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First Year Prospective Teachers' Perceptions of Chemical Solution Types and Solubility

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This study aims to compare first-year prospective elementary science and primary teachers' perceptions of chemical solution types and solubility. A questionnaire was administered to 89 prospective elementary science and 86 prospective primary teachers in the Faculty of Education at Pamukkale University in Turkey, during 2007-2008 schooling year. The questionnaire is consisted of three two-tiered questions and one solubility problem. Question-1 examines participants' perceptions about types of the solutions. Questions-2 and 3 examine the participants' perceptions about the concentration of a saturated solution when a small amount of solute is added into the solution and when half of water evaporates from the solution, respectively. Questions 1 to 3 also asked participants to write the reasons for their answers. Question-4 explores the participants' skills to solve a solubility problem. Responses were analyzed by quantitative and qualitative methods. The findings showed that prospective teachers have some difficulties to understand solution types and solubility concept.

Key Words: Prospective teachers, Misconceptions, Chemical solution types, Solubility.

INTRODUCTION

During the last three decades, many science educators have believed that students' knowledge in domain-specific areas plays a more important role than their general cognitive ability or underlying logical structures on conceptual learning of science[1]. Consequently, science education researchers have widely surveyed students' knowledge in various domains, known as students' conceptions[2]. These studies have revealed that students' conceptions are often inconsistent with scientific thinking[3,4]. Moreover, it has been argued that such conceptions once embedded in a conceptual framework are difficult to change and can affect subsequent learning[5,6]. These conceptions have been variously referred to as misconceptions[6], children's science[7], alternative frameworks[1], preconceptions[8], untutored beliefs[9], intuitive notions[10], alternative conceptions[11] and ideas[12].

Students' understanding and their misconceptions related to chemical solutions have been studied for more than two decades. These studies have concentrated on various perspectives as follows: dissolution, the nature of solutions, solubility, energy in solution processes, effects of temperature and stirring to dissolution of solid in liquid, conservation of mass during dissolution process, types of solutions and vapour pressure lowering, solubility of a gas in water, and the relationship between vapour pressure and boiling/freezing point. Solution chemistry, which is a pre-requisite for some topics such as electrochemistry, acids and bases, chemical equilibrium and phase diagrams, is one of the most investigated topics because of its importance[13]. Dissolution and solubility are the fundamental concepts of chemistry taught in the school chemistry curriculum. Numerous aspects of knowledge about the nature of solutions, which are dissolution[14], solubility[15-21] and melting point depression and freezing point elevation[17,21,22] have been examined.

There are a few studies[15-20] investigating students' understanding of the types of solutions (unsaturated, saturated and supersaturated) and solubility in with respect to students' understanding. Students were queried about how solution concentration changed when water evaporated from a beaker of water with sugar sitting at the bottom[15]. Only 32 % of students specified that the solution concentration stays the same as the water evaporates, while 64 % of them believed concentration increased and 3 % of them thought it decreased. The students were given four choices as to the reason, 40 % stated that there was the same amount of sugar in less water, while 30 % specified that the sugar didn't evaporate and remained in solution, while only 25 % stated that more solid sugar forms at the bottom of the beaker. There was a misconception about the meaning of supersaturation which is 'there is excess solid present as a separate phase in the beaker'. In a similar study[16], only 32 % of grade 12 students realized that the concentration of a saturated solution will stay the same when the solvent evaporates and only half of them (15 %) could explain their answer in terms of the precipitation of solute during evaporation. In another study[17], the chemistry students' understanding of the terms unsaturated, saturated and super-saturated was examined by means of three schematic diagrams of beakers with solution. Results revealed that a majority of students (78 %) incorrectly chose saturated solution diagram as being supersaturated solution. The students' primary reason was that 'there is excess solute (undissolved sugar) sitting in the beaker'. The results of the study revealed that although students wrote the reasons for their choices of the above-mentioned terms, 70 % of students explained incorrectly. The study reported that many students thought a solution in equilibrium are involved an undissolved solute was a super-saturated solution. In other words, most of students under investigation had difficulty in differentiating the distinction between a supersaturated solution and a saturated solution, so that the students may see a saturated solution as super-saturated if dissolved and undissolved solute is in equilibrium. Finally, the study reported that students asserted that seeing undissolved solute as a component of solution forms the idea that 'a supersaturated solution includes the undissolved solute'.

