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HSC CHEMISTRY STUDENTS' UNDERSTANDING OF THE STRUCTURE AND PROPERTIES OF MOLECULAR AND IONIC COMPOUNDS

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INTRODUCTION

This paper reports the results of an interview study which followed an earlier survey of 266 Year 12 chemistry students in ten Sydney and near-Sydney High schools to determine which concepts in the core section of the HSC Chemistry syllabus they perceived as most difficult (Butts and Smith, 1987). That survey indicated that concepts related to structure, dissolution processes and precipitation were considered to be difficult. The related items, as they appeared in the survey, and their rank order of perceived difficulty, are shown in Table 1.

ITEM	PERCEIVED DIFFICULTY	
	RANK ORDER*	PERCENTAGE**
The connection between solubilty and the formation of a precipitate.	8	30
The difference in properties between ionic compounds and molecular compounds	12	29
The difference between electrolytes and non-electrolytes (in terms of the presence of ions and molecules).	13	29

* Most difficult ranked as 1.
** The percentage of students who rated this item as 'very difficult' or 'extremely difficult'

Table 1.

While other concepts, connections between concepts and skills were rated as more difficult by the sample, these three items were seen as of particular interest because of the interrelation of the concepts involved and the fundamental nature of these concepts for the understanding of chemistry. It was decided therefore, to follow up the survey with individual interviews of a sample of students from the schools surveyed. The results of these interviews would be used to construct paper and pencil surveys to diagnose student difficulties in understanding some of the relationships between structure and properties in chemistry.

PROCEDURE

The students for interview were selected according to their responses to the three survey items above. Those who rated these items as "very difficult" or "extremely difficult" were identified from the survey data and their schools were asked to arrange for them to be interviewed. The number of students selected to be interviewed from each of the ten schools varied depending on the size of the schools' Year 12 Chemistry candidature; the largest school provided 6 interviewees, the smaller schools only two. In total 28 interviews were conducted by the authors, who visited the schools for this purpose. Interviews were recorded on audiotape for later examination. In only four cases were the selected pupils not available for interview; in these cases substitutes who had been nominated as such by the researchers, were interviewed.

The interviews followed an "interview about events" protocol (Osborne, 1980), and were designed to elicit students' understandings of:

a) the structure of solids, especially the nature and relative magnitudes of interparticle forces;

b) the nature of the dissolution process and the nature of the resultant particles in aqueous solution;

c) how an electrolytic solution conducts an electric current;

d) why a precipitate forms in a reaction between certain ions in solution.

