STUDENTS' CONCEPTIONS OF SOLUBILITY:
A TEACHER-RESEARCHER COLLABORATIVE STUDY

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Abstract

For the last fifteen years, research on students' conceptions of physical phenomena has been directing our attention to the value of knowing and considering children's prior ideas in science teaching. Although many who are concerned with science education are aware of and see wisdom in this perspective of teaching, there are many realities, including the content of the discipline, that pose great challenges in translating it into practice in science classes.

Currently, in collaboration with teachers, science educators are actively conducting classroom studies. In this process, teachers as researchers are making reflective inquiries into their own students' learning. This study followed a similar framework of research at a microcosmic level. It entailed elicitation of thirteen Grade 11 students' individual prior conceptions of solubility and a teacher-researcher collaboration to incorporate these conceptions in the instruction of a unit on solution chemistry. Consequently, the study presents a phenomenography of solubility, narrates a story about classroom instruction which took students' conceptions into consideration, reports four case studies on students' conceptual growth and changes, and outlines some of the factors that facilitate or constrain collaborative teaching that focuses on student understanding of subject matter.

The students' prior conceptions of solubility were categorized into six categories of description:

1. physical transformation from solid to liquid
2. chemical transformation of solute
3. density of solute
4. amount of space available in solution
5. properties of solute
6. size of solute particles

With regard to learning chemistry, these conceptualizations made clear four issues: (1) students' explanations were bounded by their perceptions, (2) students extended macroscopic explanations to a microscopic level, (3) students made inappropriate links to previous chemistry learning, and (4) students used the language of chemistry non-discriminately.

After studying a unit on solution chemistry, two more categories of description were added to the pre-instructional categories:

1. chemical structure of components
2. solution equilibrium

After instruction, the students attributing to the initial six categories of description diminished in number. The newly acquired conceptions of solubility reflected insufficient explanatory power and were merely overlaid with the chemical language. Learning the language of solution chemistry and acquiring some theoretical understanding of it were reflected in the change between pre- and post-instructional conceptions. This conceptual change can be considered as evolutionary. It was inferred that the abstract and ambiguous nature of chemical theories and principles sets limits to conceptual change teaching.

The influences that facilitated the collaborative efforts include: (1) the teacher's attempts to incorporate students' conceptions, (2) the teacher's openness and willingness to assess her own methods of teaching chemistry, (3) the teacher's reflections about the researcher's constructivist teaching, and (4) the researcher's active participation in the classroom interactions. The four most important influences that seriously constrained the collaborative efforts to link students' conceptions with formal chemistry were: (1) the lack of time to devote to the topic of solution chemistry, (2) the lack of teacher
time to plan lessons together in order to incorporate students’ conceptions, (3) the lack of practical experience on the part of both the researcher and the teacher in developing specific teaching strategies which acknowledged students’ prior belief in this content area, and (4) the lack of time to develop common perspectives and a shared language.

This study has implications for both teachers and researchers. Specifically, it implies that students’ conceptions form an integral component of chemistry instruction—as points of origin for lesson planning and development of curricular materials. It also implies that through science educators’ modelling and practising in their “teaching and learning” courses, pre- and in-service teachers be challenged to seek answers for epistemological questions such as: What is chemical knowledge? and, How is it acquired? A general implication is that both teachers and researchers, rather than being fence-makers, must strive to be bridge-builders so that they can be learners of each other’s theoretical and practical experiences.
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Dedication

For Chemistry Educators, Teachers and Students
Chapter 1

The Problem

1.1 Background to the Problem

While observing bubbles of gas produced in an electrolytic cell, Sandy, an eight-year-old grade three boy exclaimed, “Here are the electrons. I see electrons. Look at the electrons. Here they are.” Sandy was not only excited about “seeing electrons” but he also discussed with the researcher the theoretical aspects of the gain and the loss of electrons in the oxidation-reduction reactions that occurred in the chemical system which he had acquired from reading chemistry books. Sandy’s remarks about the electrolytic system was a striking example that revealed how children use their prior knowledge to make meaning of sensory data.

For the last fifteen years, conception research has been pointing to the value of knowing and considering children’s prior ideas and their unique ways of expressing them in science teaching (Driver and Easley, 1978; Driver and Erickson, 1983; and Gilbert and Watts, 1983). These studies include investigations of conceptions of physical phenomena held before, during and after instruction and have reported that students’ ideas are often perceptually dominated, undifferentiated, driven by everyday language, inappropriately applied to situations by using knowledge from previous learning, inconsistent with the principles taught in science class and resistant to change in spite of instruction. Students’ prior intuitive knowledge and their resistance to change may be attributed to their “conceptual ecology” composed of anomalies, epistemological commitments, and
metaphysical beliefs (Hewson, 1984). Science educators, however, persuasively argue for the importance of modifying and expanding students' conceptual ecology in science classes (Claxton, 1983). Therefore, contemporary research interests focused on teaching and learning dwell on the origins of students' conceptual difficulties, the qualitative ways in which students' conceptions differ and the dynamics by which students' conceptions change.

In this quest, some researchers have focused on identifying, documenting and addressing students' conceptual frameworks in classroom settings (Haggerty, 1986; and Snively, 1987); others have studied the effect of intervention strategies on students' alternative conceptions (Hewson, 1983; Hewson, 1981; Minstrell, 1982; Nussbaum and Novick, 1981; Roth and Anderson, 1988; Rowell and Dawson, 1979, 1983; and White and Horwitz, 1988).

Currently, groups of researchers, for example Children's Learning in Science (CLIS) in England, Students Intuition and Science Instruction ([SI]^2) in Canada, and Project for Enhancing Effective Learning (PEEL) in Australia are exploring the process of teaching and learning in schools by actively engaging in action research projects with teachers and students in very long-term studies. These groups are of the opinion that this type of research will promote professional development of the teachers involved and improve the quality of learning and teaching (White, Baird, Mitchell, Fensham, and Gunstone, 1989). An important notion of improvement with regard to learning and teaching is identifying students' prior conceptions of science concepts and using teaching strategies that will enhance conceptual change (Mitchell and Gunstone, 1984).

The present study, within this research genre, was conceived with the idea to improve chemistry teaching in secondary schools in terms of a widely accepted world view of learning among science researchers and educators. It was believed that a collaborative
relationship with the teacher would be useful to try some of the empirical- and theory-driven ideas of teaching and learning in a chemistry class. In particular, the study purported to follow through the entire cycle of conceptual change teaching in a traditional chemistry class.

1.2 Problem Statement

Three general problem areas are outlined and under each more specific question(s) arise. These problem areas are:

1. To document and categorize the conceptions students have of solubility;
   What are the most common conceptions of solubility found in Grade 11 chemistry students before an instructional unit on solution chemistry?

2. To document the teacher-researcher efforts to incorporate students' conceptions of solubility into appropriate instructional strategies;
   What are some of the influences facilitating and constraining the teacher-researcher collaborative procedures in attempting to incorporate students' conceptions in this study?

3. To document any changes which take place in students' understanding of solubility as a result of instruction of a unit on solution chemistry.
   What conceptions of solubility are held by Grade 11 students after studying a unit on solution chemistry?
   How do four of these students' conceptions of solubility relate to their own prior understanding?
   What was the influence of instruction on the students' prior conceptions?

1.3 Overview of Methodology

This dissertation focuses on describing and analyzing the process of incorporating students' conceptions of solubility in an instructional unit jointly planned and taught by the researcher and a chemistry teacher. Thirteen Grade 11 chemistry students
participated in the pre- and post-instructional clinical interviews. The interviews consisted of gathering information on students' understanding of three chemical systems:

1. System A: Sugar/Water
2. System B: Water/Alcohol/Paint Thinner
3. System C: Salt/Water

The amassed data were categorized using a phenomenographic research technique. Phenomenography provides a way to find, interpret, systematize, and describe the qualitatively different ways in which individuals experience and understand their reality (Marton, 1981).

The study followed through a complete research cycle on constructivist science teaching: eliciting students' conceptions of solubility, categorizing their conceptions according to a set of categories constructed by the researcher, incorporating these in the instructional procedures of a unit on solution chemistry by the teacher and the researcher in a collaborative mode, eliciting of students' conceptions after instruction, and examining the influence of instruction on students' conceptions. Another aim of the study was to look at the influences facilitating and constraining the collaboration process involved in planning and implementing the instructional unit.

1.4 Justification for the Study

Firstly, this study involved eliciting and categorizing students' conceptions of solubility, incorporating these into a teaching unit on solution chemistry, reflectively examining instructional procedures, analyzing students' conceptions after instruction, relating these to their prior knowledge of solution chemistry, and finally, assessing the influence of instruction. Relatively few studies have travelled through this entire research cycle.
Secondly, no study has reported on teacher-researcher collaborative effort to incorporate students' prior conceptions when teaching chemistry. Because the present study included this aspect, it gave the researcher an opportunity to examine the classroom influences on constructivist practices as well as to outline some of the essential elements for a teacher-researcher collaboration.

Solution chemistry was chosen as the content area for this study for three reasons: (a) the literature review on students' prior knowledge revealed that the concept of dissolving was only treated as a sub-topic within other major units of chemistry such as matter and chemical change; (b) the concept of solubility is a key constituent of most senior chemistry curricula; and (c) although, the principles and theories of the content of solution chemistry are school-based, many examples of the solution process are part of the everyday phenomena experienced by all students.

1.5 Overview of this Study

The study consists of seven chapters. Chapter 1 presents background to the problem, poses the problem statements, describes methods used in the study, justifies the study, and defines specific concepts. Chapter 2 reviews literature on student conceptions in topics related to solution chemistry as well as pedagogical and methodological frame used in the study. Chapter 3 discusses the methodology. Chapter 4 discusses the categories of description of students' conceptions of solution chemistry. Chapter 5 describes the teacher-researcher collaborative attempts to incorporate students' conceptions when teaching a unit on solution chemistry. Chapter 6 presents post-instructional students' outcome space of solubility. It then details four case studies in which relationships are drawn between each of the four students' post-instructional conceptions and their pre-instructional conceptions. Also featured are instructional influences on students'
conceptions. Chapter 7 draws conclusions, discusses issues of the study, outlines educational implications and offers recommendations for future work on teacher-researcher collaborative inquiries.

1.6 Description of Terms

The meanings of the most commonly found terms in this study are stated below in alphabetical order.

- **Alternative Conceptions:**
  Alternative conceptions are those sensible understandings of a certain phenomenon held by students but which vary from those accepted by the scientific community.

- **Categories of Description:**
  The categories of description are creations by the researcher of the set of students' understandings of a physical phenomenon. Each category should represent a qualitatively different kind of understanding.

- **Chemical System:**
  A chemical system is one which consists of a set of particular substances, their interactions and influences.

- **Collaboration:**
  Collaboration may be understood as a type of non-hierarchical relationship between two or more individuals that aims to accomplish common goals.

- **Conception:**
  A personal meaning or understanding of phenomena in the world around us (Marton, 1981).

- **Conceptual Change:**
  Knowledge structures that become expanded, re-defined and restructured as a result of strategic planned activities.

- **Particle:**
  In terms of chemistry, particles refer to the microscopic worlds of atoms, ions, and molecules.

- **Phenomenography:**
  A research discipline which aims at mapping qualitatively different ways in which people experience, conceptualize, and understand a special domain of knowledge (Marton, 1981).
• Polar, Non-polar, and Slightly polar:
  Substances can be grouped into polar, non-polar, and slightly polar according to the structural properties of compounds. The relative solubility of substances in particular solvents is based on this chemical character.

• Solubility:
  A process in which one substance mixes with another, resulting in a solution.

• Solution Chemistry:
  This topic in chemistry deals with the dissolution process of substances and their energetics.
Chapter 2

The Review of Related Literature

2.1 Introduction

This study focuses on the qualitatively different ways in which Grade 11 chemistry students think about solubility, and how a teacher and a researcher collaboratively incorporated these students' conceptions into a unit on solution chemistry. The study has therefore been framed within three contexts: the existing literature on student conceptions in related topic areas; the pedagogical frame used in the study; and the methodological frame adopted for the study. Based upon these distinct frameworks of the study, the literature review will be organized in the following fashion:

1. Student Conceptual Frame
   (a) students' conceptions of matter
   (b) students' conceptions of dissolving
   (c) a summary of students' conceptions

2. Pedagogical Frame
   (a) contemporary secondary teaching
   (b) an alternative world view of science learning and teaching
   (c) toward conceptual change science teaching

3. Methodological Frame
   (a) phenomenography: an analytical framework
   (b) collaborative inquiry and the construction of professional knowledge
2.2 Student Conceptual Frame

Science education literature is replete with documentations of students’ conceptions of physics, biology, and chemistry related topics. In the area of physics, studies have been done on topics such as light and vision (Rice and Feher, 1987), sound (Linder, 1989), heat and temperature (Erickson, 1979), and mechanics and atomic physics (Neidderer, 1987). Students’ conceptions of photosynthesis (Roth, Smith and Anderson, 1983), and the concept of growth and the cell (Luyten, 1990) are two examples of the biology topics that have been described. In the discipline of chemistry, descriptions of students’ conceptions include topics such as chemical change (Hesse, 1987), covalent bonding (Peterson, Tregast, and Garnett, 1986), and chemical equation balancing (Yarroch, 1985).

In relation to solution chemistry, studies have been done on student understanding of matter, states of matter, conservation of matter, chemical reactions, dissolution process, and the nature of solutions. Within these topics of chemistry, researchers have given minor considerations to student understanding of the concept of solubility. A discussion on previous studies will center around two areas:

1. students’ conceptions of matter; and

2. students’ conceptions of dissolving.

2.2.1 Students’ Conceptions of Matter

Novick and Nussbaum (1978) and Nussbaum (1985) have noted that students lack understanding of the particulate nature of matter. These researchers investigated the extent to which 14-year-old (eighth grade) Israeli pupils were able to apply several aspects of the particle model in explaining simple physical phenomena in the gaseous phase.
They found that these students conceived of matter as continuous and static. They conclude, that in school, students are expected to abandon this perceptually sensible model in favour of an abstract one developed by scientists. A particle picture sometimes contradicts one's sensory perception of matter. The aspects of the particle theory which proved to be the most difficult for the students were those most dissonant with their prior conceptions about the nature of matter. These aspects were: the empty space (the vacuum concept), intrinsic motion (particle kinetics) and interaction between particles (chemical change).

Ben-Zvi, Eylon, and Silberstein (1986) confirmed the findings of the Novick and Nussbaum study. About 300 grade ten students, average age fifteen, did not abandon their intuitive, continuous model of matter in favor of the scientific model of matter. An atom of copper was considered to bear the properties of the substance. In this sense, an atom of copper was viewed by many of these students as a small piece of the solid metal.

