Prospective Teachers' Misconceptions of Vaporization and Vapor Pressure

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Over the last three decades a large body of research has described science concepts held by students at different levels of schooling. A considerable amount of research shows that relatively young children develop intuitive ideas and beliefs about natural phenomena. As they learn more about the natural world they develop new and revised concepts based on their interpretation of this new information from the viewpoint of their existing ideas and beliefs. Students' science concepts that are not consistent with the consensus of the scientific community are called misconceptions. Some students' understandings are on the right track but are incomplete; others are simply wrong *(1)*.

Reviews of common alternative conceptions of chemistry concepts and chemical behavior *(2–5)* and an extensive bibliography *(6)* are available. Research in this domain has attempted to answer questions such as these: Which misconceptions occur? What are their origins? How extensive are they? What can be done to address these misconceptions? *(7)*. It is quite understandable why students' ideas concerning chemical phenomena have become a research focus. Many students at the secondary and postsecondary levels struggle to learn chemistry; many do not succeed. Research now shows that a majority of students do not understand fundamental concepts correctly and that many of the scientifically incorrect ideas students hold go unchanged from the early years of schooling to university, even up to adulthood *(8)*. By not fully and appropriately understanding fundamental concepts, many students have trouble understanding the more advanced concepts that build on them *(9)*.

A number of authors have studied the development of students' ideas about evaporation, at a range of age levels. One of the first was Osborne and Cosgrove's study *(10)* in which they examined students' (12–17 years old) views about boiling, evaporation at room temperature, condensation, and melting. The researchers used a multiple-choice survey and also in-depth interviews. They uncovered a number of nonscientific conceptions, finding that, while children could use labels like evaporation and condensation accurately, their understanding of these terms was not underpinned by scientific concepts.

Most of the work in this area has been done with secondary school pupils. A notable exception, Bar and Travis *(11)* studied primary school children's views. Their findings were broadly consistent with those of Osborne and Cosgrove *(10)* for older children, with some significant differences in detail. Bar and Travis *(11)* identified a growing confidence among children 6–13 years old with the relationship between water and vapor, and the existence of vapor in air. They claim that "[C]hildren from a young age have an almost correct view about boiling; they only confuse steam with vapor. Otherwise they understand that during boiling liquid is changed into gas" *(11)*. This claim has been questioned by Johnson *(4)*, who argues that the authors have no information concerning what these children understand by the gas state. Bar and Travis seem to underestimate the subtlety of the ways in which language can be used, accepting statements that water has "disappeared" at face value (whereas in fact children often use the term to mean "can no longer be seen"), or that "air" is meant by children in the same sense adults understand it. As Johnson points out, it is clear from the literature that words like "vapor", "mist", "steam", "gas", and "air" are used loosely by children, even interchangeably *(12)*.

Bar and Galili *(13)* utilized three different methods—clinical interview, open-ended investigation, and multiple-choice written tests—to explore the conceptual development of Israeli students ages 5–14 concerning the concept of evaporation. Research results indicate that students' development related to the concept of evaporation involved the following four interpretations: (i) water disappeared; (ii) water was absorbed by the floor or soil; (iii) water evaporated (meaning water was unseen and being transferred to another location or medium—i.e., in the sky, in the air, in the clouds, etc.); and (iv) water changed to water vapor, and it was spread out into the air as invisible tiny water droplets, or it was transformed to air. At the same time, there was an obvious relation between the students' change in evaporation concept and their cognition development, such as the use of conservation theory and the admissibility of abstract air models.

In one of two recent studies Tytler *(14)* studied first-year and sixth-year students' conceptions of evaporation and condensation through challenging activities based on these concepts. The results suggest that while there was substantial overlap between the conceptions used by the first-year and sixth-year students, there were also substantial differences in the patterns of conceptions, the epistemological sophistication demonstrated, and the structure of their explanations. The older children had much greater access to the phenomenological language commonly used in relation to evaporation and condensation (moisture, vapor, humidity, evaporation). Sixth-year students showed sufficient familiarity with a range of evaporation and condensation phenomena to indicate the prior formulation of questions concerning the nature of the changes to water.

