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Prospective Primary School Teachers’ Perceptions on Boiling and Freezing

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Abstract: The aim of this study was to investigate the perceptions of prospective primary school teachers on the physical state of water during the processes of boiling and freezing. There were three stages in the investigation: First, open-ended questions concerning the boiling and freezing of water were given to two groups of prospective primary school teachers (Group-A had science background; Group-B had non-science background). Second, the participants' answers were examined and analyzed. Finally, those participants who had misunderstandings were given semi-structured interviews to have a deeper insight into their perceptions. The results showed that the participants in Group-B held more misunderstandings about boiling and freezing than Group-A. A further examination of the participants' perceptions showed that the misunderstandings were based on participants' daily life experiences related to an inadequate knowledge of science. This paper discusses the answers received to the questions and interviews and makes, implications for equipping primary school teachers with scientific knowledge.

Introduction

Societies agree that all students should understand and be able to do science; therefore, they believe that students urgently need better science education. Consequently, many reforms have been taking place science the 1980s in since education, especially in the primary school curriculum. The aim of these reforms is not only to make students familiar with the scientific theories, concepts, and processes but also to help them become more aware of the complex relationships between science and its social context. In this context, the teaching of science at the primary school level has been an area of concern for many years (Appleton & Kindt, 1999) and the issue of primary school teachers' content knowledge in science has been perceived as a persistent problem (e.g., Appleton, 1995; Goodwin, 2003; Kruger & Summers, 1989; Perkes, 1975). The key role that primary school teachers play in science education shows the importance of primary school teacher education. It is true that students ultimately construct their own learning (Yager, 1991) but it is teachers who are expected to help their students understand concepts and the reasoning behind scientific theories. Osborne and Simon (1996) commented that primary school teachers who lack ability, confidence and enthusiasm for a particular science subject tend to use less stimulating didactic methods and do not respond effectively to children's questions. They are more likely to have students with poor attitudes towards science and a poor understanding of scientific concepts. Unfortunately, many primary school teachers have been found to have poor understanding of the basic scientific concepts, resulting in low confidence and expectations in their students (Harlen, 1997; Harlen & Holroyd, 1997; Kruger & Summers, 1989).

Simpson and Oliver (1990) suggested that if primary school teachers are not interested in teaching science, their students may not be able to construct an adequate background in science during the critical stages of learning, which may lead the majority of children to receive a minimal amount of scientific knowledge in subsequent levels of education. Consequently, only a small proportion of children leaves secondary school with a strong background in and a commitment to further learning in science. This vicious cycle may continue in the further steps of science education (i.e. secondary school). Therefore, it is important to explore and interpret primary school teachers' understanding of scientific concepts in order to equip children with a sufficient knowledge of science, scientific attitudes, and skills. Although, researchers in many countries have tried to answer a number of important questions related to students' perceptions, there is still limited research on teachers' perceptions. For this reason, an investigation of prospective primary school teachers' perceptions on fundamental concepts of science would be worthwhile. This study aims to explore the perceptions of Turkish prospective primary school teachers on one of the dominant topics of primary school science education, the changes in state of matter (i.e., boiling and freezing).

There are many studies which report students' alternative conceptions about science (Pfund & Duit, 2004). A large number of research studies in science education have focused on students' understandings of changes of state (Bar & Travis, 1991; Bar & Galili, 1994; Johnson, 1998a, 1998b; Osborne & Cosgrove, 1983; Paik, Kim, Cho & Park, 2004; Ross & Law, 2003); however, there are only a limited number of studies that focus on the perceptions of teachers (Chang, 1999; Goodvin, 2003). Osborne and Cosgrove (1983) conducted interviews and a written test to study the conceptual development of students from New Zealand aged 8-17 years about the changes of ice, water, and vapor. They revealed that students only have cursory understanding of the terms like condensation, evaporation, melting, and so on, and have virtually no real scientific understanding. They found that only eight students described the melting of ice in particle terms. They also found that students did not regard freezing as taking place at a specific temperature.