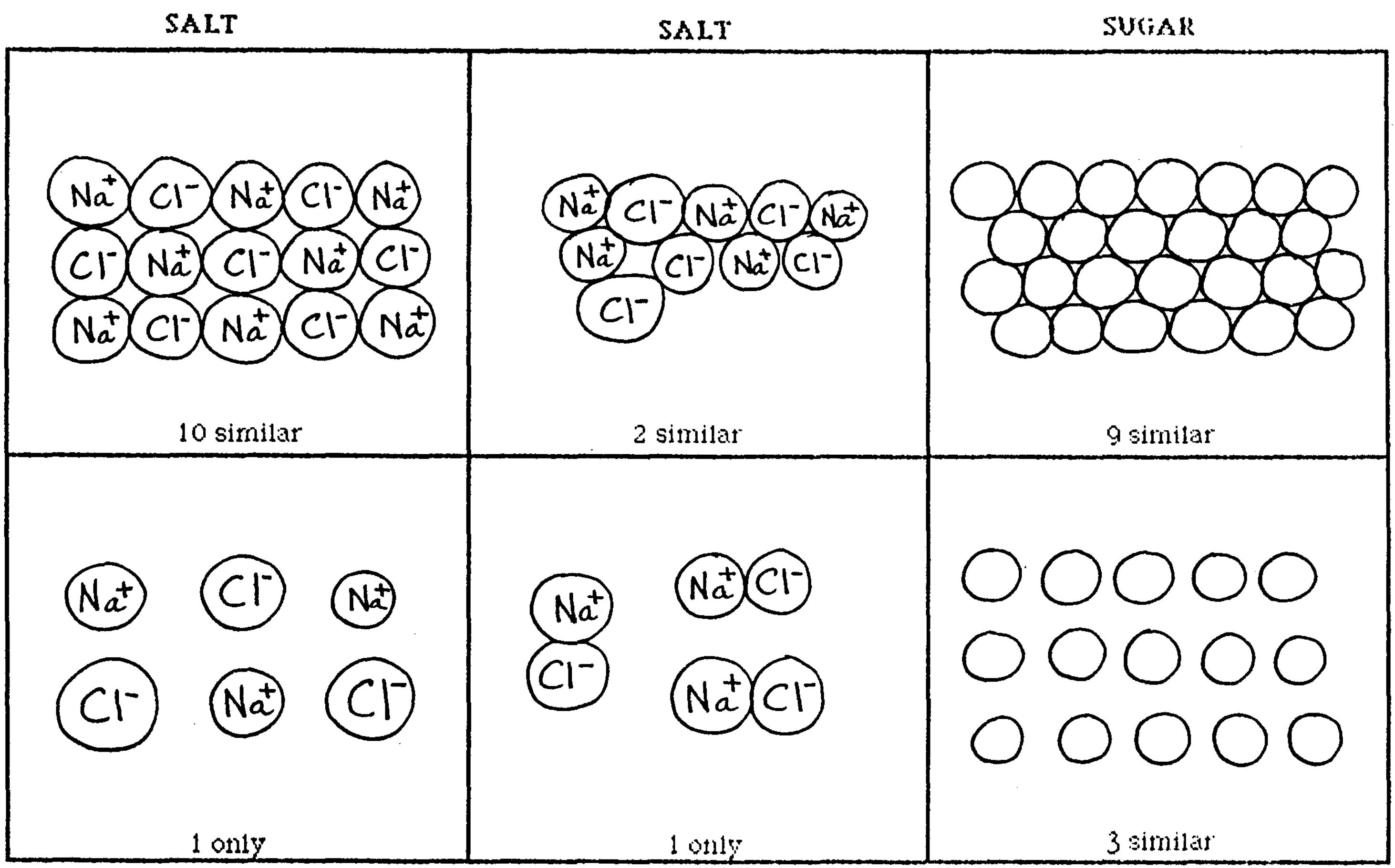
An interview protocol was developed and trialled with two Year 12 students at a high school not included in the survey sample. It was slightly modified as a result of this trial. The final interview schedule began with the student being asked to dissolve salt (sodium chloride) and sugar (sucrose) in water in two different beakers. (Throughout the interview salt and sugar were used as the exemplars of ionic and molecular compounds.) This stimulus was used to promote discussion of the dissolution process. The conductivity of the two solutions was then tested qualitatively using stainless steel electrodes in series with a battery and light globe. The observations were used to promote discussion of the process of electrolytic conduction and the nature of the particles in solution. Students were asked to draw a two dimensional representation of the way they pictured the particles to be arranged in solid sodium chloride and solid sugar and discussion of these diagrams led to an exploration of the student's understanding of interparticle bonds. Two ball-and-stick type models commonly used in NSW high schools were then presented to the student who was asked to interpret each one. These were a model of the ionic lattice structure of sodium chloride and of the infinite covalent network structure of carbon atoms in diamond. There is no model of a sucrose (or glucose) molecule nor a model representing their crystal structure, commonly available in NSW schools, so students were asked to interpret the diamond model again, this time assuming that each black ball represented a sucrose molecule. The relationship between melting point and interparticle bonds was raised to further explore the student's understanding of interparticle forces. Finally the interviewees were asked to predict whether or not a solution of silver nitrate, placed in front of them in a beaker, would conduct an electric current. The solution's conductivity was tested as before and then a solution of sodium chloride was added and an explanation sought for the formation of the resultant silver chloride precipitate.

RESULTS

Because the interview protocol was complex and the interviews had to be carried out by the two researchers each working alone, it was not possible to ensure that all questions and all activities planned for each interview were always carried out. For this reason statistical treatment of the data would be inappropriate. Nevertheless, detailed analysis of 26 of the 28 interviews (one was lost because of technical failure and another aborted because of within school constraints) did provide insights into students' understanding of the concepts involved and pointed to some possible modification of teaching practices and learning resources which might help to clarify some of the misconceptions and confusions revealed. The results will be discussed under the four aspects listed above.

A. THE STRUCTURE OF SOLIDS

Most students associated sodium chloride with ionic bonding and often volunteered information about the nature of the electron transfer process from sodium atom to chlorine atom which results in the formation of this bond. However, this does not imply that they had any clear understanding of the three dimensional nature of the ionic bonding in solid sodium chloride. Molecules of NaCl were often referred to (10 students),



STUDENTS' DIAGRAMMATIC REPRESENTATIONS OF THE STRUCTURE OF SOLID SALT AND SUGAR

FIGURE 1

sometimes these being said to be held together in the solid by covalent bonds (2 students). Others (2) considered that there was a covalent bond holding sodium and chloride atoms together to form a sodium chloride molecule but that ionic bonds between these molecules produced the crystal structure. Only four students demonstrated a clear and accurate understanding of the notion of a three dimensional lattice of sodium and chloride ions, although more were able to draw two dimensional diagrams which indicated that they did have some understanding of the crystal structure of salt. Some of these representations are shown in Figure 1.