Dow, Auld, and Wilson (1978) describe Scottish students' reasoning about the change of state of matter. They investigated nearly 1000 twelve- to thirteen-year-old students. As part of the study, the students were asked to draw diagrams to show the shape, arrangement, and spacing of atoms/molecules in a typical solid, liquid and gas. Nearly all the students' drawings showed particles in all three states, but about half of the drawings showed the particles in the liquid and gaseous state as smaller than those in the solid state. Interviews with some of the students indicated that this was not simply a question of a change in scale in their drawings but that it reflected an underlying view that molecular diameter decreases progressively from solid to liquid to gas. These researchers also found that the majority of students indicated that the particles in the liquid and gaseous states were moving, but one-third of the sample indicated no movement in the solid state.

Many of the students' ways of thinking found in the Scottish study have also been
identified in a survey of English fifteen-year-old students. In this study by Brook, Briggs, and Driver (1984), the students were asked a number of questions in which they were to explain certain phenomena using the idea that matter is made of particles. These questions were sent in a written form to nearly 300 students and a smaller group were also interviewed. They found that the majority of students (about two-thirds) used particulate ideas in their responses but only about a fifth used ideas that were explained to these students in the class. The tendency of students was to attribute changes observed in macroscopic properties of matter to the microscopic level; for example, suggesting that particles would melt, get hot or change in size.

The above studies on the particulate nature of matter show how children at different age levels and in different countries appear to reason alike. That is, the students extend the understanding of the macroscopic properties to the microscopic level. Ben-Zvi, Eylon, and Silberstein (1986) point out the difficulties that students have in adopting the particulate model.

On the contrary, Renström’s phenomenographic study (1988) on “students’ conceptions of matter” points out that students described matter in terms of a “continuous model of matter” as well as beyond this simplistic model. In her study, Renström drew a complex picture of twenty Swedish higher-level compulsory school students’ conceptions of matter. According to her, students conceptualized matter as: homogeneous substance, delimited substance units, substance units with “small atoms” aggregate of particles, particle units, systems of particles. Renström orders these conceptions of matter in “terms of inclusiveness of certain aspects concerning matter and they thus form a hierarchy.” Renström notes that the conceptions of matter expressed by each student varied and depended on the particular problem.
2.2.2 Students’ Conceptions of Dissolving

Piaget and Inhelder (1974) studied children’s ideas about the process of dissolving as part of their investigation into the development of ideas of conservation of matter. The study required students to predict what would happen in terms of weight when some sugar was dissolved in water. The researchers found that children’s reasoning was guided by their perceptual experience. The children predicted that there would not be any change to the weight or volume of the water since the sugar “disappears” when it dissolves.

Cosgrove and Osborne (1981) interviewed secondary students in New Zealand to find students’ conceptions of the solution process. These students were shown a teaspoon of sugar dissolving in water and were asked, “What happens to the sugar?” The researchers reported that over 25 percent of the students used the word “melt” to describe the process. They state that some students used the words “melt” and “dissolve” synonymously. One student’s explanation reflected the idea that the substance “sugar” is defined by its macroscopic properties, its hard crystalline structure. When it changes its crystalline form it is no longer sugar.

In the same study, some students from about age 13 used particulate ideas in their explanations. Some examples are given below:

“Well it doesn’t actually dissolve ... it just gets broken up ... into such tiny ones that you can’t see it anymore (15-year-old).”

“The sugar molecules all split apart and then their molecules just mix (15-year-old).”

“... sugar molecules are being pulled apart by the water molecules and diffusing them through the water (16-year-old).”

These statements convey that chemistry students will explain the dissolving process in terms of particles as they get older.

Cachapuz and Martins (1987) used interviews to investigate conceptions held by 30 Portuguese secondary students (grades 9 and 11) about the processes of energy changes
associated with a chemical reaction. According to these students, the processes of bond breaking/bond forming are not simultaneous, rather they take place one after the other. Firstly, the reactants are broken down into smaller structural units so that the initial substances cease to exist; secondly, new chemical species are formed. Following is an example of this type of reasoning.

Manuel (grade 11)

"When water reacts with ammonium chloride both reactants are broken down into particles ... then they combine to form new substances."

Some students stated that $H_2O$ molecules would also suffer intramolecular ruptures:

An example of this kind of reasoning follows:

Rui (grade 11)

"Maybe the molecules of ammonium chloride all split apart ... the bond of both (the reactants) are broken down and then maybe the atoms coming from the water are gathered together with those coming from the ammonium chloride."

Students also suggested that there is an interaction between the two reactants but structural changes only take place in $NH_4^+Cl^-; the water remains unchanged and only plays a passive role. An example follows:

Jose (grade 11)

"The bonds in the ammonium chloride are broken down and the water doesn't experience any change."

To these students it was not clear whether the fragments formed are $NH_4^+Cl^-$ ions or other entities.

Stavridou and Solomonidou (1989) explored the representations and conceptions of Greek students of the concept of chemical reaction. They were also interested in the ways in which these students categorized transformations of matter. The students ranged in age from 8-17 years. Children believed that physical change invariably involved only one
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substance while chemical changes involved more than one. For example, the dissolution of salt or sugar in water was classified as a chemical phenomenon, because two substances are involved (water + sugar, water + salt). These authors also found that all criteria given and used by the students to distinguish between physical and chemical changes were macroscopic.

In her phenomenographic study, Renström used nine concrete substances to elicit students' conceptions of matter. Salt and water constituted two of the concrete substances that she used. When the students had discussed both salt and water separately, Renström put them together and challenged students' thinking with questions such as, “Salt water? ...What is that like?” About salt and water, part of the conversation between Renström (E) and Charlotta (S) (Renström 1988, Excerpt 25, p.116) followed thus:

Charlotta (1)
S: The water mixes the ... the substance in the salt is mixed in the water, sort of ...
E: The substance in the salt? What is there in the salt?
S: I don't know ... but there should be some substance which mixes with water ... no I don't think it's salt ... think that is left ...

In the light of this study, Charlotta's view that there is some substance in salt that attributes to the mixing of it with water is significant.

Renström notes, for Cesar, melting of iron is the same as what happens to salt when it dissolves in water. According to Cesar, both processes (melting and dissolving) consist of molecules getting smaller through their division. Consider the following statement made by Cesar with regard to melting of iron:

They are really small ... they are divided, the big ones ... there are lots of small ones so the piece can't keep together so it melts 'out' ... these small ones can't hold together this big sheet ...

A portion of Renström's (E) interview excerpt with Cesar (S) illustrates his reasoning
about salt dissolving in water:

Cesar (2)

S: *Melts and joins with the water ... the salt molecules join with the fresh (water) here ...*
E: When you first drew the salt here ... you drew it like this ... sort of ... and you said there was salt in it ... 
S: Yes
E: What happens to these little ... things?
S: *They join with the water molecules ...*
E: and
S: *and are dissolved*
E: Are dissolved, you say ... What does that mean? 
S: *The molecules become so small so that you can hardly see them in a microscope ... finely divided ( ... )*
E: You said that when it ... melts ... you said ... something happens to it ... can you draw what happens? 
S: *There are a lot of small ones like that ... the water is full of them ...*
E: In that water and these are ... 
S: *Salt ... salt molecules ...*

For Bill's explanation about salt and water and how they interact, consider the following excerpt and the interpretation (Renström, 1988, Excerpt 45, pp. 131 & 132):
Bill (3)

E: What happens?
S: I think that the nucleus itself, when it starts to let the outer shell go, that is ... and that falls into the water ... can't be broken by pressure, instead it is dissolved ...
E: Can you draw how you picture this happening ... this is water ... and that you picture as looking like that ... Can you draw how you picture it?
S: They affect the salt, like this, then ... and want them to come out, sort of ... the salt that is here ....
E: What's supposed to come out? ... These? ...
S: The salt that ...
E: You drew salt here that ... Now what was this? ... it was ...
S: Yes, it was ... it was the actual grain here ... it's the same as water ... that's also grains ... or nuclei ...
E: They didn't have that sort of thing (shell) ...
S: They didn't have shells ... the water ... but the shell is dissolved by the water ... and the salt comes out ... The water is sort of stronger than the salt ...
E: So what happens to the shell?
S: It's dissolved ...
E: Where does it go then?
S: It goes in the ... the water sort of takes up the shell, sort of ... eats it up ... disappears, so to speak ...
E: You said the water was stronger and sort of eats up the salt ...
S: It becomes thicker, so to speak ...
E: Could you draw here ... before and after, that is ... if the water looked like that ... before ... and then it ...
S: I think it's larger ... these things that grow, sort of, they take up the salt ... here is the nucleus see ... and then it grows out from itself in layers ...
E: On those of ...
S: Salt ... because it's salt here that's stuck to ...
E: Then I see what you mean ... When there is salt in the water it tastes of salt ... Why does it taste of salt?
S: The nucleus is dissolved after a while when the shell has been used up ...

Bill considers water to be a 'stronger' substance and therefore able to 'do' something with the salt. Water has no shell and it seems to ready to 'eat' the salt shell. When he focuses on the salt, we can see that he first stresses the shell than [sic] the content. The content does not fall out in an uncontrolled manner. He shows that he conserves both the substance as such and the amount of the substance by placing it around the water nuclei and creating new units for salt water, units which we can interpret as having the attributes of a liquid, since water is the 'strongest substance' and eats the salt unit.

Ulrika, a grade nine student Renström's pilot study, drew particles of salt with air
between the particles when salt is dissolved in water. Ulrika explained this by letting the water force out the air. Consider Ulrika’s pictures of salt and salt in water:

One of the students’ conceptions in the present study was similar to that of Ulrika in Renström’s study. Gary stated that there are air particles in water, and sugar drives these out and occupies these empty spaces. This aspect of Gary’s conception of solubility is discussed in detail in Chapter 4.

Prieto, Blanco and Rodriguez (1989) describe the ideas held by 11- to 14-year-old Spanish students about solutions and the process of dissolution. These authors conclude that “in attempting to explain the phenomenon of one substance dissolving in another, students usually focus on the solute, while assuming a ‘passive’ role for the solvent.” Other findings that are salient on the basis of this study are: Only during the eighth grade do students begin to recognize the importance of solute-solvent interactions. In this context, the process of dissolving is often viewed as a chemical transformation. This finding is consistent with Stavridou and Solomonidou study. Ample evidence about solution process as a chemical transformation is provided by the present study (discussed in Chapter 4). The Prieto et al. study also showed that, for many students, the process
of dissolution is not associated with the particulate structure of matter. This aspect is discussed in Chapter 4.

2.2.3 A Summary of Student Conceptions

The foregoing studies on students' ideas of concepts related to solution chemistry have illuminated some of the difficulties students encounter in learning chemistry. In broad terms, the areas of difficulty significant to this study are: extending macroscopic properties to the microscopic level; and, using features of physical transformation as the reasons to explain a chemical phenomenon such as dissolving. Specifically, commonly found students' conceptions related to solution chemistry from the studies cited are as follows:

- Matter is viewed as continuous or homogeneous.
- Matter is viewed as static.
- Macroscopic properties are extended to microscopic level.
- The molecular diameter is expected to decrease progressively from solid to liquid to gas.
- The mass of solvent (water) is expected to be conserved because the solute (sugar) appears to disappear.
- The words melt and dissolve are used synonymously.
- The process of dissolving is described in terms of particles as students get older.
- When a substance (ammonium chloride) goes into the water environment, it is said that bond breaking and bond forming do not occur simultaneously but successively.
- Distinctions are not made between the components (ammonium chloride and water) of solution. It is understood that intramolecular ruptures occur in both of these components.
- Features of physical transformations are given as reasons for the chemical phenomenon of the dissolution process.
- Presence of a substance in the solute is understood to be the cause for it to mix with the solvent.
- Dissolving is a process in which the solute molecules get smaller by dividing.
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- It is argued that water is a stronger substance than salt, and hence the former eats the latter.
- Dissolving is when water forces out the air in salt particles.
- The solute is seen as the most important component of the dissolution process.
- Solute-solvent interactions are viewed as chemical transformations.
- The process of dissolution is not associated with the particular structure of matter.

The empirical studies cited in this section are based on phenomena appearing both in everyday and chemical contexts. Therefore, the students’ differing conceptions are seen as a function of a discrepancy between everyday thinking and school chemical knowledge. Since students learn most chemical concepts only in school, some discrepancies in their conceptions originate from the students’ reasoning of the chemistry content presented by the teacher. Both these types of discrepancies are evident not only in previous studies but also in the present study.

It is evident from this section that some categories for interpreting students’ conceptions related to solution chemistry are available. These conceptions provided a supportive structure which was used to develop some of the categories of description for the present group of Grade 11 chemistry students.

2.3 Pedagogical Frame

Beginning from a description of present science teaching, this section develops the notion of “conceptual change” (West and Pines, 1985) teaching in chemistry learning.

2.3.1 Contemporary Secondary Science Teaching

Contemporary secondary science teaching seems to be test-driven and emphasizes rote-learning. For retention of facts, “listen to the teacher carefully” and “study hard” are the normal phrases used by teachers, parents and well-wishers. Devices such as
“rehearsals” and “mnemonics” are frequently used to enhance memory work (Weinstein and Underwood, 1986). In science classes students spend a major portion of their time in listening to what the teacher has to say, and copying teacher’s notes (Bateson, et al., 1986; Ebenezer, 1987; Ebenezer and Zoller, 1990; Tobin, 1986).

Laboratory work, a fundamental mode of science learning, focuses upon practice in using scientific instruments, in applying correct methods and procedures and in verifying concepts, principles, and laws of science (Hofstein and Lunetta, 1982; Tobin and Gallagher, 1987; Stake and Easley, 1978). For instance, Novak (1988) notes that most students in laboratories gain little insight either regarding the key science concepts involved or toward the process of knowledge construction. He contends that experiments are shown to be ways to “prove” or “falsify” hypotheses rather than a method to construct new conceptual-theoretical meanings. With regard to interactions among students in laboratory work, Lehman (1990) found that during a lab activity high school chemistry students interacted with one another mainly to confirm or clarify the directions/procedures of the activity.

This model of science instruction can be attributed to the behaviourist or positivist views of science learning which consists of “metaphysical realism” (Glaserfield, 1984). A metaphysical realist views “experimentation and observation as direct experiences of physical reality” (Linder, 1989, p. 4). For a conceptualization of metaphysical realism, see Linder and Erickson, 1989.