The other studies[18-20] similarly examined the material-engineering students' misconceptions. The students were asked that if a small percentage of salt is slowly added to the glass while stirring the solution, which solid salt does remain on the bottom, what will be the concentration of the salt in the solution: a) increase, b) stay the same or c) decrease. The students[18] chose the correct answer in the rates of 39 % at Arizona State University (ASU) and 50 % at Texas A&M University (TAMU). The results of the other two studies at ASU were that 49 and 86 % of the students selected the correct answer[19,20] at ASU, respectively. The most frequent written responses indicated that the term concentration referred to 'the amount of salt that had been added to the water overall, not the amount that had actually dissolved into the water'[19]. The students correctly responded the types of solution question with rates of 38 and 63 % supersaturated, 30 and 43 % saturated and 86 and 77 % unsaturated, respectively[19,20]. Their explanations indicated that 70 % of the students did not understand the definition of saturation[19]. One of the misconceptions (11 %) was that 'there is still a lot of sugar that is not mixed' (*i.e.* the solution was unsaturated because there was undissolved sugar at the bottom of the beaker). The other misconception (59 %) was that 'there is so much sugar that cannot mix with the water' (*i.e.* the solution was supersaturated because there was excess solid in the beaker). The results of the effect of evaporation on saturated solution concentration were that 66 % of students selected the correct answer[20]. These studies show that the misconception of increasing solution concentration when solute sits at the bottom of the beaker seems to be another aspect of the previous misconception of the meaning of saturation.

Teachers' knowledge about students' misconceptions is important for students' further learning and elicitation of misconceptions is necessary for preparing remediation materials. Teachers' subject matter knowledge is one of the sources of students' misconceptions. There are some studies on the elementary or secondary students' misconceptions about chemical solutions and solubility, but no studies have been conducted on elementary teachers' misconceptions on this subject. So, it is intended to compare science majors and non-majors prospective teachers' conceptions and reasoning frameworks about solutions and solubility, which are science majors and non-majors. Therefore, the study aims to examine prospective elementary science and prospective primary teachers' understandings of solution types and in particular what misconceptions they hold about this topic. The results of this research are expected to provide useful references for chemistry teachers, educators and curriculum designers.

EXPERIMENTAL

Sample and instrumentation: Elementary Education Department trains elementary science teachers and primary teachers. Prospective primary teachers (PT) took only General Chemistry course in the second semester, while the prospective elementary science teachers (EST) took General Chemistry-I-II and General Chemistry Laboratory-I-II courses in the first and second semesters before the research was conducted.

The prospective teachers were taught the topic based on lecturing and discussions. The same lecturer gave the classroom instruction for both groups.

To explore first-year Turkish undergraduates' (aged 16 to 18) misconceptions of solution types and solubility, a multiple-choice diagnostic instrument was used. The questionnaire consisted of three two-tiered questions and a multiple-choice solubility problem in this inquiry, which were taken from the literature of students' misconceptions related to solutions[20,23]. In first-tier, multiple-choice questions were used to select participants' responses regarding questions. Later, in second-tier, free-response explanation questions were used to examine the underlying reason and conceptual basis for selection of an answer in the multiple-choice first-tier questions. Moreover, many researchers used two-tiered tests for determining the students' understanding levels and misconceptions[15-20]. The first question in this study examined the participants' understanding and definition of the concepts of liquid-solid solutions that are unsaturated, saturated and supersaturated (see Appendix). The second and third questions were utilized the previously tested definitions and concepts of liquid-solid solutions as well as the effect of a perturbation, which is small amount of salt addition or water vaporization, on the concentration of saturated solution, respectively. The forth question examined the participants' knowledge about solubility limit by problem solving skills.