This does not mean that the older children do not have ontological confusions similar to the younger children regarding the distinction between substance and properties and events like temperature and smell, or between dampness, moisture, and water. However, the older children were in a better position to reflect productively on these matters, and in particular could be expected to respond to teaching about evaporation and condensation by accurately incorporating the new knowledge with previous experience and understandings.

They could generate and evaluate similar evidence to compare different explanations; they could pay attention to linguistic subtleties and make richer links with other phenomena.

A study carried out by Chang *(15)* covered 364 prospective teachers from different content areas, including science majors. A test, composed of open-ended questions, was administered to students who were divided into four groups according to their scientific learning background. After evaluation, some representative students were interviewed in a semi-structured manner to ascertain their conceptions. The test results showed that although the science major students performed better than the non-science majors, the science majors' understandings of condensation and boiling concepts still needed to be enhanced. Most of the students did not hold the concept of saturated vapor, even among the science majors; that is, only 28.8% held this idea, and the percentages in the remaining groups were less than 10%.

Many high school and university students experience difficulties with fundamental concepts in chemistry. Despite the importance of basic chemical concepts as the foundations of chemistry learning, most students emerge from introductory courses with only very limited understandings of basic concepts *(16)*. Vaporization and vapor pressure concepts have been regarded as difficult ideas by students in chemistry. However, the studies in this area were focused on students in primary and secondary levels. Our literature review suggests that there is a shortage of research focused on students' conceptions of vapor pressure at the undergraduate level. Therefore, this study aimed to determine misconceptions related to vaporization and vapor pressure.

Research Methods

In order to determine students' misconceptions related to vaporization and vapor pressure we developed a diagnostic test composed of five open-ended questions specifically for this study (see Figure 1). Questions 1 and 2 were intended to test students' understandings and discover misconceptions related to vapor pressure and vaporization concepts, respectively. Question 3 was designed to reveal students' understandings of whether vapor pressure changes in the case of volume change of the vapor in equilibrium with its liquid. Question 4 was meant to reveal students' understandings of whether vapor pressure is affected by the amount and volume of liquid. Finally, question 5 was intended to test students' understandings of the relationship between vapor pressure and boiling point, and required students to make a comparison between solutions and pure solvents in terms of their vapor pressures and temperatures at their boiling points.

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 four chemistry lecturers. These questions were then administered to 70 third-year undergraduates enrolled in the Primary Science Teacher Training Department in Ataturk University in Turkey. The subjects took General Chemistry I and II in the first year, Analytical Chemistry and Organic Chemistry in the second year, and during the third year they were taking the Heat and Matter course as this research was being conducted. A conventional lecture approach was used in the courses. The test was conducted under normal class conditions without