In contrast, the type of learning and teaching advocated by some science education researchers has been labelled as “concept-learning” (Eylon and Linn, 1988), “concept development” (Duit, 1987) or “conceptual structures and conceptual change” (West and Pines, 1985). These terms are synonymous in meaning and have common underlying principles. A “conceptual change” perspective, an epistemology of science learning, and its implementations for science teaching are described in the next section.
2.3.2 An Alternative World View of Science Learning and Teaching

A key belief held and advocated by some researchers is that teaching is not a process of transferring objective information to the student by means of words, rather it is a strategic effort to examine the various ways in which students have conceptualized something and to change their subjective conceptions to more plausible ones. This theory of teaching and learning refers to "conceptual structures that epistemic agents, given the range of present experience within their tradition of thought, language, and social interaction, consider viable" (Glasersfeld, 1989, emphasis is the researcher's). Glasersfeld's supposition was based on one of Giambattista Vico's powerful ideas that "epistemic agents can know nothing but the cognitive structures they themselves have put together" (Glasersfeld, 1989, p. 123). As a corollary, the human knower can know only what the human knower has constructed from his/her experience in relationship with the physical and the social world. Human understanding becomes a condition of "fit" or viability rather than an "ontological match." In this sense, learning is viewed as an active construction process on the basis of constructs already available to the learner (Duit, 1987) as opposed to a "transmission view" which assumes that learners are recipients of knowledge, accumulating more information to what they already know (Barnes, 1976).

In search of a theoretical foundation that would perceive students as meaning makers of experience and builders of conceptual structures, science educators have turned to the writings of Popper (1959), Kuhn (1970), Lakatos (1970), Toulmin (1972) and Feyerabend (1978) in the history and philosophy of science; and Kelly (1955), and Magoon (1977) in the constructivist traditions in philosophy and social sciences. From subsequent research using ideas derived from these literatures, science educators have developed an understanding of how students make sense of the world. They have come to envision
children as engaged in similar mental activities to that of scientists who develop and construct theories and models from their personal context (Claxton, 1983; Driver, 1983; Kelly, 1955; Gilbert, Osborne, Fensham, 1982; Pope and Gilbert, 1983; and Pope and Keen, 1981).

The theoretical positions derived from the theorists above resulted in many "problem-oriented" (Driver and Erickson, 1983) studies of student conceptions. The instructional strategies which considered students' conceptions are known as "constructivist approaches to teaching," an application of a constructivist perspective of learning to education (Driver and Bell, 1986; Novak, 1988). These strategies aim at what now is often called "conceptual change teaching" and which are generally rooted in constructivistic frameworks. Driver (1987) advocates teachers use a variety of conceptual change models for better results in student learning.

2.3.3 Towards Conceptual Change Science Teaching

The conception and the development of conceptual change models to provide a framework of science learning originates from the realization of researchers that there might be a parallel between science learning and conceptual change in scientific disciplines.

Subscribing to Toulmin's (1972) ideas of the evolution of scientific knowledge, Nussbaum and Novick (1982a) describe major conceptual change as being an evolutionary process because of a gradual evolution of ideas characterized by periods of uncertainty for the student. These beliefs have led these authors to develop methods for promoting cognitive accommodation in the classroom by the use of 'conceptual conflict'.

In developing their conceptual change model, Posner, Strike, Hewson and Gertzog (1982) have adopted the Kuhnian concept of "paradigm shift" (Kuhn, 1970) as well as the idea of "evolutionary conceptual change," a belief held both by Kuhn and Toulmin. The major concepts of Posner et al.'s conceptual change model are assimilation and
accommodation: Assimilation is when the student uses existing concepts to deal with and consequently extend his/her ideas about the new phenomenon. This is related to Kuhnian normal science, which is analogous to Toulmin’s evolutionary change of knowledge construction. Accommodation occurs when central commitments of the student require modifications. This is related to Kuhnian revolutionary science.

Posner et al. (1982) outlines four conditions for conceptual change:

- There must be dissatisfaction with existing conceptions
- A new conception must be intelligible
- A new conception must appear initially plausible
- A new conception should suggest the possibility of a fruitful research programme

In the light of this study, the principles of conceptual change teaching might be illustrated by considering a simple example of a common conception held by students that sugar melts when it disappears into water. The purpose of conceptual change instruction is to create dissatisfaction with this existing conception and encourage them to develop a conception that is more fruitful (Linder, 1990). In the above example, the difference between “melting” and “dissolving” has to be distinguished by students. Unfortunately, the process of melting cannot be shown with sugar, because sugar does not melt when heated; it changes from a solid state to a liquid state, forming new substances. Therefore the process that sugar undergoes when heated cannot be called melting because the school chemistry definition for melting is: “the change of a solid to a liquid without the formation of any new kind of matter.” So instead of simply stating the definition of melting and having the students memorize the definition, the teacher can have the students propose a working theory for melting by heating the following: ice, wax, moth flakes and sugar. At this point, the students may have some ideas about melting and why sugar does not melt. Now if sugar is added to water, the students may conclude that something else
is happening to the sugar. This process may be used to cause dissatisfaction about the existing conception, "sugar melts in water."

The following activity can be done to show that the new conception, that is, sugar dissolving in water to form a solution, is intelligible and plausible. Students can be asked to propose theories of how sugar dissolves in water. Then, with students' theories and reasoning, the concept of dissolution of sugar in water can be taught. Students may have a better chance of understanding the difference between melting and dissolving after having gone through this process. The concepts of melting and dissolving may then become intelligible and plausible.

The dissolving process might become a fruitful event when it is extended to new areas of inquiry such as dissolution of other substances or liquids in water or other solvents, for example: salt in water. The salt can be heated with a bunsen burner to reinforce the idea of melting. Salt will not melt because its melting point is 800 °C. Students may understand that melting point is a physical attribute of substances. Some substances have low melting points and others have high melting points.

Instruction that utilizes conceptual change models such as the one described above may not easily alter strongly held conceptions. For instance, Duit (1987) points out that in the conceptual change model the first (dissatisfaction with existing ideas) and the last (the new conception must be fruitful) conditions have proven to be the most difficult ones for students. He contends that students are very often unable and unwilling to change their conceptions because they do not see clearly in which respects the new conceptions are more fruitful than the old ones. Duit's point has credibility because historians and philosophers of science point out that scientists too do not easily change their theories (Kuhn, 1970). Sometimes it took centuries before one view displaced another. At times, a theory once ridiculed and discarded is revived to shed light on the new problem. For example, Prout's conception of a sub-atomic structure of matter so lightly thrown out
“became a great charm for many distinguished chemists” (Toulmin and Goodfield, 1962, p. 243). Another appropriate example from the history of science is the assumption that Avogadro put forth: At any given temperature and pressure, all gases always contain the same number of atoms or molecules. This theory lay dormant for forty years because scientists hesitated to abandon Dalton’s newly won victories (Toulmin and Goodfield, 1962, p. 242).

Another classic example is embedded in the question: In terms of atomic structure, what makes a certain combination of bonded atoms an acid? Throughout the history of chemistry, various definitions of what constitutes an acid have been used. The first useful definition of acid came from Arrhenius, who defined an acid as any compound which ionized in water to form hydrogen ions ($H^+$). Since Arrhenius’ time, chemists have realized that hydrogen ions are much too reactive to exist alone. Hydrogen ions are hydrated in water solutions to form hydronium ions. According to the Bronsted theory of acids, an acid is any compound which donates protons. According to both of these definitions, acids ionize when they are in solution. For example, hydrogen chloride ionizes to form hydronium ions and chloride ions in solution.

$$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

So hydrochloric acid is a modern Arrhenius acid, because it forms hydronium ions. It is also a Bronsted acid because hydrogen chloride donates a proton (which is really a hydrogen ion) to a water molecule, forming the resultant ions. In chemistry classes both the Arrhenius and Bronsted definitions of acids are used. These examples suggest that old theories are not discarded to accommodate new ones for the simple reason that they are useful in interpreting certain contexts.

Gabel (1989) has indicated reasons why students find difficulties in accommodating scientific theories. She has identified three obvious ways in which student conceptions
are influenced: nature (sensory deceptions); language (cultural factors); and instruction (previous learning that has touched the surface just by presenting concepts in one or two contexts). As described earlier, numerous examples are found in the evolution of matter-theory which show that revolutionary ideas are not accepted instantly. Although Einstein’s revolutionary ideas of matter and radiation form the basis of modern chemistry and physics, “the categories of classical nineteenth-century science may still provide today the bread-and-butter for introductory courses at school” (Toulmin, and Goodfield, 1962, p. 240).

Despite concerns pointed out by Duit and Gabel, conceptual change models have provided specific instructional prescriptions for changing students’ intuitive notions and for diagnosing and subsequently altering students’ “alternative conceptions” (Driver and Erickson, 1983). Examples of conceptual change teaching are found in Nussbaum (1985) and Driver (1985). For instance, Driver’s sequence of instruction consists of orientation, elicitation of ideas, restructuring of ideas, application of ideas, reviewing the change in ideas (conceptual change), and review and testing.

The learning strategies that are in accordance with the conceptual change models include student interactions that are promoted by brainstorming sessions, open debates, and small-group discussions so that the students are given an opportunity to gradually (evolutionarily) move towards a theory without requiring them to reach “clear-cut conclusions” (Nussbaum, 1989). Students do not readily adapt themselves to accommodate a scientific theory just because an experiment might be done to shift their thinking towards the “right” conception. Driver and Oldham (1986) state:

In teaching science we are leading pupils to see phenomenon and experimental situations in particular ways; to learn to wear scientist’s conceptual spectacles. This involves pupils in constructing mental models for entities which are not perceived directly, such as light, electric current and particles of matter. The construction of such complex models involves considerable effort on the part of a learner and it is likely to take time before such ways of seeing the world become a stable and useful part of a young person’s conceptual armory.
In the light of the above arguments for a conceptual change model of instruction, this study considers acquisition of chemical knowledge to be evolutionary. Sorting, differentiating, constructing and reconstructing chemical knowledge that is often characterized by ambiguities can be considered developmental rather than revolutionary because in the process of re-weaving ideas, other knots may form casting doubts on what has been taught. So the chemistry classroom must be considered as a center for intellectual conversation and negotiation of meaning among students and between the teacher and students for undoing the conceptual knots and in helping to develop their chemical knowledge.

In conceptual change teaching, students require time to think, to make sense of what they learn, to share and negotiate their personal understanding with others so that they could come to a common understanding of an event or a phenomenon. Such social collaboration enables students to recognize, to clarify alternative understandings, as well as to elaborate, justify, and evaluate personal understandings (Tobin, 1990). The focus of a conceptual change chemistry class, then, would be to develop the meaning of science concepts through active collaboration between teacher and student, and student and student.

When children's personal understanding or theories become an integral part of science teaching, and when learning is thought of as a process of conceptual change, both the teacher and the student must change their traditional roles. The teacher and the student become engaged in the task of negotiating meaning.

Instead of transmitting chemical knowledge in the form of facts and laws from "above," the teacher attempts to provide links between children's theories and formal science. Content-specific strategies to create disequilibrium in the student's mind would be evidenced in lesson planning. The teacher becomes an experimenter in his/her own classroom rather than a mere follower of the given curriculum. The historically acclaimed
sense of teacher authority is traded for students' control of their own learning. Rather than adopting "the role of a manager in the laboratory" (Gallagher and Tobin, 1987), the teacher becomes a receiver, facilitator and sense maker of students' challenges. Both the student and the teacher must adopt different perspectives and roles in conceptual change chemistry teaching.

In this study, it was assumed that an analysis of the initial students' conceptions would give the teacher some clues to the range of ideas students had of solubility. In addition, it would provide some access to the students' common talk and/or perceptual ways of thinking about solutions and solubility. Students' initial conceptions must form the initial reference point for analysis of conceptual changes in students. Thus teacher-researcher collaboration is useful to plan and implement an instructional program that would take students' conceptions into consideration. It may also be desirable for the researcher to work collaboratively with the teacher to interpret the experiences in a traditional classroom when methods of conceptual change strategies are employed.

Conceptual change —towards what end?— might be the next major concern for collaborative chemistry teaching. This is usually a point of contention among researchers. In his paper "Toward a Coherent Constructivism," Strike (1987) argues human learning must contend with the social character of concepts. Di Sessa (1988) Driver and Oldham (1986) also allude to this notion when they discuss that students should traverse from common-sense reasoning to scientific understanding. So an important step that should be taken in a study of this nature is to provide learning experiences that would connect students' conceptions to scientific conceptions.

The knowing of students' prior knowledge, which forms the first step in a conceptual change model of learning, is not to falsify students' understanding by comparing their ideas with conventional scientific explanations of solutions, but to make students conscious of their own conceptions and through an evolutionary process help them to see
new ways of conceptualizing solution chemistry. This aim of chemistry teaching has its origins in the ways in which chemists have proposed plausible models and theories for explaining solutions/solubility and the admission that they themselves are not positive about the mechanism of the solution process. Hence, in evaluating students’ responses, an assumption of this study was that teacher-researcher collaborators keep in mind that chemists’ explanations of concepts in chemistry represent attempts at understanding phenomena and not absolute truth. The historical evolution of science was a constant reminder to the researcher and teacher that we should acknowledge students’ difficulties in understanding concepts in a unit on solution chemistry because it took time, effort and many minds to change from one conception to another.

Although conceptual change instruction is rarely practised presently, it is receiving greater recognition and prominence among teachers, science educators, administrators, curriculum developers and textbook authors. Signs of an “actual shift” to an alternative paradigm of learning and teaching are increasingly evident, particularly in the last two years. In the October 1990 issue of *The Canadian School Executive—The Magazine for Leaders in Education*, an article by Kamloops, British Columbia School Superintendent Terrance Grieve (1990) entitled “Free the Teachers and Free the Learners” seeks to help administrators understand their role as British Columbia implements recommendations from the Sullivan Royal Commission. The main theme of his article is understanding learning consistent with the ideas that the researchers of students’ conceptions of science-related topics have been promoting since the early 1970s.

More substantive support for an alternative view of learning comes from a policy document, *Enabling Learners, Year 2000: A Curriculum and Assessment Framework for the Future*. This document, prepared by the Ministry of Education of British Columbia, has included among other initiatives, certain important principles of *learning and the learner* which are in harmony with the foundations and goals of this study:
Learning is an active process. According to one widely accepted view of learning, the learning process involves selecting from available information, and constructing meaning by placing the new information and experiences in the context of what the individual already knows, values, and can do. Learning thus involves connecting new ideas to previous knowledge, often subconsciously. Opportunities to reflect upon one's beliefs and knowledge are important for successful learning. Sometimes, learning results in the individual changing his or her conceptual framework in very significant ways (Province of British Columbia, 1989, p. 9).

A document of this type is clearly an indication that curriculum decision-makers have come to an understanding of "learning" along the same lines science educators have been thinking for the last twenty years.