Interpretation of the three dimensional ball-and-stick model of the sodium chloride structure was confused, many interpreting the six wires attached to each ball ("ion") as each representing a bond of some sort ("there is one ionic bond and five physical bonds" and "I would have expected seven wires not six, because chlorine has seven electrons in its outer shell"). Very few (2) were able to explicitly state that the wires did not represent bonds but merely held the wooden balls in place. There were some who believed that sodium ions and chloride ions were released only when the solid dissolved in water ("solid sodium chloride doesn't conduct because it is in separate molecules") and two who believed that an electric current was needed for this dissociation process to occur.

Some students (6) were able to give a clear account of the nature of the bonding between the atoms in a sugar molecule and the nature of the bonding between its molecules in the solid. Terms such as intermolecular and intramolecular forces were used appropriately, as were van der Waal's forces, explained as the consequence of polarity of molecules. But such depth of understanding was uncommon. It was clear that some students had never considered the structure of solid sugar or any other solid molecular compound. Some (3) even considered one sugar grain to be a sugar molecule, relating its structure to that of diamond. It was interesting that the ball-and-stick model of diamond itself was correctly interpreted by almost all students in the sample, even to the extent that it was realized that the network extended in three dimensions throughout a diamond crystal. Some students (2) believed that the particles in sugar were less regularly arranged than those in salt. Many students found the drawing of a two dimensional representation of the arrangement of the particles in solid sucrose an unusual task, although they often accomplished it appropriately. Some of the two dimensional representations of the structure of solid sucrose are also shown in Figure 1.

Nineteen of the 26 students recognized that the bonding in solid sodium chloride was different from that in sucrose, and half this number used the relative bond strengths to explain their statement that salt has a higher melting point than sugar. Only three predicted that salt would have a lower melting point, explaining this in terms of weaker bonds. The link between melting point and interparticle bonds is well understood.