Two chemistry educators checked the content validity of questionnaire items and agreed that the questions were valid and appropriate to measure the participants' understanding of the given concepts. The participants were not involved to sample of this research. A total of 52 sophomores were involved in a pilot study. The aim was to have a sense of participants' responses to the questionnaire items. The pilot study revealed that the items of questionnaire were clear and understandable. The participants of this pilot study were not involved in the sample of this research. The subjects involved in this study were 89 (30 male, 59 female) first-year undergraduates EST and 86 (24 male, 62 female) first-year undergraduates PT at the Faculty of Education in Pamukkale University, Turkey. The pre-test was administered to EST in early October of 2007 and to PT in early March of 2008. The post-test was administered to both groups after the topics had been instructed in late May, 2008. It was observed that the participants responded the questionnaire in *ca.* 20 min.

Data analysis: The participants' responses of first-tier questions were analyzed and presented in percentages. The second-tier questions in the questionnaire, which are explanation for the reasons of first-tier questions, were analyzed[24] by allocating participants' responses into one of the following categories: sound understanding, partial understanding, partial understanding with specific misconception, specific misconception and no understanding. To analyze the data, the researcher categorized the given responses separately by means of the aforementioned criteria. Another chemistry educator also executed coding process and 91 % of agreement was found between the researcher and the other educator. The participants' incorrect responses rates of pre-test were compared with the chemistry class students' pre-test results. The participants' incorrect responses rates of post-test were compared with the material-engineering students' pre-test results, because the general chemistry course were taken by them before. Only the EST's specific misconceptions were identified from written responses on pre-test. A statement was categorized as misconception in the event of repetition by at least 5 % of the subjects.

RESULTS AND DISCUSSION

The pre-test and post-tests results for first-tier questions were presented in percentages in Table-1. The pre-test results were discussed and the correct answers were indicated in bold. On part 1 of item 1, 78 % chose saturated, 3 % unsaturated, while 19 % of EST chose the correct answer of supersaturated. On part 2 of item 1, 76 % chose supersaturated, 7 % of them chose unsaturated, while 17 % of EST chose the correct answer of saturated. Finally, on part 3 of item 1, 8 % of them chose saturated, 3 % chose supersaturated, while 89 % of EST chose the correct answer of unsaturated.

TABLE-1
PARTICIPANTS' PRE- (POST-TEST) RESPONSES IN PERCENTAGES

Items			EST	PT
			Pre- (post-test)	Pre- (post-test)
Item 1	1.1 Solution A	a) Saturated	78 (55)	78 (58)
		b) Unsaturated	3 (6)	9 (13)
		c) Supersaturated	**19 (39)**	**13 (29)**
	1.2 Solution B	**a) Saturated***	**17 (39)**	**15 (29)**
		b) Unsaturated	7 (4)	19 (13)
		c) Supersaturated	76 (57)	66 (58)
	1.3 Solution C	a) Saturated	8 (5)	10 (15)
		b) Unsaturated	**89 (94)**	**71 (76)**
		c) Supersaturated	3 (1)	19 (9)
Item 2. Concentration of solution if salt is added into saturated solution		a) Increases	23 (26)	59 (40)
		b) Stay the same	**63 (74)**	**19 (48)**
		c) Decreases	4 (0)	22 (12)
Item 3. Concentration of solution evap. of water from the sat. solution		a) Increases	24 (17)	32 (29)
		b) Stay the same	**66 (82)**	**40 (56)**
		c) Decreases	10 (1)	28 (15)
Item 4. Solubility limit problem		a) 100 g	0 (0)	1 (0)
		b) 50 g	0 (0)	4 (2)
		c) 37 g	**91 (99)**	**89 (93)**
		d) 13 g	9 (1)	6 (5)

*Correct answers are in **bold**.

As for PT, on part 1 of item 1, 78 % of them chose saturated, 9 % unsaturated, while 13 % chose the correct answer of supersaturated. On part 2 of item 1, 19 % of

PT chose unsaturated, 66 % chose supersaturated, while 15 % chose the correct answer of saturated. Finally, on part 3 of item 1, 10 % of PT chose saturated, 19 % chose supersaturated, while 71 % chose the correct answer of unsaturated.