2.4 Methodological Frame

Compatible with the above views of learning and teaching, two types of methodological frameworks, namely, phenomenography and teacher-researcher collaboration were employed in this study. Phenomenography can be understood as an analytical framework to gain an empathetic understanding of students' conceptions of solubility. Collaboration can be viewed as a type of ethnographic research which characterizes a supportive research environment where theoretical and practical aspects are intertwined.

While Chapter 3 focuses on how the researcher adopted phenomenography, this chapter describes its general principles and discusses some of the methodological concerns.

2.4.1 Phenomenography: An Analytical Framework

A branch of conceptual change research specialization labelled "phenomenography" has been conceived and developed over the past fifteen years by a group of researchers at Gothenburg University in Sweden under the leadership of Ference Marton (1981).

Phenomenography is a study of the qualitatively different ways in which people experience and conceptualize the world around them. It is an experiential perspective,
a view of conceptions of phenomena as relational (i.e. as describing relations between
the conceptualizing individuals and the conceptualized phenomena). Phenomenography
shows a concern for both the “how” and the “what” of learning (i.e., the act of
conceptualizing and the meaning of the phenomenon as conceptualized (Lybeck, Marton,
Strömdahl and Tullberg, 1988, p. 83)). These principles set apart phenomenography
as a distinct research specialization. It does not consider conceptions and ways of
understanding as individual qualities (Marton, 1981). However, it is recognized as
complementary to conceptual change theories discussed in the previous section because
Marton and his group view learning “as a change from one way of understanding
a phenomenon to another and qualitatively different way of understanding the same
phenomenon” (Lybeck, et al., 1988, p. 271).

Phenomenography has been viewed as an inquiry tool for the generation of naive
conceptions or meanings (functional and sensible from the students’ point of view) that
can be found among the students about reality and to describe the changes that take
place in those naive conceptions (Johansson, Marton and Svenson, 1985). What is
most appealing about this research is how Säljö (1988) describes learning. Adopting
the language suggested by Berger and Luckman (1967) that societies contain differing
“provinces of meaning,” Säljö (1988, p. 38) states that “science can be considered as one
(or many) such province(s) where specific ways of construing reality are adopted for the
purpose of developing theoretical accounts of nature and society. Built on this premise,
he describes learning as the “acquisition of conceptions of reality that stem from this
specific province of meaning and that differ from those employed in everyday thinking”
(Säljö, 1988, p. 38). Säljö’s interpretation of learning is an added facet of conceptual
change research.

This study looks at students’ provinces of meaning. Students’ conceptions are
acknowledged to be valid because of the different provinces in which a system is
considered. The following illustration supports this stance: From their everyday experience (province 1) students describe dissolving as melting. When they begin to learn chemistry (province 2), dissolution of salt in water is described as a physical change because salt can be retrieved from the solution by a simple mechanical process. In advanced chemistry (province 3) a solution of sodium chloride in water may be considered an electrochemical change because there are two “entirely new species” of compound. It can be stated that students may and will move from one province to another depending on the context in which the solution of salt in water is discussed. From this example it is argued that meaning given to the phenomenon of dissolution of salt in water is province or context dependent. Because of context-dependent talk, students' understanding of solubility is given empathetic considerations. The study promotes a teaching environment which will adopt this principle of phenomenography.

Thus far, phenomenography has represented students' understanding of scientific concepts, principles and phenomena in four ways: (a) a collective map of patterns of reasoning (Lybeck et al. 1988, p. 92); (b) perspectives of reasoning (Lybeck et al., 1988, p. 98, Tables, 1, 2, and 3; and Linder 1989, p. 81); (c) the categories of description or the outcome space; and (d) a hierarchy of the categories of description (Renström, 1988). Representing students' reasoning by means of a “collective map” or presenting students' perspectives of reasoning systematically in charts are classified only as by-products of this research (Lybeck et al., 1988). The categories of description are seen as central and used as the main results of the phenomenographic research enterprise.

The categories of description are distinct from conceptions. Categories of description are ways of denoting the researcher's interpretations of students' conceptions. Categories of description feature qualitative as well as quantitative aspects. The qualitative outcome is the categories of description and the quantitative result is the frequency distributions related to the categories (Renström, 1988).
An important characteristic of this research process is that categories are "systematically worked out in relation to the data during the course of research" (Glaser and Strauss, 1967, p. 6). In other words, no pre-determined categories are set by the researcher before research begins. Since the ways in which an individual construes the world is dependent on the individual's physical and social world, the number of conceptions is limited.

2.4.1.1 Phenomenography in Relation to Cognitive Science

While phenomenography describes learning as a change between qualitatively different conceptions, cognitive science views it as a development and change of a series of mental structures representing varying degrees of complexity (Driver, 1987). Driver argues that "a key feature in this perspective is that human beings construct mental models of their environment and new experiences are interpreted and understood in relation to existing mental models or schemes" (Driver, 1987, p. 3). While the nature of the representations of student knowledge are different, the pedagogical implications drawn from each are similar. For instance, both argue for conceptual change teaching and some of the strategies employed are the same (e.g., cognitive conflict strategy to change student's conceptions).

The relationship between phenomenography and Piaget's work is noteworthy. Some commonalities can be found in phenomenography and Piaget's (1973) work: (a) "the orientation towards understanding and describing how people construe significant phenomena in the world" (Säljö, 1988, p. 36), and (b) the linguistic expressions of the conceptions of a phenomenon can be numerous (beneath them are limited conceptualizations).

However, their epistemological assumptions are strikingly different. For instance, according to Piaget differing conceptions of the world are construed as results of the
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age and/or developmental level or variations in intellectual maturity of the student responding. This implies that there is a systematic quality to students' answers according to their maturity level. In the phenomenographic approach, one is more concerned with describing the possible variations in conceptions held by individuals for a particular phenomenon without a strong concern for the developmental mechanism that created that variability. In this sense, phenomenography is a methodological approach that is compatible with a relatively broad set of theoretical perspectives that focus on people's conceptions or reality and not on the quality of their answers as related to maturity and age. It adopts an epistemological perspective that the world is inherently multifaceted and open to variations in interpretation. Commitment to this epistemological stance occurs because phenomenographers believe that the world is seen through a particular "lens" and that there is no such thing as common and unbiased reality to every human. Phenomenography may be described as a field that is interested in the lens that people use to construe meaning to the world.

2.4.1.2 A Common Concern in Phenomenographic Approach

A concern that is often expressed about this type of qualitative analysis is the consistency of an individual's responses to a certain phenomenon. Based on this concern, two questions arise: (a) What if the questions are asked in a different way using a different strategy and examples? (b) If the responses are not consistent how can teachers rely on this knowledge? Phenomenography adopts the principle that human thinking is contextually determined (Säljö, 1988). It presupposes that conceptions of reality do not reside within individuals (intellectual capacity or developmental stages) because people's conceptions of reality are particular to particular context and problems raised within that context. Dahlgren (1984) illustrates how people tend to explain prices of commodities differently depending on the type of object that was mentioned in the question.
Secondly, the categories of descriptions are the interpretations made by a person who is knowledgeable in the specific discipline. They are derived in relation to specific meanings inherent in the content area or against the background material.

2.4.1.3 Validity and Reliability

Phenomenography is a scientific undertaking which consists of "rigorous qualitative analysis" (Entwistle, 1984). It results in a researcher-generated set of categories. As pointed out earlier, individuals use a lens to filter reality. Since researchers will and can have different ways of construing the interpretations (categories of description) that stemmed from the interpretations of the students (conceptions), is it possible to argue for the validity and reliability of the categories of description? For the validity and reliability of the categories of description, three canons of research apply (Säljö, 1988, pp. 45 and 46):

1. Another person can be used to test the validity of the research results by providing him or her the general explanations of the categories of description with examples of students' statements that fit the categories. The co-judging, therefore, can be thought of as a process of testing whether or not it is possible to communicate the findings to another person and whether this person, in analyzing students' conceptions, would arrive at the same conclusions as the researcher. This type of inter-rator reliability is a test of the communicability of categories. Despite this process, perfect agreement among judges may not be achieved as a result of coding difficulties and because of the difficulty in interpreting linguistic statements.

2. A mode of validating the set of categories is to compare the study with other studies. Can certain categories be applied to other studies? In addition, applicability of categories across investigations adopting a similar perspective is possible.

3. A means of testing the appropriateness of a set of categories is the internal logic of the categories themselves. As found in other studies (Linder, 1989; Renström, 1988), differing conceptions of reality relate to each other in specific ways. For example, take the concept of dissolving; if the students centre their thoughts on the macroscopic observations, they come up with certain conception(s), but if they think in terms of microscopic explanations, they arrive at different conceptions. Conceptions based on both macroscopic and microscopic characteristics are possible because of the internal structure of the concept of dissolving. Learning about dissolving then consists of acquiring or changing conceptions based on the macroscopic as well as the microscopic perspectives and learning when each is appropriate to use to address particular problems.
2.4.1.4 Concluding Comments

Driver and Erickson (1983) in their discussion of methodological issues point out that within the area of conceptions research there are variations in the research aims, methodology (generating and analyzing or transforming) and utilization. Linder (1989, pp. 20 and 21) reports that the epistemological criterion which guided him to choose the phenomenographic approach instead of the rule-assessment technique (Aguirre, 1981) and the interview-about-instance (Gilbert, Watts and Osborne, 1985) was the lack of normatively based prescriptions for instruction in the former and the explicit normative qualities in the latter ones. His argument was that phenomenography provided the best support for his belief that the outcomes of this [type of] educational research should guide teaching with insights into how students conceptualize “what” is being taught, rather than to prescribe “how” to teach.

This study revolves around a view of teaching that considers learning as a “qualitative change” in a student’s conceptions of reality, or a change in the human-world relation. Therefore, the study entails firstly a description of the students’ ways of thinking about solubility (described in Chapter 4), and, secondly, the qualitative changes in their thinking (presented in Chapter 6). For this purpose, phenomenography has been used as an analytical tool.

Insights into students’ conceptions as a type of research in education is important because “teaching and learning are communicative activities and they involve attempts to change people’s conceptions of reality in order to adopt the particular forms of thought characteristic of specialized linguistic and cognitive communicative communities” (Säljö, 1988, p. 44) such as the ones represented by chemists. In learning chemistry, one of the objectives is to guide students to acquire the conceptions or to “see” the theoretical aspects that are used to describe phenomena. Insights from the phenomenographic
approach are seen as fulfilling this objective by providing the teacher with intellectual tools or a framework to research her students' initial conceptions, to plan teaching, to analyze what is being understood or misunderstood, to trace the qualitative changes that might take place in those conceptions, and to evaluate the success of teaching. In other words, phenomenography is a tool for learning to learn the process of learning and to explicitly reflect upon the students' difficulties in understanding.

2.4.2 Collaborative Inquiry and the Construction of Professional Knowledge

The study intended to incorporate students' conceptions of solubility in the instruction of a unit on solution chemistry. In accordance with the previous work (Aguirre and Kuhn, 1988; Parsons-Chatman and Seiben, 1988) conducted by the [SI]^2 research group, of which the researcher is a member, this constructivist perspective of teaching and a reflective inquiry of it was proposed to be carried out in a collaborative mode with the students' chemistry teacher. [SI]^2 counterparts such as the CLIS in England and PEEL in Australia are systematically carrying out extensive classroom-based collaborative research on constructivist general and content-based teaching strategies. For instance, Driver (1987) contends that research and development of constructivist approaches to science teaching should be a collaborative exercise between teachers and researchers. Accordingly, curriculum materials, and teaching strategies are developed and tested in conventional classrooms. Thus far, none of these constructivist collaborative researchers have said anything about the collaboration itself. An offshoot of this study will be to state implications for future collaborative work, as "research findings that could inform collaborative efforts are nonexistent" (Tindill, 1989).

A constructivist view of professional knowledge is that it "is in a state of continual growth and change" (Erickson, 1989). Concurrently, this growth and change of knowledge must be reflected by researchers and practitioners. How can construction of professional
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knowledge be nurtured and facilitated?

Since constructivist strategies of teaching and learning are radically different from the conventional methods of teaching and learning, teacher change may be difficult. A researcher can have an influential role in helping the teacher to clarify and interpret her/his experience, to reflectively analyze her/his prior ideas, and to provide sympathetic support in the process of change. This exercise benefits both the teacher and the researcher because they are joint learners, experimenters, and evaluators in the process of bringing about the desired change. Teachers who have participated in collaborative projects have acknowledged their conceptual changes with regard to alternative perspectives of teaching and learning (Baird and Mitchell, 1986). One teacher in the CLIS Project has commented thus: "the best place for designing the curriculum is where learners and teachers meet" (Driver, 1987).

When teachers conduct research in their own classrooms in collaboration with university researchers, they generate "knowledge about learning in a manner which facilitates utilization of the findings of the research conducted on-site" (Casanova, 1989; Kyle and Shymansky, 1988; and Swift, 1989). In a collaborative venture, the teacher becomes an active participant in interpreting the knowledge acquired from research (Hoyle, 1985). A research context of this sort would encourage knowledge acquisition through a reciprocity of actions and reflections (Burton, 1986). Through thought and action, experimenting with content-relevant instructional strategies and meta-cognitive strategies consistent with a constructivist model would give the teacher and the researcher an opportunity to develop insights into and look at the current model of teaching and learning science in novel ways. The context of collaboration provides ample opportunities to test collective teaching ideas and learn from each other. It is a special type of in-service which fosters professional development. The PEEL Project reports that it is this aspect of professional development that sustained interest and motivation during the difficult
early classroom experiences (Baird and Mitchell, 1986).

Thus collaboration is an alternative to other attempts to nurture growth and facilitate change which are based on either the withdrawal of the researcher from the setting or the researcher being non-participant observer in the setting which he/she is seeking to change. Immediate application of research results in the classroom is possible not by non-participation but by developing results out of investigations involving teachers (Lieberman, 1986). Teachers "reject academic elitism and the trickle-down theory of educational change" contends Wideen (1989). Efforts at collaboration endeavour to "develop a shared language" even among professionals with different perspectives, especially when they learn through complex, long-term projects (Erickson, 1989; Jacullo-Noto, 1988; Wideen, 1989).

Attempts to introduce change are more likely to succeed if the collaborators "address the 'social' as well as the 'material' realities and barriers within the institution's unique culture" (Oldroyd and Tiller 1987). Guidelines for making collaboration work are: common goals, availability of time for shared experience, mutual trust, respect, risk-taking, commitment or political will, and institutional support (Wideen, 1989).