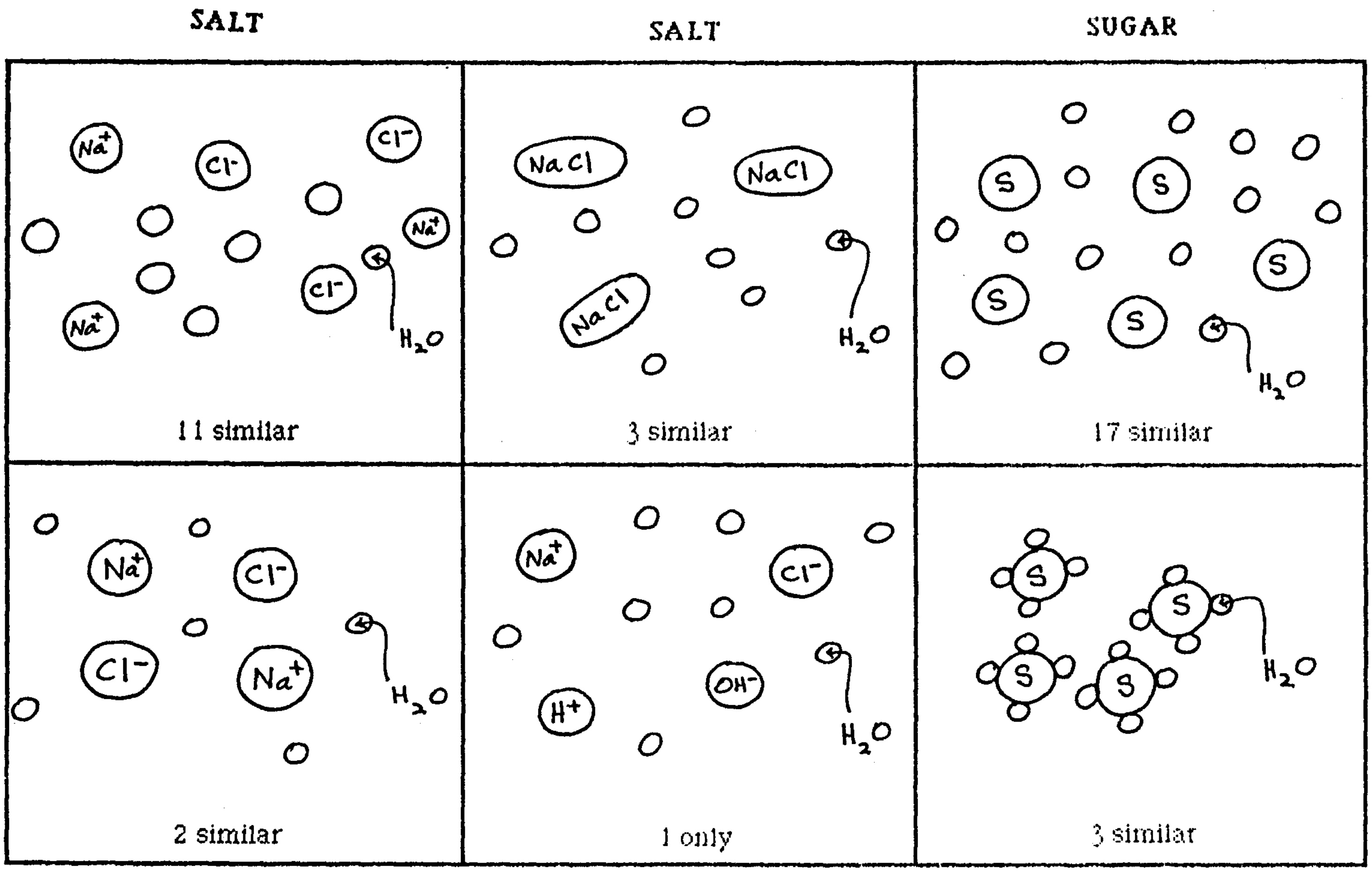
Implications

Students interpret the diamond model correctly but are confused by the ball-and-stick model of sodium chloride commonly used in schools. A space-filling model of salt, with the connecting wires eliminated, might be more appropriate. Furthermore, for consistency, a similar model showing the arrangement of covalent molecules in a molecular solid is urgently required. Teachers could make more use of two dimensional representations of the structure of ionic and molecular solids than they currently do. The old fashioned flannel board has a useful role to play in this regard. It should be realized that students will quite happily refer to ionic bonding in sodium chloride and still think about NaCl molecules, sometimes even invoking covalent bonds to account for the forces between them in the solid. Active comparing and contrasting of the bonding concepts involved seems to be necessary at all times. The following interview extract indicates that even Year 12 students are quite willing to rote learn.

Student: "The sodium and chloride molecules are ionically bonded"
Interviewer: "What does that mean."
Student: (Laughs) "I don't know that!... just know the term".

B. THE NATURE OF THE DISSOLUTION PROCESS

All students except one were able to describe the structure of the water molecule adequately. The one exception claimed that it consisted of H+ and OH- ions. However very few related its polar structure to the process of dissolution, especially in the case of sugar, only three students commenting on the polar nature of sucrose molecules. Four students mentioned the polarity of the water molecule in explaining the dissolving of sodium chloride. All students were aware that the particles in solution would be dispersed thoughout the solution, although it was sometimes stated that there would be some "residual" structure because "the sodium and chloride ions are still there and still attract one another". Two students believed that salt reacted with water to form sodium, chloride, hydrogen and hydroxyl ions. Most students were aware that sugar molecules would be larger than water molecules and that there would be fewer of them in solution. The number of water molecules was usually reported as "millions" to "thousands of millions". A few students (3) reported a definite bond forming between sucrose and water molecules in solution. Almost all students realized that the particles would be ions in the case of salt solution but several were reluctant to use the term "molecule" in referring to the particles in a sugar solution. Figure 2 shows some student drawn two dimensional representations of salt and sugar solutions. It is notable that in all cases the particles in solution are shown to be not touching one another. These diagrams, and other aspects of



STUDENTS' DIAGRAMMATIC REPRESENTATIONS OF THE STRUCTURE OF SALT AND SUGAR SOLUTIONS

FIGURE 2

the interviews, indicated that students generally had a better conception of the structure of a solid than they did of the corresponding aqueous solution, especially in the case of sodium chloride.

Implications

The actual process of aqueous dissolution, and the role of the polar water molecule in this process, seems to be poorly understood. Comparing and contrasting the dissolving of salt and sugar, with explicit discussion of the nature and physical behaviour of the particles in the solution formed, supported by appropriate diagrammatic representations or models, might help students to better understand the nature of aqueous solutions of ionic and molecular compounds.