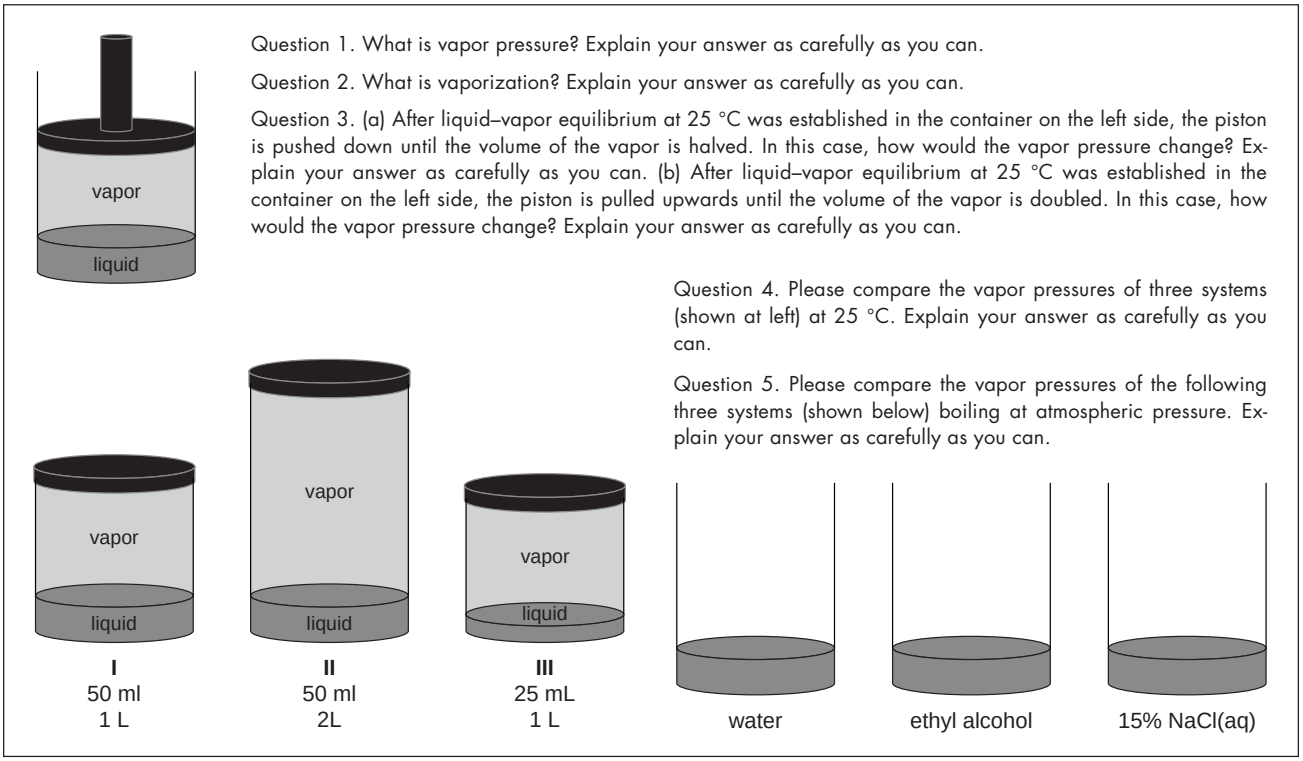

Figure 1. Assessment instrument used in this study.

previous warning. Students were informed that the results of the test would be used for research purposes and would be kept confidential.

Students' responses to the diagnostic questions were analyzed, misconceptions were determined, and percentages were calculated for the responses. Misconceptions held by over 20% of the subjects are reported here. In addition, 12 students were interviewed in order to clarify their written responses and to further probe students' conceptual understandings of the questions asked in the test. Interviewees were selected on the basis of their responses on the written test. If a student's written test response demonstrated a misconception without providing a detailed or clear explanation of his or her response, we requested to interview that student. The interviews lasted approximately 20–30 minutes. All the interviews were audiorecorded (with the interviewees' consent) and then transcribed for analysis. The interviews did not go into great detail; instead they were used to elucidate the students' misconceptions. Example excerpts from the interviews are provided below. Because the interviews were conducted in Turkish, the quotations reported in this paper are translations into English (by the authors) of the researchers' questions and the students' responses.

Results and Discussion

As shown in Table 1, analysis of the written responses revealed that 57% of the students described vapor pressure *as the pressure exerted onto the surface of a liquid by particles at the vapor phase in a closed container.* Although this view could be seen as correct initially, a detailed investigation of the written responses revealed that students did not consider the liquid–vapor equilibrium in their explanations of vapor pressure. Ignoring the liquid–vapor equilibrium suggests a lack of conceptual understanding of vapor pressure. In other words, vapor pressure was considered as the pressure exerted onto the surface of a liquid by the particles at vapor phase at any time, ignoring the liquid–vapor equilibrium.

Findings obtained from the interviews confirm that many students hold this misconception. (In subsequent interview excerpts, R and S stand for researcher and student, respectively.)

R: How does the number of particles in the vapor phase change with time when some water is left to vaporize in a closed container?

S: The number of particles at vapor increases with time.

R: Could you tell me please how the pressure changes with time in this system?

S: Pressure increases depending on the increase in the number of particles.

R: If pressure increases with time, pressure at which time will be accepted as the vapor pressure in this system?

S: Pressure at any time could be vapor pressure.

R: But, there is only one vapor pressure for any system at constant temperature, however according to your response there will be several vapor pressures at constant temperature. How would you explain this case?

S: Hmmm… I don't know.

