are the lowest numbers in the table. A considerable number of them (34) have partial and sound understanding. From the table, it appears that almost half of students (48.5%) hold two common misunderstandings: "A change in external pressure has no influence on the phase transition of ice" (24) and "decreasing external pressure will depress the melting point of ice" (27). Finally, in question 5, the number of pre-service teachers categorized as "no response" and "no understanding" is 16 and 11, respectively, but a majority (46) demonstrated partial and sound understanding levels. The analysis of the responses revealed that 30 students had the misunderstanding that decreasing external pressure would cause vapour pressure of water to increase at a given temperature and this would make the liquid water vaporize.

The value calculated by dividing the total number of students with sound understanding by the number questioned, reveals that only an average of 7.6 of pre-service teachers over all questions, a rather low proportion, demonstrated to sound understanding. A mean of 7.6 constitutes only 7.4% of total 103 students and the means per category range from 8.6 (8.3%) to 46.8 (45.4%). It is obvious that about half of pre-service teachers (45.4%) have some misunderstandings of the transition of phase in water. It can be inferred that compared to nearly 45%, the percentage (7.4%) of the students holding an acceptable, sound understanding is considerably low. In the following section, misunderstandings identified were individually discussed using the excerpts taken from written responses and interviews. Misunderstandings M1–M8 and also M3–M6 pairs were discussed together due to their similarities.

Discussion

In this section, the misunderstandings were given and their possible sources discussed.

Phase transition of liquid and solid water in a piston is independent of the external pressure (**M1 and M8**).

Student teachers stated that the liquid water with a specific vapour pressure at a given temperature, whatever the external conditions, particularly such as external pressure, would evaporate. It is clear they ignore the conditions of the system while responding to the question. It seems that they prefer solving the

Table 3 Individual misunderstandings identified from the student responses to all questions

	Misunderstandings identified (R3)	*N*	%
Q1[a]	**M1**-Phase transition of liquid water in a piston is independent of external pressure	17	16.5
	M2-Liquid water in a closed container exert no pressure on the walls of the container	18	17.5
	M3-Water does not vaporise until it reaches the boiling temperature of 100 °C	19	18.4
Total[b]		54	
Q2	**M4**-In the system at equilibrium with its vapour in a closed container at a constant volume, change in temperature has no any influence on the amount of liquid or vapour	27	26.2
	M5-If the temperature of liquid water at equilibrium with vapour in a closed container without a movable piston is raised, all liquid water vaporizes	22	21.3
Total		49	
Q3	**M6**-State transition of water is only a function of temperature	51	49.5
Total		51	
Q4	**M7**-A decrease in external pressure applied to solid water in a closed container will depress its melting point	24	23.3
	M8-The phase transition of the solid water is independent of external pressure	26	25.2
Total		50	
Q5	**M9**-If the external pressure is lowered at a constant temperature, the vapour pressure of water will raise and thus it will vaporize	30	29.1
Total		30	

[a] Q: Question number; *N*: The number of students; M: Misunderstanding; %: The percentage of students in proportion with the entire sample.
[b] Corresponds to the numbers in R3 column in Table 2.

given problem using an algorithmic approach rather than a conceptual approach. It may be related to the tendency to solve the problem by using such an algorithm or rote as "if T increases, then P_{vap} also will increase" and general chemistry textbooks rarely consider using cylinder with piston in explaining the phases subject. It is believed that because the superficial understanding of scientific concepts leads to students to develop non-conceptual one, and this situation triggers their tendency to learn by heart. A possible reason for such a misunderstanding might be the belief that they felt compelled to use all data given in the exam questions they encounter in science courses. The following excerpts taken from written responses supporting this view:

"*The vapour pressure of liquid water at* 20 °C *is* 17.5 mm Hg. *The liquid water in the container at* 20 °C *should be in equilibrium with its vapour regardless of the external pressure, so I think that liquid water will evaporate while raising the temperature to* 20 °C *from* 0 °C "(*written response*)

"*An increase in temperature always results in the vaporization of liquid water in a piston container regardless of external pressure*; *I believe that external pressure is not significant for phase transition*" (*written response*)

Pre-service teachers reasoned that since solids and liquids are never affected by variations of pressure, they exert no pressure on their surroundings. Some quotations from written responses are given below as an example.