In the foregoing section, arguments were advanced for a collaborative research project with the teacher in order to utilize students' conceptions of solubility in a chemistry classroom.
Chapter 3

Design and Methodology

The purpose of this chapter is to map out the trails of the study that the researcher took from its inception to conclusion. The study consisted of eliciting Grade 11 chemistry students' prior conceptions of solubility, documenting the teacher-researcher collaborative instruction of a unit on solution chemistry, analyzing the influencing factors that facilitated and constrained the efforts to incorporate students' prior conceptions in the instructional procedures, and examining the possible changes in conceptions in students as a result of instruction.

The research consisted of four phases:

1. preliminary work;
2. pre-instructional clinical interviews;
3. participant observations of instruction of a unit on solution chemistry; and
4. post-instructional clinical interviews.

Each of these phases will be discussed in the following sections of this chapter.

3.1 Phase 1: Preliminary Work

3.1.1 Document and Content Analysis

At the outset, the researcher examined Grade 11 chemistry course-related documents and content materials. The published written material included the Chemistry Grades 11 &
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12 Curriculum Guide (Ministry of Education, British Columbia, 1987), Heath Chemistry (Herron et al., 1987), Heath Chemistry Laboratory Experiments (Dispezio et al., 1987), Fundamentals of Chemistry (Brady and Holum, 1984), and journals such as The Journal of Chemistry Education (1980-88), and Chemistry in Education (1980-88). Content analysis enabled the researcher to choose the overall concept —“solubility”— and to identify interesting and pertinent demonstrations for the study. Document analysis of the British Columbia Ministry Grade 11 & 12 Curriculum Guide provided a broad picture of the context in which chemistry teaching was taking place.

3.1.2 The Pilot Studies

The pilot studies consisted of two strands: clinical interviews of students to examine the sorts of conceptions students had of solution chemistry, and observations of two Grade 11 chemistry classrooms to analyze the ways in which chemistry instruction was carried out.

3.1.2.1 Clinical Interview

The interview took on the features of the clinical type as propounded by Piaget. In this sense, the interview consisted of letting the student talk and noticing the manner in which his or her thoughts unfolded. It also consisted of following up each of the students' answers and allowing the student to talk freely (Piaget, 1926, pp. xiii-xiv).

The interview was an open-ended exploration of the understandings the students had about the event. The questions were formulated as the interview proceeded to stimulate openness. The students were encouraged to express their understanding of the aspects of solution and solubility and to give their interpretations of phenomena such as dissolving. The main goal of the interview was to ascertain the nature and extent of a student's
knowledge about solution chemistry by identifying the relevant conceptions he or she held.

The interview started at home in October, 1988, with the researcher's son, Sudesh, who was just completing Grade 10 through Correspondence from the Ministry of Education, British Columbia. The demonstration that was shown to him consisted of adding sugar to cold water. It was a 45-minute conversation. When the researcher's Grade 5 niece, Andrea, visited her, the same demonstration was shown and her conceptions were elicited. While Sudesh said that dissolution of sugar in water was a chemical change, Andrea's imagination was a creative one. She imagined water to be arrows which penetrated into and burst opened the molecules of sugar and lodged inside the sugar. These conversations, which were videotaped, gave the researcher some notions of how children relate to the phenomenon of the addition of sugar to water.

From January to April 1989, the researcher had the opportunity of teaching SCED 190 (a science content course for elementary school pre-service teachers). Before introducing a unit on "mixtures," an open-ended questionnaire was given to all the student teachers as part of their instructions. Demonstrations were also shown on this topic. This was done for two reasons: to introduce the teachers to a method to identify students' ideas about specific science concepts such as dissolving, and to examine their conceptions of solutions/solubility. They were told that it was not a test. However, the student teachers wondered about the consequences of this so-called questionnaire. Then they were invited to participate in clinical interviews at their convenient time. The students were told that the clinical interview is a method of eliciting children's ideas. It was mentioned to the student teachers that this experience will give them an idea of the course of a clinical interview and also give the researcher a chance to have practice in asking students appropriate questions that will follow a "depth interview" (Jones, 1985). The students were assured that non-participation in the interview would not affect their
course marks. Ten students participated in the interview. Some of the solution/solubility demonstrations published in the Journal of Chemistry Education (1980-1988) and some gathered from other sources were used with these student teachers.

The demonstrations consisted of dissolving of sugar/salt in water, miscibility of iodine in alcohol, conductivity of salt solution, chemical reactions in solutions, and equilibrium of sodium chromate in solution. The interviews with student teachers were video-taped. No analysis was undertaken to categorize students’ conceptions of solutions/solubility since these attempts were considered as pre-pilot studies.

In 1989 after Spring break, just before Grade 11 students began their study of solution chemistry, a chemistry teacher of a non-semestered school was approached to conduct a pilot study with her students. Of the three Grade 11 chemistry sections she taught, nine students were willing to participate in the study. These students were interviewed before and after instruction of solution chemistry. Pre- and post-interview demonstrations were similar. All interviews were video-taped.

Deciding on an analytical tool to analyze the data gathered from these Grade 11 students was not an easy task. Considerations were given to the following ways of analyzing the data: the words that the students used to describe what a solution was and how a solution was formed (word-sorting technique); the types of relationships the students sought among concepts of solution chemistry (a technique followed by concept mappers); and categorizing students according to the proximity of their conceptions to the scientific conceptions (Hesse, 1987).

The final decision with regard to the analytical tool for this study was influenced by two pieces of work. Cedric Linder had completed a phenomenography of sound in March 1989 with university students—physics pre-service teachers. Shortly after that, in July 1989, a seminar on phenomenography was given at UBC by Ference Marton. In this seminar, Marton discussed the findings of Renström, who had done an extensive
study of students' conceptions of matter in 1988. Subsequently, Linder's and Renström's dissertations were read carefully to follow through their arguments for adopting the phenomenographic method to analyze students' conceptions of solution chemistry. The researcher was persuaded by these arguments.

Before data analysis began, the video-tapes of the pilot studies were viewed carefully and five interviews were transcribed verbatim. During the analysis stage of data, it became apparent that trying to develop analytical categories for all of the various concepts of solution chemistry in the pilot interviews became unmanageable. Therefore, only the concept of solution process was considered for analysis and it was done by means of the "phenomenographic approach" in order to reveal the qualitatively different conceptions of students.

Phenomenography was seen as the most appropriate tool for this study because it is a research specialization aimed at revealing different ways in which people see, experience, understand, conceptualize various phenomena in the world around them (Marton, 1981). "It is a non-algorithmic, interpretive discovery procedure that —if successful— results in a set of related categories of description" (Renström, Andersson, and Marton, 1989, p. 17). The basic doctrine of phenomenography is that it is not a description of the students, rather it is a description of the "outcome space" of possible ways of thinking about a certain phenomenon (Ibid., p. 18). The outcome space is the space over which the students' thoughts may range.

The preceding premise of phenomenography is in harmony with the guiding principles of this study. The study did not revolve around placing students along a continuum of incorrect to correct thinking. Rather it described the ways in which students perceive the "content" of solution chemistry from their perspectives. An additional ground for using the phenomenographic method was that it provided a way to have an empathetic understanding of the students' perspective especially when an attempt was made to
incorporate their conceptions in teaching solutions/solubility.

3.1.2.2 Classroom Observations

For classroom observations, ethnography, a methodology compatible with a phenomenographic approach, was selected for this study. Ethnographic research requires the researcher to make detailed observations of what is said and done. According to Junker (1960), the researcher who plays the role of a participant/observer actually participates in the pattern studied—takes a role in its action system, becomes a co-worker and internalizes the pattern.

Science educators such as Easley (1982), Kilbourn (1982), and Smith (1983), suggest the above type of qualitative research in science education is important because it provides insight and understanding of the procedures of a classroom. Therefore, an ethnographic approach was considered most appropriate to do a study on chemistry teaching and learning.

During the first phase of the study, two chemistry teachers were observed without the researcher’s participation of any kind in classroom discourse. The purpose of the observations was to examine the ways in which chemistry was taught to Grade 11 students by these teachers.

The first observation was done in a small school in the Lower Mainland of British Columbia where chemistry is taught by one teacher. The teacher also taught science and mathematics for junior secondary students. The data collection process took place over a period of four weeks, from mid-February to mid-March in 1988. During this period, the teacher dealt with the following topic: Types of Chemical Reactions—combination or synthesis, decomposition, single replacement, double displacement or metathesis. The laboratory activity was “Investigating a Type of Chemical Reaction.” More specifically,
the lesson was based on (1) a discussion on the sources of error as related to the above-stated lab investigation and completion of the lab activity by the students in pairs, and (2) correction of a homework assignment, as a class, on the types of reactions—classifying different types of chemical reactions.

Analysis of the classroom data indicated three types of knowledge that a teacher engages during chemistry teaching: propositional knowledge, procedural knowledge, and laboratory skills. These types of knowledge can be subsumed under a major category which can be termed as academic knowledge. Another type of knowledge that emerged from the data could be described as private or personal knowledge which the student brings to the chemistry class.

The analysis provided evidence concerning the disparity of common knowledge that exists between a chemistry teacher and his students through the process of knowledge construction and sharing because of the tension between the academic knowledge and the student's private knowledge. Because of this disparity, the analysis showed that a most commonly used method of conveying academic knowledge was elicitation, either contributed or cued by the teacher. This results in the teacher having control and power over student learning. Analysis of classroom data also indicated that for students to be acknowledged, or welcomed, in a chemistry class, they should leave their personal knowledge outside and enter into the teacher's realm of meaning. This means that the academic knowledge should be learned in order to converse with the teacher and to be successful in chemistry.

The second observation took place in a semestered secondary school in the Lower Mainland of British Columbia. The teacher taught Grade 12 biology and Grade 11 chemistry. In the second semester, the teacher taught four sections of chemistry. Six periods were spent in this chemistry classroom during April and May 1989. During this period, topics such as structure of the atom, electric nature of the atom, history and
the evolution of the atomic model, and acids and bases were covered. Two formal labs, namely, pH and titration, and precipitation were also conducted.

The dominant method of teaching was through interesting, informative lectures that were replete with everyday examples. Lectures were augmented by demonstrations to explain most of the concepts under study. The students were allowed to play for a short while with static electricity activities. The teacher finally demonstrated all the activities of static electricity and showed the electric nature of the atom. The formal labs were conducted by students in groups. The students were expected to arrive at results for their titration that had an error of less than two percent. The main attention was to note accurately the colour change of the solution in the volumetric flask and to calculate the molarity of the unknown solution. Lab reports were graded in terms of the discrepancy of the student’s answer from the concentration values of the solutions that the lab technician had given the teacher. Thus laboratory skills, in this case the proper techniques of titrations were emphasized for accurate results.

Although the classroom events were audio-taped, no formal analysis or report was written for what the researcher observed in the second teacher’s classroom. In summary, the first teacher attempted to carry on a Socratic dialogue with his students to teach chemistry. The second teacher employed a lecture method. Both teachers exhibited an in-depth understanding of chemical knowledge.

The pilot studies of clinical interviews and classroom observations were valuable in that the researcher had the opportunity for ample experience in conducting clinical interviews. The researcher was able to sharpen her questioning techniques. Furthermore, she was able to come up with a set of appropriate demonstrations and questions for the main study. Ethnographic observations of the happenings of the two chemistry classrooms were insightful. The different teaching styles were noted. Concerns were expressed by the teachers about content coverage, and time constraints.
3.1.3 Preparation for a Teacher-Researcher Collaborative Study

Thus far, only one study in the change of students’ conceptions of science concepts has been undertaken where the researcher has worked collaboratively with the teacher (Snively, 1987). The present collaborative study was intended to be embedded in an eclectic form of an action research model. The intentions of the present collaborative action research study were:

1. to improve chemistry teaching practice;
2. to conduct the study in the real setting i.e. in a chemistry class;
3. to deliberate and consult with the teacher;
4. to converge on “the case” (Stake, 1978)—a unit on solution chemistry, chemistry teacher and her students;
5. to share students’ prior conceptions of solubility with the teacher and to incorporate students’ prior conceptions in instruction;
6. to use eclectic methodology—clinical interviews, audio- and video-taping of instruction, and examination of students’ teaching and learning materials such as lab-notes, teacher-given notes, tests and exams;
7. to link to educational and research theory appropriated by the researcher from the experience of teacher-researcher collaboration.

A collaborative action research between the teacher and the researcher can have many perspectives. The nature of collaborative research is often dependent upon the role adopted and function played by the co-researchers. A typical collaborative study suggests members of the research team working in partnership (not necessarily doing the same task) from the identification of a problem to the dissemination of research interpretations. In this sense, the members hold joint ownership throughout the process of the study and become co-authors in its publication. The present study takes a different perspective of collaboration while retaining the essential features of such research.

In the present study, the researcher identified the general research area from her many years of interest in chemistry teaching and learning. The research problem became
more focused and defined when she accepted the notion that a constructivist perspective is fruitful for chemistry teaching. That is, a deliberative attempt is made to relate new knowledge to students’ prior knowledge. Research questions were identified, transformed, and formulated during one and a half years of extensive reading in the research area of students’ conceptions. It was felt a qualitative (Erickson, 1986) classroom-based study would be most useful for the utilization of information on students’ prior knowledge of solubility so that the teacher becomes an active collaborator in the study of incorporating students’ prior conceptions in her instructions.

The success of the study, it was believed, would depend upon the following attributes:

1. the teacher’s trust of the researcher in expressing her ideas without any reservation about the teacher’s own notions of science teaching;

2. collaboration within a mutually acceptable ethical framework;

3. the teacher’s and the researcher’s willingness to adopt a critical stance towards their own practice; and

4. the teacher and the researcher jointly bridge-building between practice and theory.

Several hypotheses were put forth for this study:

1. Joint experimentation by the teacher and researcher will change and improve teaching and learning of chemistry.

2. There will be further professional development and change as the teacher and the researcher engage in reflection on the instruction that would incorporate students’ prior conceptions.

3. The study will encourage the teacher to think about the contemporary theoretical issues of teaching chemistry and introduce reflection as an integral part of her practice.

4. Because of the teacher’s intervention and mediation, the researcher will derive richer meaning of the practical issues, and the teacher’s culture and her enterprise.

### 3.2 Description of Group

Jane was chosen for this study because of her exuberance and her openness to new teaching methodologies such as cooperative learning, and because of her wanting to build
her repertoire of teaching strategies, her seeking and experimenting with new ideas, her conducting workshops and attending workshops within and outside the school district. Jane taught Chemistry 11 and Biology 12 in an urban, Lower Mainland secondary school that offered Grades 11 and 12. The school consisted of nearly one thousand students. The students belonged to upper- as well as middle- class families. Besides offering course work in regular programs, the school also made special provisions for English as a Second Language (ESL) students.