Table 1. Students' Misconceptions Identified from Assessments of Students' Test Responses

Students' Misconceptions as Identified by the Written Test	Student Adherents, % (*N* = 70)
Vapor pressure is the pressure exerted onto surface of liquid by the particles at vapor phase in a closed container.	57
Vapor pressure is pressure caused by particles at the vapor phase during boiling.	25
Vaporization starts with boiling (a liquid has to be heated up to boiling point in order to vaporize).	27
A liquid has to be heated for a certain time in order to vaporize.	30
At constant temperature, the value of the vapor pressure changes with changes in the volume of the vapor in equilibrium with its liquid.	57
A liquid's vapor pressure changes with changes in the amount of liquid.	53
Boiling liquids at atmospheric pressure have different vapor pressures.	62

One indication of students ignoring equilibrium in defining vapor pressure is the commonly held misconception that vapor pressure could be considered both for open and closed systems. Considering vapor pressure for an open system is a clear indicator of ignoring equilibrium position for vapor pressure. The following excerpts taken from two students' responses best exemplify this thinking:

> Vapor pressure is the pressure that molecules exert on themselves and each others. This could be anywhere. Vapor pressure is high in closed containers. It would be less in open containers, because some of the vapor will be distributed to air.

> Vapor pressure is the pressure caused by molecules in gas phases. It will be exerted on the side walls of open containers. However, in closed containers it will be more because there will be some molecules colliding on the top side of the container.

Another related misconception, identified in one-quarter of the responses, defines vapor pressure as *the pressure caused by the particles at the vapor phase during boiling.* This view suggests that students take the vapor pressure into consideration only after boiling starts, as indicated in the following written response by one of the students:

> [I]t is the pressure that equals the atmospheric pressure at the boiling point.

This misconception could be easily attributable to holding the following misconception—*vaporization starts with boiling*—identified in 27% of the written responses. Students holding this misconception have the view that liquids do not vaporize before boiling occurs, as indicated in the following written response:

> [F]or example, … vaporization starts when the pressure of water in a container equals to atmospheric pressure, because water boils at this point.

Also, this view was also supported by the following excerpt taken from an interview dialogue.

S: [W]hen a liquid takes energy, it boils and then vaporizes. The pressure that is exerted by the vapor formed is the vapor pressure.

R: OK. In this case, you mean we cannot talk about vapor pressure before boiling starts?

S: I think … yes.

R: OK. In this case, you mean we cannot talk about vapor pressure before boiling starts?

S: I think … yes.

R: I am wondering, how would you describe vaporization?

S: Vaporization … is transfer of liquid into gas phase.

R: OK. What is required to transfer a liquid into gas phase?

S: It must boil.

R: Could you tell me whether vaporization occurs without boiling?

S: Matter transfers to the gas phase from the liquid phase by boiling. When it boils vaporization occurs, kinetic energy has to be increased in order to vaporize, and also for this it must be heated.

As seen from the above dialogue, the student believes that in order for vaporization to take place, boiling has to occur. However, in connection with the above misconceptions some of the students (30%) thought that boiling of a liquid is not required in order to vaporize, although the liquid has to be heated for a certain amount of time to achieve vaporization. The following interview excerpt expands on this kind of view:

S: In order to vaporize, a liquid must be heated for a little bit of time. I mean a certain amount of energy is required.

R: What do you mean by a little bit of time? How long it should be? Or how much energy must be given? Could you explain little bit more?

S: Hmmm… I don't know, … enough time.

R: Until the boiling point?

S: I don't think so. I think there is no need to reach the boiling point.

Students having the misconception just characterized consider that particles at normal conditions (atmospheric conditions) could not vaporize since they have not got enough energy, therefore a certain amount of energy should be given to the system. This view suggests that students are either ignoring or do not know that liquids evaporate at every temperature. This was clearly identified in one of the written responses:

> I think that liquids do not evaporate if they aren't heated. In order to evaporate a liquid, intra-molecular forces have to be weakened. Energy is required to do this.

In the case of changing the volume of vapor in equilibrium with its liquid (at a constant temperature), the majority of the students believe that the vapor pressure value will also change. As reported in Table 1, 57% of the students displayed the misconception that at constant temperature, the vapor pressure value changes with the changes in the volume of the vapor in equilibrium with its liquid. In fact, these students think that in the case of increasing the volume of vapor in equilibrium with its liquid, the vapor pressure value would decrease, and conversely, decreasing the volume of the vapor in equilibrium with its liquid would increase the vapor pressure value. This view is explicitly shown in the following interview excerpt:

S: [I]f the volume was decreased the vapor pressure would increase.

