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First Year Prospective Teachers' Perceptions of Molecular Polarity and Properties of Solutions

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The purpose of this study is to explore the perceptions of first year students regarding particular concepts of solution chemistry and to determine the difficulties that students may have in understanding these concepts. The test was administered to 122 first year undergraduates enrolled in the Elementary Science Teacher Education Department of a State University, Turkey, at the end of spring semester during 2007 educational year. A diagnostic survey composed of 4 open-ended items was prepared for this study. Items-1 and 2 required students to define the polar/non-polar molecule and the solubility. Item-3 examines the students' reasons to explain why freezing/boiling point of a salt solution is lower/higher respectively than pure water. Item-4 was used to find out whether students predict which solvent (water, ethanol and acetone) be used to prepare solutions of the solutes (sucrose, sodium sulphate, sodium chloride and iodine) . To analyze the data, qualitative method was used and the subjects' responses were categorized separately in five understanding levels. The findings of this study showed that students have some difficulties to understand polarity of molecules, solubility and explanation of freezing or boiling point of solution.

Key Words: Molecular polarity, Solubility, Solvent, Freezing and boiling points of solution.

INTRODUCTION

Previous researches have indicated that students held some alternative conceptions and have little connection to their conceptual understanding in solution chemistry[1-3]. Understandings of underlying concepts are prerequisites for many science concepts taught in the later stages of schooling. Polarity is one of the central concepts in the undergraduate chemistry curriculum. Polarity of a molecule has profound effects on the physical properties of the substance. Molecular polarity determines the strength and types of intermolecular forces of attraction at work in a sample of the substance. The magnitude of these forces is directly proportional to boiling and melting points. In addition, molecular polarity affects solubility in that polar molecules are best solvated by polar solvent molecules and non-polar molecules are best solvated by non-polar solvent molecules.

More than 75 % of the students identified polar molecules successfully, yet only 26.4 % of the students applied the correct reasoning[4]. Three alternative conceptions were identified[4] in polarity: 'Polar molecules form when the atoms in the molecule have great difference of electronegativity'; 'Polar molecules form when there are non-bonding electrons in the molecule' or 'Polar molecules form when high electronegative atoms are present'. Analyses of alternative conceptions revealed that students neglected the symmetrization of molecular geometry when determining polarity of molecules and attributed polarity of molecules to either presence of atoms with high electronegativity, large difference of electronegativity between atoms, or the presence of non-bonded electron pairs. Students considered only one of the following factors when determining the shape of a molecule: bond polarity, electronegativity of each atom, repulsion between non-bonding pairs, or repulsion between the atoms in the molecule[4].

34 % of the participants (grade-12 chemistry students) thought that non-polar molecules form when the atoms in the molecule have similar electronegativities[5]. Grades-11 and 12 students have an alternative conception: 'If the electronegativity of atoms is similar, the molecule is non-polar, if it is different it will be polar[6].' One-fifth of the grade-12 and first year undergraduate students believe that the polarity of the molecule depends only on the electronegativity difference between atoms forming each bond in the molecule[7]. An essential prerequisite for the correct determination of polarity of a molecule is the knowledge of its geometry. Researchers explained the reason for the low percentage obtained by grade-12 students in the case of $BeCl_2$ by the lack of understanding of the valence shell of Be[7]. The difficulty found by the students in the case of polarity of SH_2 and SCl_2 molecules prediction is interpreted by Lewis planar structure. 15 % of students showed reasoning for polarity of SH_2 and SCl_2 molecules like that 'due to the fact that geometry is linear and so symmetrical, then it has no net dipole moment'.

Dissolution and solubility are the fundamental concepts of chemistry taught from the secondary schools. Students were queried about how solution concentration changed when water evaporated from a beaker of water with salt sitting at the bottom[8]. Only 67 % (post-test) of students specified that the solution concentration stay the same as the water evaporates. There was an alternative conception that 'the meaning of supersaturating is that there is excess solid present as a separate phase in the beaker[8].' The studies that are most pertinent to understanding of solution concepts related to solubility, including the meaning of the terms unsaturated, saturated and supersaturated. In a study[9] the chemistry class students' understanding of these terms were examined. The researchers used three schematic diagrams of beakers with water from which students had to match the appropriate word with the diagram. A significant majority, 78 %, incorrectly chose the supersaturated solution diagram. The students explained the primary reason of their response that there was excess solute (undissolved sugar) sitting in the beaker. In a new study[3] similar diagrams of the two earlier researchers were used. When three tablespoons of salt are mixed into a glass of water and stirred, about a teaspoon of water-saturated salt remains at the bottom. The students were asked that if a small percentage of salt is slowly added to the glass while stirring the solution, will the concentration of the salt in the solution: a) increase; b) stay the same; or c) decrease. In their responds, 61 % of the students selected the wrong answer, which was that the concentration increases. The reason of the students response was probably, an alternative conception about the definition of the term supersaturating.