"*There is only pure ice in the container. Since no solid and liquid states are influenced from the pressure of a piston, but only gas states are affected from pressure exerted through a piston, therefore, a phase transition will not occur*"

This view may be due to the fact that, in numerous chemistry textbooks, pressure concepts are usually taught and modelled using a gas phase without mentioning pressure in liquids and solids. Liquid pressure concept is mainly introduced as part of the hydrostatic subject in physics textbooks. Thus, it may be thought it has caused scientific knowledge, and its comprehensive contextual structure, to be taught as discrete, isolated bits of knowledge in science classes. Compartmentalization of physical science subjects (*e.g.*, treating chemistry and physics as distinct and independent subjects by using different terminologies to describe the same phenomena) is considered one of the sources of scientific misconceptions. As a result, such a situation might be counted as one of the possible reasons of why students' conceptual understanding of science subjects is low (Sanger and Greenbowe, 1997).

Liquid water in a closed container exert no pressure on the walls of container (**M2**)

As seen clearly from the following excerpt, students thought that liquid water in a piston container exerts no any pressure on the piston.

"*Since liquids do not exert pressure on the walls of the containers in which they are present, thus the liquid water also in this case will exert no pressure on piston. But with the raising temperature, some amount of the liquid will evaporate, and this will enable the piston to move out by exerting the extra pressure on it*."

As mentioned when discussing previous misunderstandings, this misunderstanding may result from separately teaching scientific concepts and phenomena in chemistry and physics courses.

Water only evaporates when it boils at just 100 °C (**M3**) and *State transition of water is only a function of temperature* (**M6**)

The misconception (M3) confirms the results of the study conducted by Canpolat *et al.* (2006) that vaporization starts with boiling (that is, a liquid must be heated up to boiling point in order to vaporize). Students frequently encounter the concept of boiling point, especially the boiling point of water, in science courses. As is known, all chemistry courses involving the boiling point concept almost always introduce the topic with water, with a boiling point of 100 °C as a substance example. The misunderstanding that vaporization of water requires a temperature of 100 °C shows that students confuse boiling and vaporization. Similar to the misconception above, this misunderstanding suggests students' algorithmic problem solving approach in science courses. The written responses given below represent this view.

"*I think that no phase transition will occur. As you know, liquid water boils at* 100 °C, *as the temperature of water under the given conditions is under its boiling point, it will not vaporize at the temperature and therefore the piston will remain constant*"

Similar to those answers obtained from question 1, pre-service teachers hold the misunderstanding that the change in external pressure has no effect on the phase change of liquid water

"*I think that phase transition will not take place, because change in the external pressure has no effect on liquids and solids. Temperature is the only significant variable in determining phase transition*"

It is well known that an important source of science misunderstandings is students' daily life. Because they encounter the terms heat and temperature on a daily basis outside the classroom, it seems that they ignore that a factor like pressure can lead to a change of phase. They usually see and experience evaporation on a temperature gradient, such as boiling water in kettle and evaporating water in soups in their kitchen. This misunderstanding is consistent with those reported by Canpolat *et al*. (2006) and Gopal *et al*. (2004). In their studies, participants stated that evaporation requires a temperature gradient. Gopal *et al*. (2004) also tried to explore the reasons for the temperature-gradient misunderstanding. They reported that students looked for some sort of trigger to cause evaporation to occur, and their initial response was that the temperature gradient triggered the evaporation process.

In the system in equilibrium with its vapour in a closed container at a constant volume, change in temperature has no influence on the amount of liquid or vapour (**M4**)

It appears that students ignored that the physical equilibrium between the two phases shifts in favor of the vapour phase with rising temperature, and instead consider the system to be temperature-independent. Excerpts below from responses represent the idea.

"*As a result of the temperature increase, both evaporation and condensation rates will equally increase, therefore the amount of liquid water also will remain constant with time*"

R: *what do you think temperature change will affect the phases*?

S: *I do not think that the temperature will influence the present phases*. (*interview*)

R: *Please could you explain your response*?

S: *I believe that temperature also will equally influence both phases and these two change will compensate each other* (*interview*)

If the temperature of liquid water in equilibrium with vapour in a closed container without a movable piston is raised, all liquid water vaporizes (**M5**)

Interestingly, none of students used the phase diagram of water to explain their responses. They ignored the notion that the increase in the amount of water vapour would increase the pressure exerted on liquid water by its vapour. The following excerpt from an interview supports this idea.

I think that as long as the temperature is raised, vaporization continues until there is no liquid left in the container.