R: Why do you think so?

S: The volume of the vapor decreases, thus the number of gas molecules per volume increases. Consequently, more molecules collide per unit of surface area, and thus the pressure increases.

As could be inferred from the above quotation, students holding this misconception consider the vapor in equilibrium with its liquid as an ideal gas in a closed container, and they consider a change in volume in terms of the equation $PV = nRT$. This could be best illustrated by the following excerpts from a written response:

> [A]ccording to the $PV = nRT$ equation, if we decrease the volume by half, the pressure is doubled; vice versa if we decrease the pressure by half.
>
> $P_1V_1 = nRT \rightarrow P_1 = nRT/V_1$ and if
> $V_2 = V_1/2 \rightarrow P_2\,(V_1/2) = nRT$, thus $P_2 = 2(nRT)/V_1$

These examples indicate that the students tend to explain the phenomena in terms of mathematical equations $(PV = nRT)$ instead of focusing on liquid–vapor equilibrium.

The students' responses given to question 4 revealed this misconception: *a liquid's vapor pressure changes with changes in the amount of liquid.* In other words, some students believe that a change in the vapor pressure value depends on the amount of liquid at constant temperature. Just over half of the students (53%) answered the question that $P_1 > P_2 = P_3$, indicating that they consider a direct relationship between the vapor pressure and the amount and the volume of matter, although there is no relation among these variables.

On the basis of these responses, it appears that the students thought that the vapor pressure in the first container is greater than that of the third container. The students explained their responses in these terms: the vapor pressure would be greater in the first container because there was more water in the first container and thus it will evaporate more, causing more vapor pressure compared to the third container.

In addition, a majority of the students holding this misconception indicated that the value of the vapor pressure in the first container is twice that of third container since the amount of matter in the first container was twice that of the third container. When vapor pressures of the second and the third containers were compared, students correctly answered that their vapor pressures were equal. However, they explained this equality of the vapor pressures incorrectly, as follows:

> [T]he number of particles in the vapor phase in the second container would be twice that of the third container, since the amount of water in the second container is twice that of the third container; nevertheless when the volume of the second container (twice that of the third container) was taken into consideration, the vapor pressures in both containers (2 and 3) would be equal.

The above response indicates that some students still hold the misconception that the amount and volume of matter have an effect on the vapor pressure of liquids. In fact, the vapor pressures of the second and third containers are equal. Because the vapor pressures in these containers only depend on the temperature of the liquids and since the temperatures of the liquids are the same, their vapor pressure values must be the same. Similarly, when the vapor pressures of the first and second containers were compared, the students thought that the vapor pressure of the first container was greater than that of the second container because of differences in the volume of the containers. As explained previously, the students reasoned this using the ideal gas equation.

Finally, the students' written responses related to question 5 showed that they have a misconception that boiling liquids at atmospheric pressure have different vapor pressures. This misconception was previously revealed by Pinarbasi and Canpolat *(17)*. The reason behind this misconception was misapplication of the converse relation between boiling point and vapor pressure to boiling process. Using the fact that lower the boiling point, the higher the vapor pressure, 62% of the students addressed question 5 by ordering the three compounds in decreasing value of their vapor pressures: ethyl alcohol > water > 15% NaCl (aq). This view could be seen in the following excerpt taken from a written response:

> [T]hese have different boiling points, therefore their vapor pressures are different. Ethyl alcohol has the lowest boiling point, and therefore exerts the highest pressure. So the order would be as ethyl alcohol > water > 15% NaCl.