The third year undergraduate chemistry class students' alternative conceptions about some selected concepts in phase equilibrium were investigated[1,10]. Two alternative conceptions were identified related to colligative properties: Freezing point is constant for each substance; its value does not depend on pressure changes, which is 24 % of students' answers and NaCl molecules dissolved in water weaken the attraction forces between water molecules and more water molecules evaporate, as a result vapour pressure increases, which is 19 % of students' answers[10]. In the earlier study[9], which investigated the relationship between the solution and pure solvent in terms of lowering of vapour pressure, an alternative conception was found out *i.e.*, attractive forces between solute and solvent molecules in a solution engendered vapour pressure lowering. An alternative conception was reported in solution chemistry that freezing and boiling points of salt dissolved in water are not different from those of water because salt dissolved in water is liquid like water, at grades-9 and 10, 5 % of the student responded[11].'

The study aims to examine first year teacher education students' understanding of solution chemistry and in particular what alternative conceptions they hold about solution chemistry. The findings of this research are expected to provide useful references for chemistry teachers, educators and curriculum designers.

EXPERIMENTAL

In Turkey, the first elementary chemistry teaching begins with a brief introduction of physical and chemical changes (as a part of 'science and technology' instruction) in grade 4. Then, introductory chemistry concepts such as atomic structure and chemical reactions are taught in grade 7. More formal chemistry lessons start with secondary education in grade 9. The same curricula for all primary and secondary schools have been developed and implemented by the National Ministry of Education. An entrance examination is required for students who wish to progress to higher education after the achievement of their secondary education. Elementary Education Department trains elementary science teachers. The subjects took General Chemistry I and II and General Chemistry Laboratory I and II courses in the first year and at end of the second semester they conducted the research. The instruction was based on lecturing, discussions and laboratory experiments.

A diagnostic paper and pencil survey composed of 4 open-ended items was prepared for this study. The test items considered in this study are shown in Table-1. Items included in the instrument were composed to determine students' understandings of polar/non-polar molecules, solubility, certain colligative properties (freezing point depression, vapour pressure depression), suitable solvent selection for ionic, polar or non-polar compounds and to reveal their alternative conceptions. Two chemistry educators checked the content validity of test items and agreed that the items were valid and appropriate to measure the students understanding of the given concepts. A group of 46 sophomores were involved in a pilot study. The aim was to have a sense of students' responses to the survey items. The pilot study revealed that the test items were clear and understandable. The subjects involved in this study were 122 first year undergraduate elementary science students registered at Faculty of Education of a State University at Turkey. The test was administered after the topic had been instructed, at the end of spring semester during 2007 educational year.

TABLE-1
FOUR TEST ITEMS THAT WERE USED IN THE STUDY

Student Survey on Polarity of Molecules, Solubility and Properties of Solutions
1. Define polar and non-polar molecules. …………………………………………………………………………………….. ……………………………………………………………………………………..
2. Define the solubility of a solute. …………………………………………………………………………………….. ……………………………………………………………………………………..
3. Why does the boiling point of solution increase and the freezing point of solution decrease (*e.g.* aqueous sodium chloride solution)? Explain your answer. …………………………………………………………………………………….. ……………………………………………………………………………………..
4. You want to prepare the solutions of sucrose, sodium sulphate, sodium chloride and iodine solid substances. There are pure water, ethyl alcohol and acetone liquids in the chemistry laboratory. Which solvent is suitable for preparation of each solution of solute? Explain your answer. …………………………………………………………………………………….. ……………………………………………………………………………………..

Data analysis: The direct open-ended items in the test were analyzed[12] by allocating students' responses into one of the following categories: Sound Understanding (SU), Partial Understanding (PU), Partial Understanding with Alternative Conception (PUAC), Alternative Conception (AC), No Understanding (NU). A statement was categorized as alternative conception in the event of repetition by at least 5 % of the subjects. To analyze the data, the author categorized the given responses separately by means of the aforementioned criteria. Another chemistry educator also executed coding process and 88 % of agreement was found between the researcher and other educator.