C. HOW AN ELECTROLYTIC SOLUTION CONDUCTS AN ELECTRIC CURRENT

No student in the sample was able to provide a complete and accurate account of this process. All students who made an attempt to explain the conduction of an electric current through a salt solution realized that charged particles were the clue (20 out of 26). However there was often confusion about what these particles were. While none of this group believed that electrons actually flowed through the solution in the way that they flow through a copper wire, the role of the ions in electrolytic conduction was seldom clearly understood. Sometimes the chloride ion (presumably because of its negative charge) was seen as the only ion involved in the process. The idea that "ions just convey the electrons across and complete the circuit" was common. One student used the rather colourful analogy of "ions ferrying the electrons from one electrode to the other". Nevertheless there were 13 students who realized that electrode reactions were involved in the process. In only 6 cases was this statement related to the observation that gases were liberated at the two electrodes. Students who understood this much often became confused when they tried to explain the process in detail and to trace the path of the electrons through the circuit, being unsure of the direction of electron flow. Two students believed that the electrons which constituted the circuit were produced in the beaker; the role of the battery was just to help their flow along.

Implications

The mechanism of electrolytic conduction needs to be explained fully in term of electron flow in the conducting wires, ion migration of both the positive and the negative ions and electron transfer reactions at the each electrode. The sign of the charge associated with each ion and the polarity of each electrode needs to be emphasised, rather than unnecessary use of the terms "cathode" and "anode" which frequently seem to lead to confusion. Again animated diagrams (perhaps computer generated) simulating the process of electrolytic conduction would seem to be a valuable teaching resource.

D. WHY A PRECIPITATE FORMS

Fourteen students predicted that a solution of silver nitrate would conduct an electric current because of the presence of silver and nitrate ions. However another four explained the expected conductivity as due to the presence of silver, a metal and hence a conductor! One student even expressed surprise at the demonstrated conductivity of the solution saying "I generally don't think of silver as a conducting metal". Most realized that the white substance formed when a solution of sodium chloride was added to the solution of silver nitrate was a solid and often it was postulated that it must be either sodium nitrate or silver chloride. Nine of the group who made this postulate deduced that the solid must be silver chloride because "all nitrates are soluble". However very few (2) actually related the formation of the precipiatate to the (low) solubility of silver chloride. Eight students did predict that silver chloride mixed with water would not conduct an electric current because of the absence of ions in solution. Some of these reasoned that silver chloride cannot be an ionic compound since it does not dissolve in water, and so would not conduct an electric current when mixed with water or when melted. Only 3 students predicted that molten silver chloride would conduct an electric current.

Implications

The interview study reinforced the conclusion of the survey study that precipitation from a mixture of ionic compounds in solution is difficult to explain. The belief that all ionic compounds are soluble is not uncommon. Perhaps this misconception is at the root of students' difficulty in explaining why some ions, when mixed in the same aqueous solution, unite to form an insoluble solid. This question needs more investigation than it received in the current study.

AN EVALUATION OF THE CLINICAL INTERVIEW TECHNIQUE

This study confirmed that conducting reliable and valid clinical interviews is not an easy task and that data interpretation is difficult, especially when one is working without full printed transcripts. Factors which appear to have affected the validity and reliability of the interview data include:

1. The tension created by an interview with a strange person;
2. The students' perception that the interview was a test;
3. The interview being out of the context of chemistry, if the student was taken from a class in another subject;
4. The interviewers interrupted the interviewees too frequently;
5. Some planned questions were omitted from interviews due to oversight;
6. The interviews had to be spread over a three week period;

7. The interview is a learning experience for the interviewees and so affects their responses as it proceeds. Thus there were many significant changes of mind on the part of students during the interview. Was this due to the student recalling information overlooked in a previous part of the interview or was understanding being created by the interview process itself?

CONCLUSION

The results of this study suggest that there is no "short-cut" way to obtain valid and reliable data from an interview study. Time needs to be spent in developing the interview schedule which must be trialled not only for its content validity but also to see how interviewees will react emotionally to its approach. The skill of effectively conducting a clincial interview of this type is not easily acquired and needs practice and critical feedback from an informed observer over a period of time in order to be mastered. Research interviews need to be monitored in some way by an external observer to ensure that all aspects of the research questions are covered in every interview. It is unwise to attempt to interpret interview data without having a complete transcript of each interview.

In spite of the limitations of this study, it did reveal several aspects of the topics covered which indicated why students rated the survey items from which the interview schedule was derived as "extremely difficult" or "very difficult". These impliciations can be taken into account by chemistry teachers in the teaching of these topics in the future. Futhermore, the nature of the misconceptions revealed has suggested a series of alternative responses which will be made use of in devising a diagnostic survey instrument for identifying the difficulties which individual students have in understanding the relationship between the structure and properties of ionic and molecular compounds.

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