Conclusions and Implications for Teaching

The results of the study reflect the general view that students have weaknesses in conceptualizing vaporization and vapor pressure, and that significant numbers of students hold several misconceptions. These common misconceptions could be summarized as follows:

- Inadequacies in understanding liquid–water equilibrium at conceptual level
- Considering that vaporization occurs simultaneously with boiling
- Considering that a liquid has to be heated in order to vaporize
- Considering that the pressure of vapor in equilibrium with its liquid is affected by volume changes, as in the case of ideal gases
- Considering that vapor pressure depends on the amount and volume of matter
- Misinterpretation of the relationship between the vapor pressure and the boiling point of a liquid

The results of the study reveal that the students did not acquire the concepts meaningfully. The origins of the learning difficulties could be attributed mainly to inadequate acquisition of conceptual knowledge about vaporization, and to the insufficient explanation of the relevant concepts in textbooks. Several reports state that chemistry courses and all or most of the assessments of these courses in various countries are based on quantitative problem solving *(18)*. The situation in Turkey is no exception. In this case, for many students, a lack of conceptual understanding of chemical processes is not a detriment. This disparity between students' abilities to solve quantitative chemical problems and their conceptual understanding of underlying chemical processes needs to be addressed *(19)*.

Students' preconceptions greatly influence subsequent learning. Preconceptions not only affect the interpretation of new knowledge, they may also make the comprehension of new knowledge difficult or impossible if the preconceptions are inaccurate. Whether acquired before or during formal education, prior conceptions about the basic concepts that make chemistry teaching and learning difficult should be taken into account in chemistry instruction. By making a connection between students' existing and new knowledge, teachers can increase the possibility of replacing misconceptions with accurate understandings of science concepts.

The conceptions that students have about vaporization and vapor pressure obtained in this study can be referred to by instructors in teacher preparation institutes. If this information were included in pre-service teachers' chemistry education, or used for in-service education and teacher workshops for primary and secondary school teachers, students would have many opportunities for their misconceptions to be challenged and to learn new (and accurate) chemistry concepts. This would be helpful in interrupting the cycle of teachers' chemistry misconceptions propagating and students' chemistry misconceptions going unaddressed. Pre-service chemistry teachers need to have a real understanding of fundamental chemistry concepts in order to underpin their own thinking, learning, and teaching of these basic concepts *(15)*.

Although the results of this study are based on a small sample of Turkish students, many of these misconceptions would likely be found among chemistry students elsewhere. Thus, these findings may provide some clues about the quality of student learning in typical chemistry classes. This study suggests that a substantial review of teaching strategies at the tertiary level is essential. Chemistry instructors sometimes overestimate students' understandings of key chemical concepts and underestimate students' difficulties in acquiring them. If instructors recognize the possibility of misunder-

standings concerning basic concepts and difficulty of learning advanced-level concepts on the basis of these misunderstandings, they will be better able to teach difficult concepts.

Research in this area suggests that efforts to overcome students' misunderstandings should focus on identifying and modifying students' preconceptions and teaching students how to monitor and control their learning *(3).* Diagnostic questions are among the most frequently used technique for identifying students' preconceptions, together with interviews, concept mapping, and classroom discussions. The diagnostic questions used in this study (see Figure 1) were found to be successful in identifying some students' misconceptions. Therefore, it could be useful (in the light of the evidence gained from this research) to use a systematic simple diagnostic test prior to teaching the topic in order to identify students' existing misconceptions.

Alternatively, classroom discussions can provide a wealth of information about the students' existing knowledge. Once students' ideas have been identified, the task of modifying those ideas begins. Several different successful conceptual change and cooperative learning approaches (e.g., conflict and confrontation strategies, problem-based learning, context-based learning strategies, etc.) have been reported in the literature *(3).* Accomplishing meaningful learning may be facilitated by a combination of individual, small-group, and whole-class activities in which alternative explanations and descriptions of scientific phenomena are verbalized, justified, debated, tested, and applied to new situations, as suggested by Wandersee et al. *(3).*

Another possibility might be to focus on the quality of students' learning rather than quantity of concepts covered during the course *(9).* Students may require extensive help to revise their thinking about the concepts and acquire correct scientific meanings. Otherwise, although students correctly answer the examination questions, they may still hold on to their misconceptions. It is also important to recognize the importance of the examination questions. In chemistry exams, questions mostly require quantitative solutions rather than qualitative discussions. It is suggested by Sozbilir *(16)* that questions need to be of a kind that required students to demonstrate an understanding of the concepts involved. Mathematical calculations tend to promote algorithmic learning rather than conceptual understanding.

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