Item 1.1 revealed that the 78 % of EST and PT did not understand the concept of saturation. From the responses of the EST for item 1.1, three distinctive misconceptions were identified. As indicated in Table-2, these misconceptions: the possible amount of sugar is dissolved in water, so it is saturated solution (45 %), the maximum amount of sugar is dissolved in water and there is not any solid, so it is saturated solution (20 %) and the dissolved sugar molecules are homogeneously dispersed in water, so it is saturated solution (7 %). Two examples of the participants' written explanations were as follows:

Faruk response: If the sugar molecules precipitate, it is supersaturated solution; if the sugar molecules disperse in the solution in sparsely, it is unsaturated solution. There is not any solid sugar and then it is saturated solution.

Esranur response: A supersaturated solution has a deposit on the bottom of beaker, there is no deposit and then it is saturated solution.

TABLE-2
MISCONCEPTIONS OF EST IDENTIFIED FROM PRETEST RESPONSES

Items	Misconceptions	%
Item 1	Related with supersaturated solution:	
	1. The possible amount of sugar is dissolved in water, so it is saturated solution.	45
	2. The maximum amount of sugar is dissolved in water and there is not any solid sugar, so it is saturated solution.	20
	3. The dissolved sugar molecules are homogeneously dispersed in water, so it is saturated solution.	7
	Related with saturated solution:	
	1. There is excess solid sugar sitting in the beaker, so it is supersaturated solution.	74
Item 2	1. The dissolved salt content increases by the addition of salt, so that the concentration of solution will increase.	11
	2. The dissolved salt content increases by the mixing of solution, so that the concentration of solution will increase.	7
Item 3	1. As the volume of solution decreases, the concentration of solution increases.	16
	2. As some dissolved sugar precipitates, the concentration of solution increases.	6

The level of performance for item 1.2 was that 83 % of EST and 85 % of PT incorrectly answered, which is similar to the result[17] in chemistry students, where 78 % of responses are incorrect. On the other hand, in post-test results, 61 % of EST and 71 % of PT incorrectly answered, which is similar to the material-engineering students' results, where 61, 70 and 57 % of the responses are incorrect, respectively[18-20]. The results of saturated solution revealed that the 76 % of EST and 66 % of PT did not understand the term supersaturated. Almost the entire EST had a misconception that there is excess solid sugar in the beaker, so it is supersaturated solution (74 %), which is similar to the earlier studies[15,17,19,20]. Their assumption for supersaturated solution is that there is undissolved sugar sitting in the beaker. Most of the participants had difficulty in differentiating the distinction between a supersaturated and a saturated solution, so that the participants may see a saturated solution as supersaturated if dissolved and undissolved solute is in equilibrium. Thus, both of these terms are related to misconceptions that are misunderstandings of the definition of saturation and the associated concept of solubility limit. According to the results of item 1, the prospective teachers performed better when the item 1.3 (unsaturated solution) was considered, than when the items 1.1 and 1.2 were considered.

The results for item 2 were that 23 % of the EST selected the incorrect answer 'increase'. The correct answer 'stay the same' was selected by 63 % of the EST, while 4 % of them selected the incorrect answer 'decrease'. As for PT, the results for item 2 were that 59 % (40 % post) of them selected the incorrect answer 'increase'. The correct answer 'stay the same' was selected by 19 % of the PT, while 22 % of them selected the incorrect answer 'decrease'. Most of the EST wrote that reason '*the salt addition increases the amount of solid salt in the beaker*' in their correct responses. They had two misconceptions: the dissolved salt content increases by the addition of salt, so that the concentration of solution will increase (11 %) and the dissolved salt content increases by the mixing of solution, so that the concentration of solution will increase (7 %). The results of item 2 in post-test, 52 % incorrect answer rate given by PT is similar to 61 and 51 % incorrect answer rates in material-engineering class[17,18], but 26 % incorrect answer rate given by the EST are fairly different than 51 and 14 % incorrect answer rates[18,19], respectively. The participants' reasoning for their misconceptions about increasing solution concentration depends on the belief that 'increasing the number of moles of dissolved salt leads to increased concentration of solution when solid salt sits at the bottom of the beaker'.