Bar and Travis (1991) used three different ways (an oral, a written, and a multiple-choice test) to explore the conceptual development of 6-14 year-old students in Israel about the phase changes. Although it is a scientific fact that the evaporation of water can occur before boiling, the researchers found that students' understanding of boiling precedes that of the evaporation of water. Further, some children said that when a solid object such as a wet saucer dries, water disappears or penetrates the solid object. Students observing the phenomenon of evaporation supposed that water simply disappears or sinks into the floor.

Bar and Galili (1994) conducted a clinical interview, an open-ended investigation, and multiple-choice written tests to explore the conceptual development of students from Israel aged 5-14 years about the concept of evaporation. Their main findings showed that the development of the concept of evaporation by students involved the following four interpretations: (1) water disappeared; (2) water was absorbed by the floor or soil; (3) 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 (4) water changed to water vapor, and it was spread out into the air as invisible tiny water droplets, or it was transformed to air.

Paik et al. (2004) investigated the various conceptions held by 28 K-8th grade Korean students regarding the 'changes of state' and the 'conditions for changes of state'. Several activities that involve a change in the state of water were chosen and attempted by the students. Interviews were then conducted with them, and it was found that most kindergarteners and second-grade students were unable to explain concepts related to the changes of state and the conditions under which the state the changes, and that most upper-grade students held conceptions about boiling water's change of state from liquid to gas. It was also determined that kindergarteners and second graders generally perceive the phenomena related to state change based on their sensory experience.

Chang (1999) studied the conceptions of prospective teachers from Taiwan regarding evaporation, condensation, and boiling. He found that the performance of participants on tasks relating to the concept of boiling was not impressive. Most students thought that bubbles generated when water boiled contained air. Examining the students' perceptions carefully, the researcher concluded that learning difficulties regarding the aforementioned concepts could be a result of a poor conceptual understanding of changes of state.

Goodwin (2003) examined 52 trainee science teachers' understandings of evaporation and boiling. To provide a consistent stimulus for the explanations from the participants, the researcher presented six short scenarios as video sequences. The five out of six scenarios involved bubbles in some form, together with evaporation, and these served to focus on the more specific notion of 'boiling'. After the participants viewed the video, they completed a short questionnaire which asked them to answer questions and to explain their answers as far as possible. The findings showed that majority of participants had given correct answers, but there were many instances where ideas expressed deviated from the accepted 'answer'. For example 23% of the participants stated that the substance inside the bubbles of boiling water was air or heat.

Some research studies showed that teachers frequently use terms such as "substance", "solid", "liquid" or "gas" in science courses. They assume that students understand these and other fundamental concepts when they begin the course and very little time is generally spent in reviewing these terms. However, the findings of these studies also showed that naive conceptions held by children about matter during their primary and middle school years persist at the high school and even to college level (Osborne & Simon, 1996; Stavy, 1990a, 1990b, 1991). As the study was conducted with Turkish prospective primary school teachers, it would be useful to describe primary school teacher education along with the basic education system in Turkey.

Structure of primary school teacher education in Turkey

In Turkey, primary school teachers follow a 4-year course of teacher education, which prepares them to teach students aged 6–10 years. During a typical four-year program, prospective primary school teachers are required to take a certain number of courses in each of the primary branches of science. These include physics, chemistry and biology courses which are compulsory as they relate to teaching professionals (see Table 1).

Courses	Total Credit
Introductory Physics	2
Introductory Chemistry	2
Introductory Biology	2
Introductory Mathematics	4
Science Laboratory	2
Introduction to Teaching Profession	3
Methods of Science Teaching	4
School Experience	6
Teaching Practice	5

Table 1: A list of courses related to science, education and the teaching profession that prospective primary school teachers are required to complete in Turkey

In the first year, students are introduced to the nature of primary science. During the second year, they complete a science practicum course that includes laboratory experiments in science education. This course endeavors to improve and develop skills relating to setting-up and conducting experiments that demonstrate scientific principles to students. The third year focuses on methods that help students to develop their knowledge and understanding of science and how to plan a sequence of activities to help students learn. Finally, students are introduced to practical teaching in the fourth year of the program and this in-class practicum component has to be completed successfully.