RESULTS AND DISCUSSION

The data are categorized with regard to conception levels relate to each item. Only students' alternative conceptions for items are presented in Table-2.

TABLE-2
PERCENTAGES OF THE STUDENTS' ALTERNATIVE CONCEPTIONS EXCERPTED FROM THEIR RESPONSE

Items	Alternative conceptions	%
Item-1	1. Polar molecules are consisted of different non-metal atoms; non-polar molecules are consisted of the same non-metal atoms.	16
	2. Polar molecules are consisted of different elements; non-polar molecules are consisted of the same elements.	9
	3. Polar molecules form when the atoms in the molecule have great difference of electronegativity[4-7,13].	8
	4. Non-polar molecules are symmetrical, polar molecules are asymmetrical.	5
Item-2	1. The solubility is a homogeneous mixture of a solute and a solvent.	21
	2. The solubility is the separation of ions or molecules by the action of solvent.	7
Item-3	1. Attraction forces between salt ions and water molecules in the solution engendered boiling point elevation[1,9].	30
	2. Salt ions increase waters' impurity which affect both the boiling and freezing points[11].	34
	3. Increasing of the concentration of solution by salt engendered the boiling point elevation.	17
Item-4	1. Acetone is suitable solvent for sucrose.	9
	2. Ethanol is suitable solvent for sodium sulphate.	49
	3. Ethanol is suitable solvent for sodium chloride.	28
	4. Water is suitable solvent for iodine.	8

Item-1: Perception of polar and non-polar molecules

Item-1 was related to the polar and non-polar molecule concepts. In the first item, the students were asked the definition of polar and non-polar molecules. According to the experts a sound understanding includes, "A polar molecule has a net dipole which is achieved by the molecule being made up of polar bonds arranged unsymmetrical so that the dipoles do not cancel out, A non-polar molecule has no net dipole which is achieved by the molecule having only non-polar bonds or polar bonds arranged symmetrically so that the dipoles cancel out."

In their responses for item-1, 38 % of students showed sound understanding, 21 % of them wrote "Polar molecules have net dipoles; non-polar molecules have no dipoles," 17 % of them wrote "Polar molecules have partially charged electrical poles; non-polar molecules have no partially charged electrical poles." Sixteen percent of students had partial understanding with alternative conceptions *i.e.*, polar molecules have dipole-dipole interactions among molecules; non-polar molecules have London forces among molecules, 11 % of the students responded.' and 'Polar solutes are dissolved in polar solvents; non-polar solutes are dissolved in non-polar solvents, 5 % of the students responded.'

As can be seen in Table-2 for item-1, the students held some alternative conceptions about polarity of molecule: 'polar molecules consist of different non-metal atoms; non-polar molecules are consisted of the same non-metals, 16 % of the students responded'. 'Polar molecules are consisted of different elements; non-polar molecules are consisted of the same elements, 9 % of the students responded'. 'Polar molecules form when the atoms in the molecule have great differences of electronegativity, it will the polar, 8 % of the students responded'. 'Non-polar molecules are symmetrical, polar molecules are asymmetrical, 5 % of the students responded'. Only the electronegativity difference between the central atom and the one around it was taken into account to predict the molecular polarity. They attempted to define covalent bonds which forms among non-metal atoms.

Periodic variation, chemical bonding, electronegativity, dipole moment and molecular geometry are essential for understanding molecular polarity[4]. The university chemistry students explained the dependence of the polarity of molecules to molecular geometry without paying attention to attached atoms; and grade-12 students identified non-polar molecules as those formed only between atoms of similar electronegativities without considering the molecule shape[7]. The students may have appeared to know about the concept of polarity, but they did not associate it at all with electronegativity[14].

The students appeared to have difficulty differentiating among matter, element, atom and molecule. In the descriptions of polar or non-polar molecules, two of students used 'elements' term for meaning 'non-metals,' two of them used 'matter' and nine of them 'molecule' term for meaning 'atom' in their response. Polar/non-polar covalent bond definitions were given by 25 % of students without touching the effect of electronegativities of atoms or molecular geometry. They had given correct examples for non-polar molecules: once Cl_2, Br_2, N_2; twice CO_2, BF_3, ethane, ether; three times benzene; six times F_2, acetone; nine times O_2; ten times H_2; twelve times CCl_4; fifteen times CH_4; twenty two times I_2 (incorrect examples: once H_2O, NH_3, O_3, $FeCl_2$, diamond, graphite) and correct examples for polar molecules: once CO, NO, HF, HBr; twice SO_2; three times NH_3, glucose; six times HCl; eight times ethanol; forty seven times H_2O (incorrect examples: once CO_2, KCl, naphthalene; five times Na_2SO_4; twenty three times NaCl). These show the students' lack of knowledge about classification of matter, chemical bonds and molecular polarity.