The results for item 3 were that 24 % of the EST and 32 % of the PT selected the incorrect answer 'increase'. The correct answer rate was 66 and 40 % for the EST and PT, respectively. 10 % of the EST and 28 % of the PT selected the incorrect answer 'decrease'. The EST wrote the only reason that '*more solid sugar forms at the bottom of the beaker by evaporation*' in their correct responses. They had two misconceptions: as the volume of solution decreases, the concentration of solution increases (16 %) and as some dissolved sugar precipitates, the concentration of solution increases (6 %). According to the results for item 3, 60 % incorrect answer rate given by PT is similar to 68 % incorrect answer rate in chemistry class, but 24 % incorrect answer rate given by the EST are fairly different than their result[15]. On the other hand, 44 % incorrect answer rate given by PT is similar to 34 % incorrect answer rate, but 18 % incorrect answer rate given by the EST are fairly different than 34 % incorrect answer rate in material-engineering class[19].

The EST's explanations for item 2 and 3 revealed that the participants misunderstood the definition of concentration, which is similar to the findings of previous studies[19,20]. The misconception of increasing solution concentration when solid matter settles at the bottom of the beaker seems to be a misconception of the meaning of saturation. That is, if students do not know what the characteristics of a saturated solution, then the perception that solution concentration increases with water evaporation or with solute addition, may be related misconception. The most frequent written explanation for solution concentration increases indicated that participants believed that the term 'concentration' referred to the amount of salt that had been added to the water overall, not the amount that had actually dissolved into the water. This faulty reasoning of EST indicated that they approached to select the incorrect choices of the conceptual questions, which is similar to an algorithmic problem using the molar concentration formula. They used the molar concentration formula, (*i.e.*, M = n/V, where; M: molar concentration, n: number of moles dissolved solute, V: volume of solution). Their reasoning for item 2 is that adding salt increases the number of dissolved solute moles which results a bigger concentration value while the volume of solution stays the same. As for item 3, evaporating water from the solution providing the amount of solute stays the same; a bigger concentration value is obtained while the volume of solution decreases. The using molar concentration formula by omitting the means of the letters concluded incorrect decision-making in both cases.

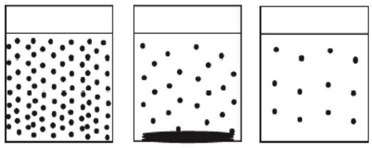
Item 4 examined the participants' problem solving skills of the solubility topic. The EST and the PT correctly solved the solubility problem in rates of 91 and 89 %, respectively. The findings for item 4 showed that the participants had skills to solve a solubility problem correctly in high rate. These results showed that some of the participants, who may be successful at solving mathematical problems, but they do not understand the chemical concepts (*e.g.* solubility, saturation and concentration) behind their memorized algorithmic solutions. As can be seen from Table-1, the PT's achievement rates for items 1-4 were lower than the EST's rates in both pre-test and post-test responses. This is not surprising because they took Chemistry course at grade 9 and General Chemistry course (only 2 h weekly in second semester) at the first-year of college. They are not science majors, but they are as much successful as EST for item 4 in problem solving skills.

Helping students develop problem-solving skills is a frequently cited goal of science educators. The National Science Teachers Association (NSTA), in its 1980 position statement, advocated that science teachers help students learn and think logically, specifying that '...high school laboratory and field activities should emphasize not only the acquisition of knowledge, but also problem solving and decision making'[25]. An important goal of chemistry education is to help students develop an understanding of concepts and use them when solving a problem in a new situation. Traditionally, general chemistry content knowledge is measured with mathematically based questions. Most chemistry problems solving in chemistry tends to be algorithmic in nature, while problems in life tend to be very open ended[26]. Many studies have focused on the use of algorithms, in which the rules that can be followed more or less automatically by reasonably intelligent systems[27]. Discussing conceptual learning in chemistry it was stated that most educators see solving chemistry problems to be the major behavioural objective for freshman chemistry. Textbooks appear to focus on quantitative problems and this may be what establishes the supreme importance of numerical problems in student minds. The students can solve problems about gases without knowing anything much about the nature of the gas and they can solve limiting reagent problems without understanding the nature of chemical change[28]. It was showed that 85 % of the students could successfully answer the algorithmic gas law question, but only 49 % could correctly answer its conceptual counterpart[29]. Little connection was found between solving an algorithmically based problem and understanding the chemical concept behind that problem. Chemistry teachers need to keep in mind that solving problems is not equivalent to teaching pupils about the nature of matter[28]. Together with a previous study[28], it was concluded that, across all levels of student, conceptual problem solving ability lagged far behind algorithmic problem solving ability. Many students can answer an algorithmic question about a chemical idea but cannot answer a conceptual question dealing with the same idea[29]. Upon exit from secondary education grade 12 learners are poorly prepared for first-year chemistry in terms of conceptual understanding[16].