The Basic Education System in Turkey

Basic compulsory education in Turkey has two stages: first five years (primary) and last three years (middle). Primary school teachers are employed in the first stage and usually teach the same group of students throughout the initial 5-year program. Science courses in primary school are taught in the 4th and 5th grades as four contact hours a week and are called “Science and Technology”. “Matter and Changes of State” is one of the four learning strands in this course and comprises one fourth of the total course time. In this learning strand, the concepts of boiling and freezing are explained using water as an example. Primary school teachers’ responsibility in the Turkish basic education system is to plan and evaluate the learning process so that students reach an understanding of science concepts (Balci, 2005; Somken, Guler & Ekmekci, 2005).

Research Question

In spite of a large number of studies related to students’ conceptions of changes of state, there are few studies related to students’ conceptions of boiling and freezing. In addition, it is difficult to find data that demonstrate prospective primary teachers’ conceptions related to boiling and freezing. Therefore, the aim of this study was to explore the perceptions of prospective primary school teachers in Turkey with regard to two crucial concepts in the Turkish Primary Science Curriculum: the concepts of boiling and freezing with water used as example. As a teacher’s knowledge of science will affect a student’s learning of scientific concepts, the findings and educational implications obtained from this research are expected to provide useful references for primary school teacher education and curriculum planning. The research was undertaken to answer the following questions:

What are the perceptions of prospective primary school teachers about boiling and freezing?

What beliefs underlie these perceptions?

Method

Sample

The sample of this study included 110 first year undergraduate students who completed an introductory chemistry course for prospective primary school teachers. The students were divided into two groups according to their background knowledge of science. This division was necessary as the background levels of students are not homogeneous in Turkey.

Group-A: Consisted of 50 (17 female and 33 male) participants who had completed a major course in natural sciences at high school.

Group-B: Consisted of 60 (18 female and 42 male) participants who had completed major courses of study in a range of high school subjects including the social sciences, mathematics, foreign languages, arts and sports.

The average grades for these two groups in the introductory chemistry course (Table 2) are consistent with their respective academic backgrounds in that Group A obtained a higher grade average than Group B. In the Turkish Higher Education System, students take a final examination at the end of each semester and at least one midterm examination for each course. The students' grades in the final examination represent a cross-section from 1 to 100. Passing grades range from 50 to 100; grades below 50 are used to indicate failure to satisfactorily complete the course.

Groups	The number of participants (n)	The levels of achievement ($\bar{x}$)
Group-A	50	67.36%
Group-B	60	54.86%

Table 2: The participants' grades of achievement in introductory chemistry course

Research Instruments

In order to explore the range of prospective primary school teachers' perceptions about boiling and freezing, two criteria were used. First, two open-ended questions were administered at the end of the introductory chemistry course. These questions related to the boiling and freezing of water, and are listed below:

Question 1: *It is not advisable to fill aquariums with non-agitated water that has been cooled down after boiling it. What could be the reason for this preference?*

Question 2: *Consider that you have put some water into a freezer and kept it therein until it is completely frozen. What kind of changes do you think will occur in the molecular structure of liquid water as a result of freezing?*