Item-2: Understanding of solubility concept

The students were asked what is the definition of solubility in item-2. According to the experts a sound understanding includes, "The solubility of a solute is the maximum quantity of solute that can dissolve in 100 g of water at a specified temperature. Solubility (S) is sometimes reported as the concentration in molarity (M) at the point of saturation at 25 ºC." It may be said for example that the solubility is often (although not always) measured as the mass of salt which would saturate 100 g of water at a particular temperature. A solution is saturated if it won't dissolve any more of the salt at that particular temperature - in the presence of crystals of the salt.

According to results, only 7 % of students showed sound understanding. The solubility was defined by 25 % of students without stating 'at a specified temperature by 25 % of students without the term 'maximum' and by 13 % of students without stating both of these terms in partial understanding responses. 50 % of students had partial understanding of the item-2. Nearly half of students used the '100 g water' criterion to describe the solubility. 21 % of students explained the 'solubility' term by 'dissolving salt in water' and 7 % of students by 'dissociation of salt in water' in specific alternative conceptions (Table-2). It could be resulted that the students did not fully understand the solubility concept, because they omitted 'the maximum quantity of solute', 'the amount of solvent' and 'the effect of temperature on solubility of a solute' in their definitions. It is noteworthy that anyone of the students did not write a clue about the relationship between 'solubility' and 'saturated solution' concepts.

The supersaturated solution diagram was selected in rates of 70, 67 and 78 % of students incorrectly in similar studies[3,8,9], respectively. These studies showed that students did not understand the concept of solubility limit. Thus, students held alternative conceptions that included the types of solutions, which are alternative conceptions of the definition of saturation and the associated concept of solubility limit[3].

Item-3: The causes of decrease in the freezing point and increase in boiling point of solutions

The item-3 was related to the causes of decrease in the freezing point and increase in boiling point of solutions. The students were asked to make comparisons between freezing and boiling points of both salt solution and pure water. According to experts, "The vapour pressure of a liquid increases with increasing temperature and the liquid boils when its vapour pressure is equal to the external pressure acting on its surface. Because non-volatile solutes lower the vapour pressure of the solution (Raoult's Law), a higher temperature is required to cause the solution to boil and a lower temperature is required to cause the solution to freeze." In any real solution, *e.g.* of salt in water, there are strong attractions between the water molecules and the ions. That would tend to slow down the loss of water molecules from the surface.

Only one of the students showed sound understanding for the item-3 by writing "salt ions decrease vapour pressure of solution." According to the results, the students' alternative conceptions were: 34 % of the students wrote that the freezing and boiling points of solution differ from those of pure water because salt delays both freezing and boiling, 30 % of the students explained the given event by writing about stronger intermolecular forces in the solution and 17 % of them wrote salt increases the concentration of solution and affect both the boiling and freezing point (Table-2).

The students did not distinguish between solution and pure solvent in terms of lowering of vapour pressure and students held alternative conception: 'Attractive forces between solute and solvent molecules in a solution engendered vapour pressure lowering[9].' The sources of the students' alternative conceptions about the boiling point elevation and the freezing point depression, which are related colligative properties, were based on 'the intermolecular interactions instead of the particles number in the solution[1].' One can show that for sufficiently dilute solutions, the magnitude of the vapour pressure decrease depends only upon the ratio of solute to solvent molecules and not at all on the properties of the solute particles. It's noteworthy that any of the students did not mention that the boiling point elevation and the freezing point depression are colligative properties.

Some of the students' explanations such as, five students wrote 'The increasing of the number of particles in the solution by mixing salt resulted in more stable configuration which causes the boiling point elevation and the freezing point depression, four students wrote 'the freezing point of salt must be considered and twenty students attempted to respond item-3 using the formula $\Delta T_f = k_f . m$. The value of decreasing the freezing point of solution is proportional to the molality of solution. Seven students stated that ordinary salt (sodium chloride, NaCl) poured over icy roads lowers the freezing point of ice below the temperature of the surrounding air in the winter.