As seen in the above excerpt, students think that vapour space is large enough to take in all liquid water, although the knowledge of the volume of vapour phase is not given to them in the question. In science courses, students usually study the relation between vaporization and heating in the system with open atmosphere at a constant pressure, with such conditions commonly reproduced on exam and homework questions. This view may again originate from the approach that an increase in temperature always brings about vaporization, whatever the other conditions.

A decrease in external pressure applied to solid water in a closed container will depress its melting point (**M7**).

In fact, in opposition to the understanding given above, the correct scientific response was that a decrease in external pressure exerted on ice would elevate its melting point owing to density difference between ice and liquid water. It is clear that students misunderstand the unique phase properties of water in comparison to other substances with higher solid density than that of liquid states. The following statements from a student's written response and interview reflect this misunderstanding.

R: *Why do you think that all ice is transformed into liquid when the pressure is reduced to zero*?

S: *I think that the pressure exerted on ice is a factor that prevents ice from melting*. *Since compression of liquid water leads to freezing of liquid water*, *the cancellation of pressure on ice will again cause ice to melt*

If the external pressure is lowered at a constant temperature, *the vapour pressure of water will rise and thus it will vaporize* (**M9**)

Following excerpts exemplifies the aforementioned idea.

R: *When the external pressure is lowered from* 2 *bar to* 1 *bar in such a system*, *why do you think some liquid will be converted to vapour*?

S: *I think that since the pressure on the liquid is decreased*, *liquid water will reach the point in which its vapour pressure is higher than its initial value and so it will start to evaporate*

The results are similar to the findings in question 1. Students believe that the liquid water at a given temperature should exhibit a physical property, called vapour pressure, regardless of considering whether the external pressure is higher than the vapour pressure at the temperature. The findings support the claim that they prefer solving problems using an algorithmic approach, that is, a sequence of finite instructions. In the literature, there are various studies that analyzed chemistry students' problem-solving strategies. In the previous studies it was found that students could be characterized as rule learners considering how they looked for the rule to apply and applied it. In addition, they found that most students solved problems successfully using an algorithmic approach (Bunce *et al*., 1991; Gabel *et al*., 1984; Herron and Greenbowe, 1986; Hand *et al*., 2007). Also in this study, it seems that there have been many students who tend to use the algorithmic approach to solve the given problems. Pushkin (1998) identifies some possible reasons for algorithmic approach:

(a) Novice learners tend to be more declarative and procedural, in their knowledge orientation. That is, novice learners tend to be very adept with arbitrary facts and generalized algorithms. Rarely do novices think in terms of integrated or applied knowledge.

(b) They tend to be very dualistic in their thinking regarding their role in the education process. Dualistic learners are very submissive in accepting what they are told by their instructors as unquestioned knowledge.

(c) They are subjected to science curricula and pedagogy that discourage critical and conceptual thinking.

(d) Those who teach introductory chemistry and physics place more value on algorithmic learning than on conceptual learning, giving learners the impression that science is "math in disguise".

Gabel (1993) point out that three levels on which chemistry can be taught: atoms and molecules (microscopic level), sensory (macroscopic level), and the symbolic level. Using an equilateral triangle with a level at each vertex, any point within the triangle can represent the percentage of time allocated to using a given level in the teaching of chemistry. Today, most chemistry courses are taught at the symbolic level with little emphasis on the microscopic and the macroscopic levels (Gabel, 1993). As similar to Pushlkin's fourth item above, the emphasis on symbolic level in chemistry teaching can be counted as one of possible causes of why students tend to use algorithmic approach. The findings of the present study also demonstrated that student teachers used frequently a language at symbolic and macroscopic level. They preferred to use usually symbolic language and sometimes macroscopic in their responses to questions using the variables like temperature, volume and pressure rather than a microscopic language.

Nakhleh and Mitchell (1993) demonstrated that in a study of first-year chemistry students, conceptual problem-solving ability lagged far behind algorithmic problem solving ability. Their findings showed that majority of first year students are low conceptual but high algorithmic students; students adept at solving problems with algebraic equations, but having only limited understanding of the chemistry behind their algorithmic manipulations. By chemical educators have often been assumed that success in solving mathematical problems should indicate mastery of a chemical concept. However, there is little connection between solving an algorithmically-based problem and understanding the chemical concept behind that problem. Many students could not use chemical concepts to solve conceptual problems (Nakhleh and Mitchell, 1993).