These two questions were asked to the sample of the study. Answers were evaluated by the researcher, and 20 participants were identified for interview as having misunderstandings. These prospective primary school teachers then were interviewed to further explore the sources of their misunderstandings. There was a period of two weeks between the answering of the questions and the interviews. The direction of inquiry adopted during the interviews was based on the participants' answers to the questions. The aim was to confirm the participants' views through verbal communication, obtain rich data about the conceptions of participants regarding state change, clarify misunderstandings in the answers to the questions, and provide greater access to the participants' thoughts on the subject. The questions in the present interview reflected the goal of the research, yet provided participants with opportunities to discuss answers in more detail. For example, "What did you mean when you said that when water freezes, the number of molecules in it increases?", "Can you tell me the reasoning behind your answer that boiling purifies water?", "What is the reason behind your answer that certain inorganic substances evaporate when water is boiled?" The researchers conducted the interviewer. Each interview took approximately 30 minutes, and permission was obtained from participants to audiotape the discussion. Each interview was then transcribed and analyzed.

Data Analysis

Mixed methodology was used in this study (McMillan & Schumacher, 2006). The qualitative part of the study attempted to describe the main features of the prospective primary school teachers' perceptions in relation to "boiling and freezing". The data gathered in the qualitative portion of this study were analyzed using a tailored version of Wolcott's (1994) three-phase approach: description, analysis, and interpretation. However, only the analysis and interpretation of data are presented and discussed here because of space constraints. Quantitatively, the study attempted to determine the incidence of particular perceptions or concepts. It was thought that quantitative measures would usefully supplement and extend qualitative analyses. The methodology used in the analysis of the data was a simple categorization of the answers based on extracted key perceptions from the answer-sheets or interview transcripts.

Results

The majority of the participants (75% in Group A; 55% in Group B) correctly answered the questions. A 'correct answer' was one that was deemed to be consistent with the current scientific thought. The other answers were accepted as misunderstandings, as described by different researchers (Nakhleh, 1992). However, important misunderstandings about boiling and freezing were also identified through the analysis of the participants' written responses. These misunderstandings are presented in Table 3 and discussed in detail in the following sections.

Misunderstandings			Number of Participants (% of total) Group A	Group B
Boiling	When water boils,	it turns pure, and inorganic substances in it disappear.	4 (8.0%)	14 (23.3%)
		the minerals and elements in it are destroyed.	_	15 (25.0%)
		all inorganic substances in it evaporate.	6 (12.0%)	_
		its chemical structure will be damaged.	5 (10.0%) _	_
Freezing	When water freezes,	the number of its molecules increases.	7 (14.0%)	9 (15.0%)
		the volume of its molecules increase.	3 (6.0%)	10 (16.7%)
		it increases in mass and volume.	_	3 (5.0%)
		bonds among the molecules shrink and get smaller.	_	3 (5.0%)

Table 3: The participants' misunderstandings about boiling and freezing of water

Analysis of participants' perceptions about boiling of water

The majority of the participants in Group-A (70%, 35) stated that water that was boiled and allowed to cool was not used to fill aquariums because the dissolved gasses in water would disappear. The remaining participants in Group-A explained the reluctance to use boiled and cooled water in aquariums differently. One participant stated, "When water boils, some of the inorganic substances evaporate thanks to boiling". Another participant said, "When I drink boiled and cooled water, it tastes different. Thus, I believe that the chemical structure of water molecules becomes damaged when water boils". During the interviews, participants were asked to explain the reasons behind their responses. Some of the participants' answers were as follows:

> "I believe that boiling eliminates the substances in water because my mother used to boil drinking water when I was a child."
>
> "I think that boiling decreases the amount of minerals in water. Boiling purifies water because when water evaporates, so do the minerals in it."
>
> "I believe that boiling destroys the bonds between water molecules, and thus causes it to decompose into its components (hydrogen and oxygen). Therefore I can say that boiling damages the chemical structure of water."