Item-4: Convenient solvent choices

The item-4 was related to preparation of solutions of sucrose, sodium sulphate and sodium chloride and iodine with suitable solvent (water, ethanol or acetone). As a general evaluation of the data in regard to the students' responses for item-4, according to the experts a sound understanding includes, water is suitable solvent for sucrose, sodium sulphate and sodium chloride; acetone or ethanol for iodine. Sodium chloride and sucrose are slightly soluble in ethanol (585 mg NaCl/100 mL ethanol). According to results of item-4, the students showed sound understanding as about water suitable solvent for sucrose and sodium chloride; and acetone for iodine in rate of 58, 46, 72 and 59 % for the solution of the solutes, respectively, for students. More than half of students identified correct solvent for solutes except for sodium sulphate. Partial understanding with alternative conceptions that about suitable solvent (ethanol) for sucrose is in rate of 29 % among the students. Alternative conceptions are suitable solvent for the solution of the solutes in rate of 9, 49, 28 and 8 %, respectively, among the students (Table-2).

In general, ions (which are charged) are attracted to the molecules of polar solvents, while non-polar molecules are attracted by the non-polar solvent molecules. Ionic compounds dissociate into ions when they dissolve in water, but covalent compounds cannot. The most of the students used the "likes dissolve likes" as a guiding rule of thumb in their responses. This generalization describes the fact that polar solvents will dissolve polar solutes and non-polar solvents will dissolve non-polar solutes. Water and ethanol solve the sucrose molecules by hydrogen bonding and dipole-dipole interactions and the ionic compounds by ion-dipole interactions. Acetone and ethanol dissolve iodine, which is made non-polar molecule by London forces.

The participants considered acetone and ethanol are suitable solvents for sucrose, sodium sulphate and sodium chloride; and water is suitable solvent for iodine. The half of the students indicated ethanol as a suitable solvent for sodium sulphate and nearly one third of the students indicated ethanol as a suitable solvent for sodium chloride and sucrose. Acetone and ethanol are selected as a suitable solvent for iodine. These results showed that ionic compounds were not identified correctly enough by some of the students.

The students categorized the given solvents as polar molecules (*e.g.* water and ethanol) and non-polar molecules (*e.g.* acetone). Twenty-four of students described sucrose, sodium sulphate and sodium chloride as polar molecules and iodine as non-polar molecule. Five of the students stated sodium sulphate and sodium chloride are ionic compounds, but three of the students described sodium sulphate and sodium chloride non-polar compounds. Some of the students indicated the other possibilities to prepare a solution. Some of them wrote 'sucrose is a polar molecule, but they did not mention the covalent bonds in it. A noteworthy result of this study is any of the students did not mention hydrogen-bonding come out among the molecules of water with ethanol or sucrose molecules. In that case the students' difficulties about polarity may have been the cause of their alternative conceptions about dissolution.

In this study, first year undergraduate students' understandings revealed that students have conceptual difficulties in explaining the phenomena that require good understanding of polarity, solubility, suitable solvent and two colligative properties (freezing point depression, vapour pressure depression). Thirteen alternative conceptions were identified through analysis of the students' answers (Table-2). That means traditional general chemistry lessons did not make difference in the students' expressions at a sufficient level.

The students' understanding and their alternative conceptions related to solutions in chemistry were reviewed for more than two decades[2]. Some researchers have gone beyond knowing prior conceptions and determining students' difficulties to reporting students' post-instructional conceptions as a result of having tested their explanatory models through specific strategies. To design strategies to replace students' conceptions with those of scientists ideas, the researchers have taken three general steps: firstly, students' prior instructional conceptions are identified. Secondly, intervention for conceptual change is designed and implemented. Thirdly, students' post instructional conceptions are assessed to observe if there is any conceptual change. To incorporate students' conceptions, conceptual change studies have had strategies such as worksheet, analogy, collaboratively working with a teacher, hypermedia and group exploration. The results of conceptual change studies generally have had a positive impact enabling students to consider their ideas and develop plausible models of solution chemistry.

The instruction, which included team-based active learning activities and discussion of the concepts given on the pre-test, on phase diagrams was effective in addressing students alternative conceptions on the concept of solubility and the meanings of unsaturated, saturated and super-saturated solutions[3]. It is clear that the students hold a prior alternative conception about the general chemistry class and did not learn or understand scientific definitions during instruction. Most instructors have assumed that their students have a solid understanding of the nature of solutions and the meaning of the terms polar/non-polar molecule or solubility, but this is not true. In some sense this could be considered as a some instructors holding alternative conception about students' prior knowledge.

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