The results of this study revealed that the first-year prospective elementary science teachers held 4 misconceptions about types of solution, 2 misconceptions about solution concentration increases in saturated solution with solute addition and 2 misconceptions about solution concentration increases in saturated solution with water evaporation. The results also showed that prospective teachers solved solubility problem successfully using memorized algorithms with the lack of understanding of solubility limit and saturation concepts. The following educational implications may be presented to chemistry teachers and educators. Firstly, precipitation-dissolution equilibrium is an example of heterogeneous physical equilibrium in solid-liquid systems. Dynamic characteristics of equilibrium for heterogeneous solid-liquid systems should be studied in class with miscellaneous appropriate exercises like homogeneous chemical equilibrium reactions. Teachers therefore need to emphasize the concept of the solubility whenever the opportunity presents itself in other chemistry topics. Secondly, it should be called the students' attention to conceptual definition of molar concentration *i.e.*, the molar concentration = (the moles of dissolved solute)/(volume of solution in litre). This conceptual formula should be suggested to students to learn and use instead of symbolized formula. The amount of solute added into the solution will might be different from the amount of solute that dissolved in solution which is placed in molar concentration formula. In addition, the volume taken in the molar concentration formula is not identical to the total volume of liquid and solid phases at saturated solutions. It is clear that the students bring a prior misconception with them into the general chemistry class and most of them carry this misconception to the other courses in the next years.

APPENDIX: Questionnaire is used for prospective teachers' perceptions of solubility and types of solutions (correct answers are in bold).

Question-1. There are different concentrations of sugar solutions in glasses **A**, **B** and **C** at 25 °C. One of the solutions is saturated, another is unsaturated and the other is supersaturated. (The dots represent the dissolved sugar molecules and the increasing density of the dots in the diagrams illustrates increasing concentrations. The undissolved sugar is shown as a darkened area at the bottom of the glass **B**)



In the questions below, *please circle the correct answer* and then give an explanation.

1.1. Solution **A** is saturated, unsaturated or **supersaturated**. PLEASE EXPLAIN!
1.2. Solution **B** is **saturated**, unsaturated or supersaturated. PLEASE EXPLAIN!
1.3. Solution **C** is saturated, **unsaturated** or supersaturated. PLEASE EXPLAIN!

Question-2. Salt is added to water and the mixture is stirred until no more salt dissolves. The salt that does not dissolve is allowed to settle out. What happens to the concentration of salt in solution if small amount of salt is slowly added to the glass while stirring the solution? In the following question, *please circle the correct answer* and then give an explanation.

The concentration of the salt, which has been dissolved into the solution, will increase, **stay the same** or decrease. PLEASE EXPLAIN!

Question-3. Sugar is added to water and the mixture is stirred until no more sugar dissolves. The sugar that does not dissolve is allowed to settle out. What happens to the concentration of sugar in solution if water evaporates until the volume of solution is half the original volume? In the following question, *please circle the correct answer* and then give an explanation. (Assume the temperature remains constant.)

The concentration of the sugar, which has been dissolved into the solution, will increase, stay the same, or decrease. PLEASE EXPLAIN!

Question-4. 50 g of table salt (sodium chloride) are put into a beaker containing 100 cm^3 of water at 50 ºC. After stirring, it is observed that some of the salt dissolves, leaving a quantity of undissolved salt at the bottom of the beaker. When this salt at the bottom of the beaker is separated (by filtering), dried and weighed, it is found that the weight of this undissolved salt is 13 g. This means that solubility of salt in water at 50 ºC is

a) 100 g/100 cm^3 b) 50 g/100 cm^3 c) 37 g/100 cm^3 d) 13 g/100 cm^3

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