When asked to explain why boiled and then cooled water is not used to fill aquariums, 50% of the participants from Group-B stated that gases dissolved in water would leave water when boiled. The remainder of participants provided alternative explanations as to why boiled and cooled water is not used in aquariums. For example, one participant stated, "If we boil water, we destroy the minerals and elements existing in it. Therefore if we put it in an aquarium, we prevent fish from benefiting from these minerals and elements". Another respondent said, "Minerals and elements in water disappear when it is boiled. Boiling purifies water and I do not think that fish can live in pure water". The rest of the alternative explanations were similar: "When water boils, it becomes purified"; "Minerals in water disappear when it is boiled"; "If water is boiled, it loses some of its characteristics". During the interviews with the participants, they were asked further questions about their answers related to using water which had been boiled and then cooled. Sample student answers are listed below:

> "I think that when we boil water, it becomes purified and the minerals in it disappear. Water is limey in our country and we always boil it. By doing so, we ensure the evaporation of lime from water. When water evaporates, minerals evaporate with it."
>
> "In primary and middle school, I learned that minerals in water die when it is boiled. Therefore, I think that boiling causes water to lose its chemical properties. That is why we should prevent fish from feeding in that water."
>
> "When I was a child, my mother used to boil our water because it was limey. However, I felt that boiled and cooled water tasted different. Thus, I think that the chemical structure of water must change when it is boiled."

Analysis of the participants' perceptions about freezing of water

The findings from the second question showed that the majority of the participants correctly understood the concept of freezing; however, some participants from both groups held some misunderstandings. A detailed examination of each response provided by the participants to the second question follows.

When asked about the sort of changes that may have occurred in the structure of water at the molecular level when it was frozen, most of the participants (80% in Group-A) gave correct answers such as: "The number of bonds between the molecules increases as a result of freezing"; "The density of water decreases but its volume increases"; and "The kinetic energies of water molecules decrease". However, some participants expressed alternative conceptions which may be defined as misunderstandings. For example, one participant stated, "When water freezes, a growth in the number of water molecules causes an increase in the volume of water". Another one stated, "When water freezes, an increase in the volume of water molecules causes an increase in the volume of water". Two further examples of the statements on freezing of water provided by the participants during the interviews were:

> "I know that the volume of water increases as a result of freezing and I think that this increase can only be caused by an increase in the number of water molecules."
>
> "Freezing makes water molecules expand. More precisely, their volume enlarges. For example, when we put a plastic bottle filled with water into the freezer and the water completely freezes, the bottle becomes swollen."

When the same question was asked to the participants in Group-B, 60% gave correct responses similar to those provided by participants in Group-A. However, other participants (40%) in this group held misunderstandings about the freezing of water. For example, one participant stated, "When water freezes, an increase occurs in the volume of water molecules.

As a result of this increase, the volume of water also increases". Another participant said, "When water freezes, the number of water molecules increase due to the change of state from liquid to solid". During the interviews, the participants were asked to explain the reasoning behind their thoughts about freezing of water. Responses included the following:

> "Once I put a bottle in the freezer and it burst when water had frozen. It must have happened because the volume of water molecules increased."
>
> "When water freezes its volume increases. For an increase of this kind, the number of water molecules needs to increase. When water freezes it gets bigger in mass and volume."
>
> "When water freezes, there is a transition from liquid to solid state. As a result, the volume of water decreases. I think that this decrease is caused by shrinking bonds between water molecules. Also, I believe that a transition from solid to liquid state would mean that the bonds between water molecules would get longer."

Conclusion and Implications for Teaching

The scientific understanding of prospective primary school teachers with regards to boiling and freezing were investigated in this study. The results showed that a considerable number of prospective primary school teachers held misunderstandings. Some of the misunderstandings detected were similar to those reported by other studies investigating primary school teachers (e.g., Lawrenz, 1986; Kruger & Summers, 1988; Kruger, 1990; Kruger, Summers & Palacio, 1990; Mant & Summers, 1993). Findings obtained from the interviews showed that students tended to use their daily life experiences to explain questions especially related to boiling. For example, when asked to explain the statement, "When water boils, it turns into pure water", the response was "I think this way because my mother used to boil our drinking water when I was a child". Paik et al. (2004) supported this finding by suggesting that these types of answers were formed by participants' sensory experiences. Ball and MacDiarmid (1990) also suggested that, in general, the knowledge of subject matter among primary school teachers was grounded in daily life and educational experiences.