The difference between conceptual learners and algorithmic ones is that the former are more advanced and less dualistic in their thinking, more experienced in problem solving, more situational in their knowledge orientation, and more verbal in their reasoning. By no means are these dichotomous modes of thinking; conceptual learners are clearly at the more evolved end of the spectrum of cognitive development. Conceptual learners are rarely unable to be algorithmic (Pushkin, 1998). Algorithmic learners can master assessment items requiring mimicking, regurgitation, and short-term memorization, but cannot master assessment items requiring evaluation, comparison, and attribution skills. Such assessment items would require long-term cognitive development where knowledge is genuinely stored, structured, and networked. Conceptual learners can master these types of items. They are capable of probing information and explaining the underlying reasons for their observations and conclusions regarding scientific phenomena (Pushkin, 1998).

Conclusions and recommendations

The findings of this research revealed that students have inadequate understanding and some common misunderstandings of vaporization, melting, and the effect of temperature and pressure on phase transition in water. Only an average of 7.6 of them, making up 7.4% of total number of pre-service teachers, demonstrated an acceptable, sound understanding of the effect of temperature and pressure on phase transition of water. About half of them (45.4%) have some misunderstandings, and rather significant misunderstandings, suggesting that the undergraduates have significant difficulty understanding the phase transition of water.

The investigation of student teachers' misconceptions and alternative frameworks, is important because of its contributions to the construction of new teaching approaches, which can take into consideration students' difficulties in learning scientific concepts (Azizoğlu, 2006). The results have the great importance of training of the undergraduates who will be teachers in coming years and teach the subject to many primary students, because their understanding will directly affect the primary students' understandings. The results of the study indicate that undergraduates' understanding of the effect of temperature and pressure on solid liquid phase transition of water is quite weak, and they hold some misunderstandings. This study identified nine misunderstandings held by pre-service teachers about the phase behavior of water. It is an interesting result that none of the students used microscopic approach or the phase diagram of pure water to answer the questions or interpret the phase changes. In addition, the findings of the study suggest how effectively the hypothetical questions, such as those in this research, could be used to probe students' understandings. The findings of the present study suggest that a revision of the traditional instruction approach used commonly in chemistry courses and alternative teaching methods should be considered in order to enhance student understanding of phases or other science topics. They should be more effectively introduced to science teacher training programs. There are some studies indicating that students consistently achieve algorithmic understanding of science concepts, especially chemistry concepts, more readily than the conceptual understanding we wish that they would also acquire (Nurrenbern and Pickering, 1987; Nakhleh and Mitchell, 1993; Gabel, 1999). And some science education research shows that many novice learners in science are able to apply algorithms without significant conceptual understanding, a phenomenon independent of major (Pushkin, 1998). It does not seem that presenting an algorithm and demonstrating the myriad of problems that can be solved using that algorithm facilitate understanding of the underlying concept. So, the current teaching must take on a much more concept-based framework. Previous research suggests that the current methods of teaching chemistry are, perhaps, not teaching chemistry, but teaching how to get answers to selected algorithmic problems. The current algorithm-based teaching does not necessarily lead to conceptual learning (Nakhleh and Mitchell, 1993). In other words, success on algorithm does not imply success on conceptual. So, it is crucial to move chemistry instruction from an algorithmic knowledge recall approach to conceptual one (Zoller and Lubezky, 1995).

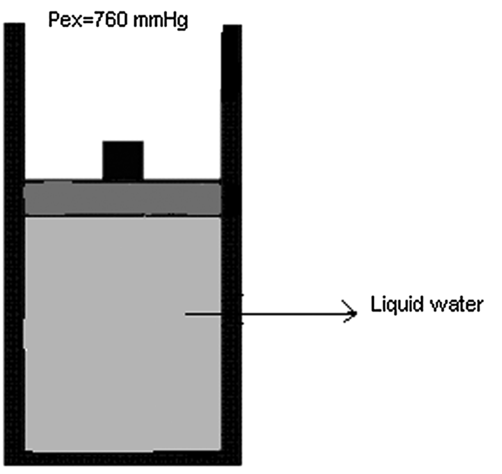
It is clear that the lack of knowledge of fundamental concepts and issues may result in subsequent misunderstandings. Therefore, care has to be taken to establish solid knowledge of fundamental chemical ideas before teaching advanced ideas. It is important that prospective teachers develop conceptual understanding of science concepts, because they will teach those concepts on their own students in the near future. It is believed that the results of the study carry valuable knowledge for the researchers and teacher educators. Although it is not appropriate to generalize the findings from this single, limited study using the illustrated questions, the results suggest that misunderstandings identified in this study can be seen in various levels and grades as well.