Thirteen of Jane's Grade 11 students (nine females and four males) participated in the study. Included were: five Asian-Canadians (three ESL boys, and two girls), one Filipino-Canadian (girl), one Indo-Canadian (girl), six Caucasian-Canadians (five girls and one boy). Two of the thirteen students (girls) were officially registered in the Grade 12 program, but were taking Grade 11 chemistry.

3.3 Phase 2: Pre-Instructional Clinical Interviews

Phase 2 of this collaborative study consisted of data collection for the main study. It included the researcher identifying conceptions of solubility of Grade 11 chemistry students of the collaborating teacher. The thirteen Grade 11 chemistry students voluntarily took part in a clinical interview during lunch time and after school hours. Arranged by the teacher, the interviews with students took place in her classroom. Each interview consisted of thirty minutes and it was audio-taped.

3.3.1 Interview Activities

The demonstrations for the interview consisted of three chemical systems: sugar/water (System A), water/alcohol/paint thinner (System B), and salt/water (System C). The

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1See Appendix A for a letter of acceptance.
descriptions for chemical systems B and C were obtained from a chemistry teacher from Memphis, Tennessee, who attended the Chem Ed '89 conference with the researcher. In his session, this teacher stated to the audience that he taught chemistry by using bottles. The teacher called System B “frustration bottle” and System C “concentration bottle.” The bottles were displayed in his classroom while he taught solution chemistry, the teacher stated. At the end of the unit, he expected students to write all what they knew about the two systems. The teacher stated that his students’ talk revolved around these bottles and that they showed interest and curiosity as they developed the concepts of solution chemistry. The three systems were chosen because all of Grade 11 solution chemistry can be taught using these. In the next section, the three chemical systems depicting the phenomenon of solubility and some of the interview questions will be presented.

3.3.1.1 System A: Sugar/Water

A cube of sugar was introduced into a beaker containing hot water.

Questions:

- What might be happening to the sugar?
- What do you understand by dissolving, breaking, diffusing, melting, transforming into a liquid, combining, disappearing, decomposing, falling apart, separating, mixing, attaching, reacting, becoming a solution, and attracting?
- What do you mean by “particle”?
- Can you draw a picture to describe what is happening to the sugar in water?

3.3.1.2 System B: Water/Alcohol/Paint Thinner

Alcohol was poured into water. A drop of food colouring was added for desired effect. Paint thinner was poured into the water/alcohol mixture. Two distinct layers were seen.
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The bottle was turned end to end if the student wanted to see if any mixing would take place. **Questions:**

- Can you tell me what is happening?
- Why are there two layers?
- What do you think is in the upper layer?
- Why do you think there is no room for paint thinner in the water/alcohol mixture?

3.3.1.3 System C: Saturated Solution of Table Salt

A closed bottle containing water and recrystallized table salt was displayed. **Questions:**

- Why has salt settled at the bottom?
- Is there salt in the upper part of the bottle?

Some of these questions evolved in the pilot studies with Grade 11 students and pre-service teachers. A complete pre-instructional interview transcript (Nila—one of the four students selected for case studies) is included in Appendix B.

3.3.2 Procedures of Data Analysis

The pre-instructional interviews took about seven days. At the end of each day, interviews were transcribed verbatim. To make the analysis stage less difficult and less time-consuming, an enormous amount of time was invested in transcribing the tapes. While transcribing, certain categories became readily apparent.

At first, interview transcripts for each system were analyzed separately. This was because in the pilot study, the students were asked to depict the solution process by observing the sugar/water and salt/water systems. In the pilot study, the outcome space of solubility consisted of students' conceptions such as "salt was melting" and "turning
into a liquid." The disappearance of salt in water was viewed as a chemical change. These types of reasoning are evidenced in the following excerpts:

To protect the anonymity of the students, they have all been given names that begin with the letter "J". In the excerpts, "R" denotes researcher and "S" denotes student. The excerpts are supported by a preliminary analysis to give some insight into a comprehensive data analysis of the present study.

Julie (1)

R: Here I have a beaker of water. I am going to add table salt to water. What happens to the salt as I stir it in water?
S: It is dissolving.
R: What do you mean by dissolving?
S: It's turning into a liquid.
R: Could you explain what you mean by 'becoming a liquid'?
S: It's transforming. There is salt and the water comes in. It changes the taste.
R: Can you tell me more about what is happening?
S: It's a chemical reaction.

A portion of another excerpt when a student was shown sugar dissolving in water is in line with the above thought.

Janet (2)

Sweetness is imparted to the water. It is thought of as forming a new product.

The foregoing idea conveys that since water has acquired a characteristic taste, either salty or sweet, dissolving is thought of as a type of chemical process. In addition, the student notes that the salt is transforming from a solid state to a liquid state. Such physical transformations are given as reasons for considering a mixture of salt or sugar and water to involve a chemical reaction.

In the following excerpt, the taste of water produced by lemonade mix is not given as a reason for considering the lemonade mixture a chemical reaction. Instead, the presence of two parts, that is, a mixture of water and lemonade mix, was the suggested reason for the mixture to be a chemical reaction.
Jansi (3)

Lemonade is an example. There are two parts. You have to add water and the mix, right. Then they combine to form a new product. But there are solutions in science, like these things have. Right here. Like sodium hydroxide is a solution. ...Na, O, and H combined and, like, something has happened. ...It's a chemical reaction. It's usually soluble or insoluble. There are all sorts of solutions. They combine things.

Here the student advances a different argument for the solution process. She states that the parts are combining to form a new product. In the case of lemonade, the parts are water and mix and in a like manner to the case of a sodium hydroxide solution, she considers each element or atom, that is, Na, O, and H, as a component. This type of reasoning gives the clue that this student is confused between the formation of a compound and the formation of a mixture. She sees logic in stating that Na, O, and H are parts just like lemonade mix and water. But the explanation given is not in harmony with what chemists' offer about the difference between a compound and a mixture.

Consider the following excerpt. This student takes us a further step by giving a particular name to the solution process. His reasoning is not guided by his perceptions. It seems that this student is trying to remember what he had learned in previous chemistry lessons.

Jagan (4)

R: You said NaCl and water will be a solution. So when I add salt to water, what happens?
S: Okay, it's like a reaction is going on. It's a single-displacement reaction going on in the jar and it's like NaCl with water in the jar.

He writes the equation and tries to balance.

\[ \text{NaCl} + \text{H}_2\text{O} \rightarrow \text{NaOH} + \text{HCl} \]

The solution process was considered as a chemical reaction by all four students. However, each one gave a different explanation. This implies that these students' understandings
of the solution process were qualitatively different. In addition, students’ explanations were characterized by different levels of complexity and sophistication.

The preceding type of interpretation arises from the researcher’s conceptualizations of the students’ perspectives of the phenomenon “solution process.” When a researcher adopts this stance, Marton (1981) refers to it as a second-order perspective. It means the researcher is not interpreting the phenomenon but students’ perceived ideas about the phenomenon. As well, the researcher is not describing the student, but his or her perceptual world.

Having gone through this type of analytical process during the pilot study, the researcher read the interview transcriptions to see if students’ conceptions manifested the same type of categories as in the present study. It was found that some conceptions were similar. In the main study, however, the interview transcripts were read over and over again to see whether there were any variations within these categories. For example, dissolving as a process of melting was described in terms of continuum theory and particulate theory in the present study. Hence such variations were looked at carefully.

The current transcripts also showed other interesting categories of descriptions of solubility, such as density of solute. This was because the salt/water system was shown in a different form in the present study. In addition, the water/alcohol/paint thinner system was introduced in this study.

During the pilot study as well as in the main study, in order to categorize students’ conceptions, the original interview transcripts were photocopied and colour coded. These were then cut up into pieces and gathered into individual piles. Each pile characterized a category of description. A tentative title was given to each of the categories. Although the wording of the titles of the categories was changed to give the best picture of students’ conceptions, the meaning remained the same. This procedure of data analysis for the construction of categories was not a simple task. It took many hours, days, and months
of reflective analysis. Sometimes two related categories were put together. For example, "melting" and "forming a liquid" were amalgamated because students' conceptualization was the same, although different word sequences were used to describe the process of melting. During the writing stage also, it was made sure that the title depicted a more accurate picture of what was conceptualized by the students. To get ready for instruction, a tentative set of categories of students' conceptions of solubility was presented to the collaborating chemistry teacher as soon as the initial analysis was done.

3.4 Phase 3: Classroom Observation

Normally, in a non-semestered school, solution chemistry is taught in the last part of the academic year. In Heath Chemistry (Herron et al., 1987), solution chemistry is the 16th chapter. According to the Grade 11 and 12 British Columbia Curriculum Guide, 15 hours are allotted for the study of solution chemistry. Because of research plans the instruction in solution chemistry was moved to November. Solution chemistry was taught beginning November 2 and it was concluded on December 7. Two sections—chemical reactions in solutions and precipitation lab, and pH and titration—were left for February since the students were getting ready for their major research project for the year.

The first three lessons were taught by the researcher. Each of these sessions was video- and audio-taped. The rest of solution chemistry was taught by the teacher. The unit on solution chemistry was interrupted because of a review for the major exam on the previous unit, and the exam. These took two days. Another day was taken up for Professional Development. A period was also used for the introduction of a major project. Two days the teacher was away from school. In her absence, a substitute teacher taught solution chemistry. Therefore, the researcher was present in the classroom on eight days—the first three days, a lesson on model building, polar and non-polar lab, post lab-discussion,
review for the exam, and solution chemistry unit exam.

Whenever the researcher was in the classroom, the lesson was audio- and videotaped to capture the instructional setting. The teacher reflected on the researcher's first lesson, her lesson on model building of water and ethanol molecules, and on the research project after the unit on solution chemistry was over. Informal conversations were also held on five different days prior to the study. Most of the conversations were audio-taped. Reflection logs were written about the nature of the conversations. The teacher's actions, her critical reflections upon her practice, and a profile of the collaboration were documented through ethnographic description, narrative and interpretive accounts.

3.5 Phase 4: Post-instructional Interviews

At the end of the unit, soon after the exam, the same thirteen students participated in the interview. The same demonstrations were used. Each interview took about 30-45 minutes. Questions were asked for in-depth learning (interviews were audio-taped, transcribed verbatim, and categorized). What is the "outcome space" after instruction? Have the students' conceptions changed, and if so, in what ways? Links were also made in terms of pre- and post- conceptions for four students. The criteria for choosing four students for case studies are outlined in Chapter 6.
Chapter 4

Students' Conceptions of Solubility

4.1 Introduction

This chapter discusses students' conceptions of solubility as it pertains to the following question:

What are the most common conceptions of solubility found in Grade 11 chemistry students before an instructional unit on solution chemistry?

A phenomenographic approach is used to generate an "outcome space" (defined in chapter 1 and described in chapter 2) of students' conceptions of a phenomenon. Phenomenographers are of the opinion that "the differing understandings of various phenomena are not specific to particular contexts, although they cannot occur other than in some context" (Marton, 1988). If this view is accepted, one can argue that the experts will explain all three chemical systems in terms of the concept of solubility and by referring to the chemical structure of various components used. It is very unlikely that students will view the three systems to be similar. Therefore Chapter 4 will not only present the outcome space of solubility derived from all three chemical systems, but it will also outline the outcome space for each chemical system. Considering the three systems together, the outcome space for solubility consisted of six qualitatively different conceptions. The outcome space for Systems A, B and C was comprised of two, four and five qualitatively different conceptions respectively.

From a practical point of view, it is believed that an understanding of the "outcome space" of students' conceptions will provide the teacher and the researcher insights for
developing instructional strategies that would help accommodate students' alternative conceptions. Furthermore, presenting the reader with a frequency distribution for the outcome space will help her/him to see which conceptions should be given priority during instruction. The students' conceptions can also serve as the starting points for curriculum development and lesson planning.

Although the outcome space for each chemical system is provided, a major portion of this chapter is devoted to presenting the six categories of description for solubility which were generated when all three systems were considered:

1. physical transformation from solid to liquid
2. chemical transformation of solute
3. density of solute
4. amount of space in solution
5. size of solute particles
6. property of solute

These differing qualitative categories of description were drawn from students' responses to three related chemical systems. The first system consisted of dissolving a cube of sugar in hot water. The second system exhibited the miscibility of alcohol and immiscibility of paint thinner in water. The third system characterized the dissolution and crystallization of table salt in water. The physical state, and the chemical composition of the substances that were added to water in each case, were different. The main thrust of the systems, however, was to find out how students conceptualized solubility depending on the systems chosen.

The researcher's interpretations are grounded in students' responses to questions. Therefore, for each category of description, excerpts of the interview dialogue are included. These excerpts are illustrative—often, there were other example(s) of a particular kind of conception.
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Students’ conceptions are compared and contrasted. Wherever possible, the conceptions are described in terms of everyday chemistry, formal chemistry, and historical developments of chemistry. In some cases, possible source(s) for students’ conceptions is (are) traced.

As much as possible, the interview dialogue excerpt is left intact to give the reader a contextual basis upon which to judge the researcher’s interpretation. But those conversations that are not directed to a particular conception have been omitted to keep the reader on track. This omission has been denoted by means of an ellipsis. In the excerpts, “R” stands for the researcher and “S” stands for the student. The students are given pseudonyms.

4.2 Physical Transformation From Solid To Liquid

Many students viewed dissolving as a process of a solid transforming into its liquid. Some students called this process “melting.” Two sub-categories of description were recognized when students spoke about the transformation of the solid state into its liquid state, or melting. These were:

1. continuous view of “liquid state”; and

2. particle view of “liquid state.”

4.2.1 Continuous View of Liquid State

Consider the following excerpts for the first sub-category, “continuous view of liquid state”:
Shamila (1) [sugar/water]
R: I am going to drop a cube of sugar. See what happens.
S: Is it hot water?
R: Yes, it is. Could you describe what might be happening?
S: There are bubbles going up and sugar cube is melting. The sugar is going. It is melting practically. It is no longer a cube.
R: What do you mean by melting?
S: It dissolved. It was a cube. When you dropped it in the water and like you see it, it is falling apart. I think hot water is making it softer. It will be more stickier. Yeah, it will stick. Sugar melted somewhat like a syrup. That's what I think.
R: Let me stir this and let us see what happens. What is happening?
S: There are no more crystals. Mixed in with hot water.
R: What do you mean by saying 'mixed in with the hot water'?
S: It liquefies like the water.
R: Do you think the sugar is in the liquid state?
S: Yeah.

Ami (2) [sugar/water]
R: How does the sugar appear to you when it is in the dissolved state?
S: Ah. Like this. I guess in the liquid form.

Sheila (3) [sugar/water]
R: Sugar water is different from sugar and the water?
S: Yeah, because sugar is no longer solid anymore. It is more like a liquid. Something like that.