As for participants' perceptions of freezing, both group-A and group-B participants hold misunderstandings, particularly about why the volume of water increases. In current scientific content, freezing is defined as a change of state from liquid to solid. As a result of freezing, the volume of a liquid generally decreases and its density increases. However, these phenomena are incorrect for water, because water is anomalous. In spite of this anomaly, water is mostly used by teachers as an example of freezing when teaching change of state. This contradiction may have caused confusion for students, thus leading them to develop misunderstandings. As can be seen from the findings of this study, while students expected a decrease in the volume of water as a result of freezing, they found an increase instead. They subsequently tried to attribute this to an increase in the number, volume, or mass of water molecules. Ross and Law (2003) asked students what mass of ice would be obtained if 10 g of water were frozen. Some of the participants provided the 'correct' answer, but the only reason given was '*our teacher told us that the mass stays the same*'; they could not provide a reason why. Water is a crucial part of our daily lives and living organism are mostly mater. Therefore, it is critical that we understand the nature of phase change with water and understand the anomaly. However, the findings of this study makes one wonder whether it is a mistake to use water as an example when teaching the phenomenon of freezing because of some over generalizations or incorrect casual connections. Although the findings of this study suggest some clues about this contradiction, more detailed research is needed to examine the effects of water as an example on students' understanding of freezing.

Although the study found that the participants of Group-A were better able to complete the questions and had fewer misunderstandings about boiling and freezing than the participants of Group-B, their learning of these concepts still needs to be enhanced. This also indicates that participants with a science background are more able to learn these concepts. This is supported by the observation that the participants of Group-A had a higher level of achievement than the participants of Group-B in the introductory chemistry course, as shown in Table 2. Studies on primary school teachers' knowledge of scientific content have demonstrated that teachers have an inadequate scientific background and are unable to draw on their own understanding of these concepts to help facilitate understanding in their students (Kruger & Summers, 1988; Smith & Neale, 1989). Anderson and Mitchener (1994) described prospective primary teachers' knowledge in science as limited in amount, narrow in perspective and characterized by lack of understanding. Other studies about primary school teachers and the teaching of science (Haladyna, Olsen & Shaughnessy, 1982; Harlen & Holroyd, 1997) found that teachers' knowledge of science was a significant factor that influenced their teaching of science, and teacher quality was particularly critical in the development of students' attitudes towards science. The results of the present study are important because they demonstrate the effect of background knowledge on prospective primary school teachers' learning of science, and suggest important implications for an effective teaching of changes of state.

It is clear that both teachers and students have misunderstandings about the processes of boiling and freezing. Some researchers suggest that such misunderstandings may be a result of poor presentation in textbooks, over-laden syllabi that allow inadequate time for conceptual reflection, teachers who do not adequately take into account students' previous learning experiences (Calik & Ayas, 2005), or chemistry lessons that include assessment techniques based merely on quantitative problem-solving (Ozkaya, 2002). It is important to reveal these misunderstandings; develop teaching strategies that have been effective in dispelling of them; and bridge the gap between such misunderstandings and the scientific thoughts.

In the light of the findings of this study, four general conclusions can be made. First, teachers should acquire a better and deeper understanding of changes of state in matter so that they are able to teach properly without passing on their own misunderstandings to students. Second, prospective primary school teachers should be selected among candidates with a better background in science as they have acquired an adequate level of science knowledge. Third, as prospective primary school teachers will play a key role in educating the next generation, there should be a comprehensive discussion regarding their misunderstandings of scientific concepts such as boiling and freezing. Finally, the perceptions that prospective primary school teachers have about boiling and freezing obtained in this study can be used by instructors in teacher preparation colleges.

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