Appendix A: the questions translated to English

"Do not regard the thermal expansion of the liquid and solid water with temperature in the following questions."

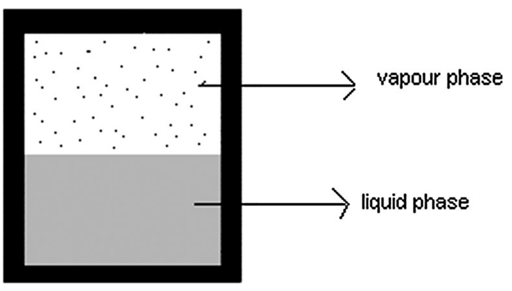
The changes in temperature and external pressure were achieved by immersing the system in a heat reservoir and placing a proper weight on the piston, respectively.

1-



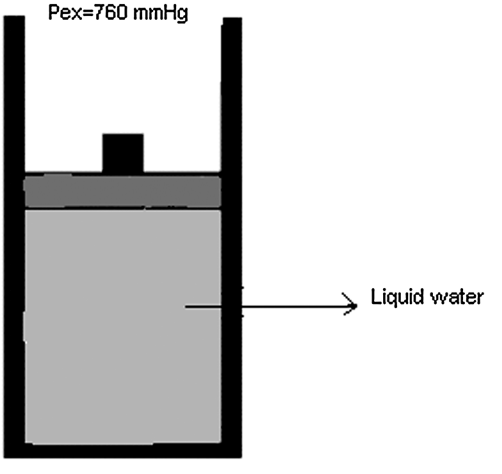
A cylinder with movable piston contains liquid water at 0 °C and the external pressure above the piston is 760 mm Hg. At constant pressure, if the temperature of liquid water was raised from 0 °C to 20 °C, would any change of state take place? (the vapour pressure of water at 20 °C is 17.5 mm Hg).

2-



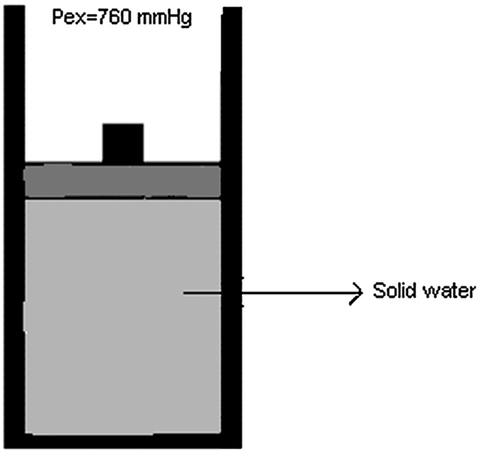
The figure above indicates liquid water in equilibrium with its vapour at 50 °C in a closed container. If the container was heated by a heater from 50 °C to 100 °C, would any change of state take place during heating process?

3-



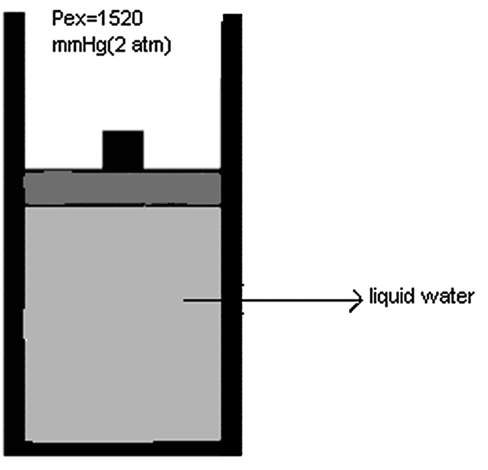
A piston cylinder contains liquid water at 1 °C and an external pressure of 760 mm Hg. Keeping temperature constant at 1 °C, if the external pressure was suddenly varied from 760 mm Hg to zero, would any change of state take place?

4-



A piston cylinder contains some pure solid water at −10 °C and an external pressure of 760 mm Hg. At constant temperature, the pressure was suddenly varied from 760 mm Hg to zero. After this treatment, would any change of state take place?

5-



A piston cylinder contains some pure liquid water at 90 °C and an external pressure of 1520 mm Hg. At constant temperature, the external pressure was suddenly lowered to 760 mm Hg. After this treatment, would any change of state change occur? (Vapour pressure of water at 90 °C is 535.8 mm Hg).

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