Shamila (4) [salt/water]
R: Here I have mixed salt with water. Could you describe this system? Why do you think salt has settled down?
S: It seems like you boil the water and it dissolves. And some melted and stuck together. It crystallized at the bottom.

Al (5) [salt/water]
R: When you put salt in food, it disappears, right.
S: Because when you cook, there is heat. When it is hot, it melts. It is cool here. So it does not change. But if you put hot water and stir, it will melt and become salt water.

The foregoing excerpts suggest that some students have the notion that the solute (sugar or salt) when added to water melts and becomes a liquid. Students subscribing to this notion appear to have a "continuous liquid state" conceptualization. This view was not surprising because an analysis of the historical developments of matter reveals that the early scientists conceived matter to be "continuous" or "homogeneous" (Renström,
The students found it logical or plausible to think of the process of dissolving in terms of melting—the solid becoming a liquid—because these students did not see the solid sugar any more. They saw a liquid in the beaker. From experience, they know that the water will taste sweet because of the dissolved sugar. To them it seemed reasonable to state that solid sugar had been converted into its liquid form (disappearance of crystalline identity). Particularly, note what Shamila stated, “It [sugar] liquefies like water.” By this Shamila meant that the sugar is presently like liquid water. Also, Shamila talked about hot water making solid sugar soft and sugar turning into a syrup, a liquid state. What is interesting here is how Shamila brings her everyday talk to a chemical system. When a piece of candy is sucked, often children say that it is melting in the mouth. The candy becomes syrupy and sticky inside the mouth. Similarly when sugar was put into hot water, students were found to state that sugar is melting.

When sugar dissolves in water, it is understood that the resulting solution is in liquid form. Often students seemed to be confused between the liquid-solution state and the liquid state, such as wax or ice melting. When a solid melts one can see the change in state by the resulting liquid. However, when solid sugar is added to water, the state change does not occur. But students seem to think that there is a change of state from a solid state to the liquid state. Therefore, it can be argued that a confusion exists among students in terms of what is meant by the true liquid state and the liquid-solution state.

Chemically speaking, the argument that hot water caused sugar to melt seems to be appropriate because when a solid melts, the molecules must overcome the attractions that tend to hold them in place within the solid. They need energy to accomplish this. In this case the energy supplied was heat energy. If the temperature of the substance remains constant, the molecules must obtain this energy from outside the solid. So energy must be absorbed. According to this reasoning, these students seem to have some idea that
the energy for the solid to melt is supplied by hot water.

In this conception, the initial stage of the dissolving process is analogous to the melting process. In both processes, heat energy plays a vital role. In the dissolving process, as is the case with melting, the solid solute particles are held together by forces of attraction. It will require energy to break the forces of attraction between solute particles. Therefore, the solution process would be considered as an endothermic or energy-absorbing process. Some of the energy is expended in moving the solute particles away from each other so that forces of attraction can be set up between the molecules at the interfaces (meeting points) of liquid solvent and solid solute. So in a very primitive form, the students seemed to recognize (albeit in partial form) the relationship of heat to the processes of both melting and dissolving and considered these processes to be identical.

4.2.2 Particle View of Liquid State

Some students stepped into the microscopic world in order to explain the process of dissolving as melting or a solid turning into a liquid. They used terms such as atoms, molecules and particles. The following excerpts manifest this conceptualization:

Jo (6) [sugar/water]

R: When you say it is disappearing, where does it go?
S: Melt.
R: So what do you mean by melting?
S: The sugar molecule is diffusing into particle. I cannot see it.

Celin (7) [sugar/water]

R: There is hot water here. I am going to introduce a cube of sugar into it. I’d like for you to describe what might be happening to the cube of sugar.
S: The sugar cube is decomposing. Going into solution with water.
R: What do you mean by decomposing?
S: Decomposing—it is breaking the molecules down into a liquid state from a solid state.
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Nila (8) [sugar/water]
R: I have hot water here. I am going to add a cube of sugar. Could you tell me what is happening?
S: It is dissolving.
R: What do you mean by dissolving?
S: It's combining with water. It is mixing. It's not like it started out with the solid, but the molecules are all tightly packed together and when you mix it with the water, it mixes with water, something like that. I am not sure. ...Then when they are moving freely but not really becoming like a gas, really spaced out. It is in a different state. ...They are all just mixing together in the liquid state.

Sujatha (9) [sugar/water]
S: ...Sugar is turning into a liquid form of sugar which is mixing with water. It looks like it anyway.
R: All right, you mentioned that sugar is in the form of a liquid. What do you mean by that?
S: Well, when the molecules are, I guess it is elements or whatever when they are far apart, it becomes a liquid like water. I don't know how to describe a liquid. When it is in a runny (laughs) runny state. They are fairly far apart and they are always moving because they are farther apart. They are not like all together. Like makes a lot of sense. So we can't see it. Because they are so farther apart, they are moving, moving quicker and it takes up a bigger space and makes up a liquid.
Nila (10) [salt/water]
R: *Could you describe what you see here?*
S: That is salt and water. Salt does not dissolve in water. Oh no, salt does. When you started with this, was the water hot or cold?
R: *It was hot.*
S: What happens is when you put the salt in, it melts. Then when it cools, the molecules cool down and they re-form in the bottom. So that is just a physical change from a solid to a liquid. Then it came back to the solid and then because (long pause)—I don't know why, I guess some of it escaped and they came down.
R: *Why do you think some of it escaped?*
S: I think it was melted. Well, it was a liquid, right? Now that it is cooling, it's all (did not complete). All the molecules are going crazy because they are hot and when they are cooling down, they are slowing down, I think. And when it is really hot some of them could evaporate, because they escape, they move so fast. They get pushed away by all the other molecules. And they get out and it cools off right away. They call it cool air.
R: *Do you think there is any salt in this part of the jar?*
S: No.
R: *You think all the salt has come down?*
S: I think it has gone back to the original state. Some of it out of the water. Some of it in the water.
R: *Is there anything happening between the water and the salt?*
S: Oh yes, there is water. The water molecules are moving around just like the solid. They are still moving but so tightly packed, not like moving freely.

The foregoing excerpts are also suggestive that students' conception of dissolving is melting or a solid turning into a liquid. However, students explained the conversion process or the transformation of solid to liquid state in microscopic terms. Celin and Nila used the term “molecules” for sugar crystals.

Jo talked about the invisibility of sugar. In particular, he stated that he cannot see the sugar because it has diffused—a word that is often used in chemistry. Jo an ESL student, remembered the term “diffusing” when he tried to explain dissolving because he may have learned it from the previous chemistry lesson on kinetic molecular movement of solids, liquids and gases. The students' notes indicated that molecular movement was explained by the teacher spraying perfume on one side of the room. While students
who stood on the other side of the classroom were asked to note the consequences. In this simple activity, diffusion of perfume from a region of higher concentration into a lower concentration, and its conversion of liquid state turning into its vapour state (evaporation) could be observed. Since a substance in its vapour state is invisible, it may be inferred that Jo’s understanding of the word diffusing and his explanation of the invisibility of sugar could have risen from his study on diffusion of perfume. A parallel explanation might be, just like perfume molecules would diffuse into the atmosphere, the crystalline sugar would dissociate into molecules and diffuse into the water environment.

Celin’s microscopic depiction was that the conversion of sugar from its solid state into its liquid state is because of the decomposition or the breaking down of the molecules of sugar. Celin called the crystals of sugar “molecules.”

Nila distinguished the molecular arrangement in solid, liquid and gas. She noted that in a solid, molecules are tightly packed; in a liquid, molecules are moving freely, and in a gas the molecules are really spaced out. Nila considered that molecules of sugar are in movement when sugar is added to water. Therefore, she argued that sugar has to become a liquid like liquid-water.

With regard to the salt/water system, Nila stated that heat melted the salt. She figured that on cooling, salt will re-form. Her idea was that heat energy speeds the process of dissolving. Nila brought her understanding of kinetic molecular theory to bear upon the relationship between heat energy and dissolving. She stated that the molecules are “going crazy” when the salt is in the melted form (liquid), and when the molten salt cools, the molecules would slow down. In her explanation, Nila extended the macroscopic phenomenon to the microscopic world. She stated that the molecules will cool down. Furthermore, Nila did not think there was any salt in the solution state.

In line with Jo, Sujatha stated that the sugar is no longer visible because sugar is now in the liquid state and in this state the molecules of sugar are farther apart. For Sujatha,
the reasoning, the sugar has become a liquid, is because sugar is spaced out. Sujatha argued that both "liquid-sugar" and "liquid-water" are able to mix because liquid-sugar is spaced out to accommodate the liquid-water. Some notions of kinetic molecular theory of liquids are exhibited here: the molecules of sugar are in random motion and because of this random motion the sugar is in the liquid state. As liquid sugar and liquid water move, they create space for each other to mix. A claim was also made by Sujatha that sugar in its "runny" state is moving very fast and it takes a bigger space than when it is in solid form. Perhaps Sujatha's conception can be interpreted in two ways: the space that liquid sugar occupies is greater than its counterpart in the solid state, or, the molecules of liquid sugar have expanded in size compared to the molecules of solid sugar.

4.3 Chemical Transformation of Solute

As found in my pilot study, some students had the notion that when sugar is added to water some form of chemical reaction or combination is taking place. At least half the class gave the idea that dissolving is a process of combining. The goal then was to find out what these students meant by "combining." How do students picture this combination?

Since interview dialogues include several slightly different mechanisms for describing the nature of chemical transformation, excerpts of each kind of conceptualization will be presented separately.

4.3.1 Attachment or Attraction Between Components

Note Sheila's explanations concerning the relationship between sugar and tea (Sheila's example) and sugar and water when sugar is added to tea and water respectively.
Sheila (11) [sugar/water]

R: You said it is mixing, dissolving, it is a solution. What ideas do you have about these words?
S: Um, one thing mixes into another. Like it can be combined.
R: What do you mean by combining?
S: I don't know. The sugar dissolving in tea. It mixes throughout. It does not stay that way.
R: What picture do you have in mind when sugar dissolves in tea?
S: (Laughs). Oh, it is stuff in tea and sugar combines throughout all over. . . .
R: You said there is tea, water, and sugar, right. How do you picture these?
S: Oh yes, tea and everything like is attaching to another like a molecule.
R: Could you draw what you mean by attaching?
S: (Draws). This is the tea, sugar and it's all put together. So that's the way it looks like in a cup. . . .
S: The heat melted it. Combined. (See Diagram 1)
R: *In what way is it combining?*
S: Not absorbing. By mixing together they are becoming one. Not two anymore. ... 
R: *Any new substance being formed?*
S: Yeah, sugar water (laughs).
R: *Sugar water is different from sugar and the water?*
S: Yeah, because sugar is no longer solid anymore. It has turned to gas. It's more like a liquid. Something like that.
R: *You say it is a new substance?*
S: Yeah.
R: *Can you get back the sugar?*
S: Yeah. Boil it. Let it cool. ... 
R: *Could you draw a picture for what you mean by sugar has combined with water?*
S: (Draws). If these are all water. Instead of just being the sugar here, sugar is spread throughout the water. So it is like... (See Diagram 2)
R: *So are there any arms and legs going out of the water and the sugar?*
S: (Laughs, and laughs, and laughs). I don’t think so. They are by themselves. There is an attraction towards.
R: *What type of attraction do you think there is?*
S: Mm. I don’t know. (Laughs). Not a magnetic attraction. (Pause). Something is pulling them together.

Sheila explained her understanding of a solution with an example, sugar dissolving in tea. She used words such as mixing, dissolving and combining to describe the process when sugar was added to hot water. Sheila was asked to visualize the relationship between sugar and tea. Sheila immediately stated that the relationship between sugar and tea is like the attachments in a molecule. In my pilot study, a student argued similarly. The student stated that sodium hydroxide is a solution. When asked why, the student explained that sodium, oxygen, and hydrogen are components of the solution. As well, from my pilot study, from this study, and in talking to chemistry teachers I have come to know that students consider water, to be a solution. The reason that students give is that water consists of hydrogen and oxygen. Once when I asked a student to explain which is the solvent and which is the solute in water one student suggested that hydrogen is the solvent because water has two parts of hydrogen (meaning solvent is in a greater quantity) and oxygen is the solute because water has one part of oxygen (meaning solute.
is in a smaller quantity).

Sheila seemed to see a similar relationship between sugar and tea. To show what she meant by attachments in a molecule, Sheila drew two circles (one large, one small) to indicate that one is for sugar and the other for tea. She drew these circles attached to each other. Does it mean that Sheila’s notion of combination is the same as a molecule formation? Does Sheila fully understand what type of combination exists in a molecule for her to have said that tea and sugar are attached like the molecule?

When probed again for the meaning of combination with the sugar/water system, Sheila stated that heat melts the sugar and then it combines with water, becoming one. She did not think that sugar and water are separate entities. However, when Sheila drew sugar and water she did not have any linkings between sugar and water like she depicted for sugar and tea. Sheila noted that there is some kind of an attraction between sugar and water, but they are by themselves. She was even inclined to think of magnetic attraction. This shows that sometimes a student’s statement may not correspond with what that student might draw.

According to Sheila, the new substance that formed was sugar-water. It is rather interesting to note how Sheila drew two different pictures of two different examples for the same word “combination.” In the case of the sugar and tea mixture, the components are attached whereas in the sugar and water mixture, sugar and water are drawn separately but she stated that there is some pull between the two latter components.

Sheila emphasized that sugar is no longer a solid but it is a liquid. According to Sheila, the change of state is another reason why sugar dissolving in water can be considered a chemical change. Sheila does not associate retrieval of the original substance as a characteristic of physical change. So Sheila continued to propose that the combination of sugar and water was chemical.
Nila’s explanation of chemical combination between sugar and water follows:

Nila (12) [sugar/water]
R: *What do you mean by dissolving?*
S: It is combining with the water....
R: *You said combining. What do you mean by that?*
S: Oh, combining is they are not like two separate things. They are mixed up together. Like they are moving out throughout the molecule.
R: *...There is sugar. There is water. Do they combine to produce a new substance?*
S: Well.
R: *Or they don't produce any new substance. What ideas do you have?*
S: It is a physical change. I guess, this is a new product. It has different qualities. No, it is a chemical change. You can't get back the sugar to its original state. So it is like a chemical change. You create a new substance with new properties.
R: *Could you illustrate with a diagram, how this combination has taken place? You have some kind of a picture?*
S: Okay, sugar and the water.
R: *How do you visualize? Maybe you have a model that comes to your mind when sugar and water are together.*
Nila draws the picture and then she explains:
S: These are the water molecules. They are Mickey Mouse ones. Hydrogen and the two oxygens like $H_2O$. I am not sure that could be like a clump of sugar. One molecule of sugar because it got all different elements in it. They are all just mixing together in the liquid state.

R: You remember, you said that they are combining together. In this picture, how would you show the combination. Or is there a combination between the two? Maybe this is what you mean by combination?

S: Well, they could form a new molecule but then it has to be like ions. They have to be like water has to give up something. I don't know. I am not sure. I am sure they give or they share electrons. Some sort of transfer going on. Like ions, positive and negative, and they transfer.

Nila also used the word combining. Like Sheila, Nila stated that combining means that substances do not remain as two separate things. Initially Nila mentioned that the sugar/water combination is a physical change, but she quickly changed her mind and stated it was a chemical change. This judgement that a new substance with new properties has been created was justified. Her argument is further substantiated when Nila stated that if a change is chemical, the original substance cannot be regained. She applied this information to the phenomenon and concluded that sugar cannot be regained.

Nila had a microscopic perspective when she drew a diagram for the sugar-water combination. This combination was attributed to the sharing or transfer of electrons between the sugar and water to form a new molecule. This idea certainly stemmed from her study about the differences between ionic and covalent compounds in one of her previous lessons in chemistry.

So while Sheila talked about the molecular formation between sugar and tea, Nila explained how a molecule is formed either by the transfer or sharing of electrons between two components.

4.3.3 Bond Breaking in Solute

The following excerpt presents Willy's arguments how sugar and water combine:
Willy (13) [sugar/water]

R: What comes to your mind when you say dissolving?
S: I think these are atoms. They split into small particles. When you stir, each reacts with the water and disappears.
R: What do you mean by react?
S: Water is H₂O. What is sugar? I don't know.
R: It doesn't matter. Just tell me, what is happening to the sugar?
S: Water is H₂O. I think sugar is . . .
R: You want the formula for sugar?
S: Yeah.
R: C₁₂H₂₂O₁₁.
S: (Writes the formula of sugar). This is the same as the ratio of H and O in H₂O. Is the same as H and O in sugar. H and O in water is 1:2 and H and O in sugar is also 1:2. I think this becomes water. This became carbon dioxide bubbles. (Laughs).

R: You think there is a chemical reaction going on?
S: Yeah, a chemical reaction.
R: Could you draw a picture to show how sugar and water are together?
S: The bonds between the two are breaking.
Willy (14) [salt/water]

R: *In this jar I have water and table salt. Salt is settled at the bottom. What ideas come to your mind when you look at this?*

S: What is the formula of salt?

R: *Salt is NaCl.*

S: I think the water cannot. The outer shell need one more electron....

R: *You add salt to food. Why do you think salt dissolves in food?*

S: Heat can break down substances. Ionic bond is not so strong. Because when they completed the outer shell it became salt again.

Willy convincingly proposed that sugar and water react. Then he found a way to state how the two would react. Noting the bubble formation when the sugar cube was gently immersed into the hot water, Willy stated that carbon dioxide was formed. Again Willy argued how this carbon dioxide was formed (Excerpt 14). He tried to figure with the formula how carbon dioxide evolved. When he did this, Willy seemed to exhibit some knowledge of the formation of new products from the original substance. To emphasize that a chemical reaction is taking place between sugar and water, Willy also talked about bond-breaking.

Willy argued similarly when the salt/water system was shown to him. He suggested that salt crystals are neutral and they have to gain electrons in order to settle as salt crystals. He further noted that heat can break the ionic bond and when in the solution form, salt dissociates into ions.

### 4.3.4 Solute Occupying Air Spaces in Water

Gary's picture of how sugar "reacts" with water can be understood from the following excerpt:
Gary (15) [sugar/water]

R: There is hot water direct from the tap. I am going to introduce a cube of sugar. Can you tell me what might be happening to the sugar?

S: It is dissolving in the water. Eventually it will be all gone.

R: What do you mean by dissolving?

S: It will react with water and join with it. Going to the molecules of air that are empty.

R: What do you mean by “react”? Does sugar react with water to form a new substance?

S: No, it actually—in a way it is. It is turning into different things.

R: What different thing is it turning into?

S: Changing texture, I guess, with the mixture of water and air.

R: What kind of texture do you think it will have?

S: Lighter and less denser structure.

R: What happens to the water?

S: It will become sweeter.

R: Could you draw a picture for me as to how you imagine this to be?

S: You mean when it all dissolves?

R: Yeah, when it all dissolves.

S: (Draws).

R: Wiggly line is the top of the water.

S: Yes.

R: These little dots are...

S: ...bits of sugar.
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R: Sugar reacts with water and it fills the air spaces. How do you picture that?
S: Because there is air in the water and sugar takes this place.
R: Could you draw that for me? I'd like to see it.
S: (Draws).
R: You think granules of sugar settle inside the air spaces in water?

S: Mmm.
R: What would you call this whole thing?
S: Solution.
R: Can you give me another example of solution?
S: Salt and water.
R: Same thing happens to salt and water?
S: Basically, yeah. I think.
R: Can you give other examples of solution?
S: Like water—oxygen and hydrogen.

Like Willy, Gary also stated that sugar will react with water and join with it. Like Sheila and Nila, Gary argued that sugar is turning into a different thing. Gary stated that the change is attributed to the difference in texture.

Gary proposed the notion that there are small pockets in water which was once occupied by air. When air is driven out, these pockets are filled by sugar. Like Willy, Gary also noted the evolution of air bubbles when sugar was dropped into hot water. This may very well be the reason why he stated that sugar occupied the empty air spaces.

4.3.5 Addition of Two Substances Yielding One Substance

The following excerpt gives Al's idea of a combination of sugar and water:
Al (16) [sugar/water]

R: What do you mean by mixture?
S: Is sort of two compounds mixed together. It is a combination of two substances.

R: What do you mean by combination?
S: Two things added together to form one thing.

R: What are the two things here and what is the one thing?
S: Sugar is added to water—a mixture called sugar water.

R: How do sugar and water appear to you when they are in the mixed form?
S: After the sugar melts the molecules of sugar will flow and stick around the beaker and float on top of the beaker and the water molecules moving around in the space between the sugar. After stirring, both the sugar molecules and the water molecules mix together and they combine and they move around everywhere. So you cannot see the sugar molecules because they are mixed together. After stirring they move around and you cannot tell the difference between sugar and water molecules (diagrams shown below).

For Al, like Nila and Sheila, combination meant that two things were added to form one thing. Like Sheila, Al also stated that sugar-water is formed. Al stated that sugar cannot be seen because melted sugar is now mixed with water and "together" they travel everywhere.

In summary, combining was viewed as an attraction between components to form products. To two students the product was known as "sugar-water." Initially in the
reaction there are two components which become one, which is sugar-water. Sugar has lost its identity of being a white crystalline solid. The original sugar is no longer seen. It is mixed with water. Water has lost its identity of being a colourless, tasteless liquid. Although the water looks exactly the same as it did before, experience tells us that the water now tastes sweet. Hence the new product is considered to be sugar-water, which is different from its components. These students’ conceptualization might be depicted in the following word equation:

\[
\text{sugar} + \text{water} = \text{sugar-water}
\]

In line with the above argument one student noted the attraction between sugar and water to involve the transferring or sharing of electron density from one component to another in forming the sugar water. This idea stems from a study of bond formations in electrovalent and covalent compounds in their previous lessons.

Another view was that there are molecules of air in water and that some water molecules are empty, and sugar occupies this empty place. This idea seems to take the following line of reasoning: Cold water from the faucet or refrigerator contains dissolved oxygen. If a glass of cold water is allowed to warm up to room temperature, small bubbles will be seen trapped on the side of the glass. These are air bubbles which have been removed from the saturated solution as the temperature of the water increases. As well, when water is boiled, just before the water boils vigorously, many small bubbles will be seen at the edges of the container and solution. So when a sugar cube is put in hot water, the hot water causes the air to escape and creates empty spaces for the sugar to occupy.

It was interesting to note another type of reasoning. Because table sugar and water have similar ratios of hydrogen and oxygen atoms, it was proposed that the hydrogen and oxygen atoms in sugar molecules combined to yield water. In addition he argued
that one of the products was carbon dioxide.

4.4 Density of Solute

Differences in density between the two substances was given as a reason why liquids did not combine or why salt settled at the bottom of the jar. In the case of the water/alcohol/paint thinner mixture, no separation was seen when alcohol was added to water. However, when paint thinner was added to the water/alcohol mixture, it was observed to float on the mixture. Hence they reasoned that paint thinner was lighter than the water/alcohol mixture. The following excerpts reveal the conceptualization that dissolving depends on the density of solute:

**Candy (17) [water/alcohol/paint thinner]**
R: *Let me add a bit of paint thinner. What is happening now?*
S: It is forming a suspension. Paint thinner is not combining with alcohol and water.
R: *Why wouldn't it combine?*
S: ...It is too heavy or light. So it is on top.

**Rosie (18) [water/alcohol/paint thinner]**
S: Whatever there is, it is mixing. Because it is not combining.
R: *Why is it not combining?*
S: Does it have something to do with the density of paint thinner, because paint thinner should be lighter. ...

**Al (19) [water/alcohol/paint thinner]**
R: *Why doesn't it mix?*
S: Heat will dissolve. Rest of it like oil stuff. Like it is sticky and it is thick and sticky. They form the top layer. The stuff is sort of lighter and it is easier to go on the top. The rest of it will stay in the bottom.

**Tammy (20) [water/alcohol/paint thinner]**
R: *This is paint thinner.*
S: It went to the top like oil because it is lighter than water...
R: *So that is why you think they don't mix together?*
S: They keep coming up to the top whereas salt, they always went down to the bottom. It is heavier than the water.
Sujatha (21) [water/alcohol/paint thinner]
R: Why would paint thinner sit on top?
S: It is like oil. It is a different texture. It is a different density. It doesn’t sound right, either.

Shamila (22) [water/alcohol/paint thinner]
R: I am going to add some paint thinner now.
S: Okay, it is not mixing. It is like the green stuff is alcohol and water. The other layer is on top. You want to know why it happens?
R: Yeah.
S: (Laughs and laughs) (Pause). Well the reason that it is not mixing is because the paint thinner is lighter than water that is floating on top. And why there is a layer of alcohol and water on the top is because I have no idea. I have never seen that before.
R: Is alcohol with the paint thinner or is it with the water?
S: Well it is just all there. It did not mix.
R: So the top layer is composed of paint thinner?
S: The very top layer is the water and then there is the paint thinner.
R: So there are three different layers?
S: That is how it looks like to me.

Ami (23) [water/alcohol/paint thinner]
R: Here is paint thinner (pouring into the alcohol/water system). What do you think of that? Why are they in two different layers?
S: The paint thinner, I think, has something that is really thick, that is holding. It is just like the oil. It is moving itself together and it won’t break up unless you do something. Heat it up or stir it. Heat it up. That is the only way it will break down.
Jo (24) [salt/water]
R: This is salt in water. Why did salt settle down at the bottom?
S: Because I think that the water cannot dissolve. There is many salt. So the water cannot dissolve. ... There's not enough of water molecules to dissolve the salt.
R: Is there anything going on between the salt and water?
S: This is high-density salt water. The upper part is low-density.
R: Is there anything taking place between the two parts?
S: Moving from low to high. You can't see the salt molecules in the low region. Salt molecules are more. So I can see it. I can see the salt in the water because there's many salt together so that I can see it. ... The salt is heavier than the water. So the salt is seen there in the under and the water is seen in the upper.
R: Is there any salt here?
S: Yes, many salt, but not more than this and this also has many.

Tammy (25) [salt/water]
R: Here I have a jar containing salt and water. Salt has settled down. Can you describe what this is all about?
S: Salt is at the bottom of the water. It is heavier. Have more mass than the water...
R: How come some went to the bottom and just a few are still in the water.
S: Like some are little bit lighter than the others. It's broken apart more than the other one.

Shamila (25) [salt/water]
R: Why did some of it melt and stick together?
S: Because it is heavier than water. It seems like there are bigger crystals, too. Small granulated salt.

Jo, Tammy, and Shamila mentioned that because of its weight, salt tends to seek the bottom of the jar. In particular, Tammy stated that the ones that are still suspended are lighter because of their “broken” state. While some students attributed “density,” a physical phenomenon, for the separation of the liquids, others (Al, Tammy, Sujatha, and Ami) extended this aspect of density by pointing out the physical appearance of the liquid (oily).

Paint thinner is not thick and sticky by itself, but it appears to be oily and sticky when it floats on water. Obviously some students took it for granted that the texture of paint thinner was like oil. And this is why students (for example, Ami) stated that
the paint thinner is sticky or glue-like and holds together and float on water as a thin film. Because of its seemingly oil-like texture when added to water and since it floated on water, students thought that the density of paint thinner was lower than the density of the water/alcohol mixture. The students' claim that paint thinner is less dense than water/alcohol is correct. However, it does not explain why they do not mix.

In an attempt to explain why salt settled, Jo also talked about why he was able to see the salt. He argued that there were more salt molecules. It was similar to an argument made by a student in my pilot study. This student stated that she can see the molecules when sugar is in a sugar bowl. Otherwise molecules cannot be seen.

Shamila painted the "melting of wax" depiction. According to her, the salt melted and stuck together. Also, because the stuck salt crystals are heavier and bigger, they settled down (gravity). On the contrary, Al stated that hot water and stirring melted the salt and it became salt water.

4.5 Amount of Space in Solution

Some students argued that substances do not dissolve because they do not find space in the dissolving medium. Consider the following example for the above conceptualization:
Sheila (26) [water/alcohol/paint thinner]

R: Alcohol and water are soluble. Why isn’t paint thinner soluble?
S: The particles are closer together than the paint thinner. That is why water and alcohol are soluble. Maybe not attracted to each other (meaning water/alcohol to paint thinner). May be both of them are attracted (meaning water to alcohol).

R: *Can you draw a picture of what you are telling me?*
S: There is the paint thinner. Then there is alcohol and water together. This stuff is insoluble. I don’t know what it means. It is not able to mix. Maybe there is no room in the alcohol and water mixture for the particles to come in. There is no combination. It is not attracted towards them.

Gary (27) [salt/water]

R: Why did the rest go down?
S: Because there is no room in the air pockets for them to be.

Sujatha (28) [salt/water]

R: *I have a jar containing salt and water. What ideas come to your mind when you look at this system?*
S: I don’t know. I don’t want to use the word react. They didn’t mix. ...Maybe it was dissolved so much that it can’t accept anymore. But it doesn’t make any sense. Maybe it has accepted too much salt. I don’t know.

According to Sheila, there is no space available in the water/alcohol mixture for the paint thinner to lodge because the attraction or closeness (affinity) between the particles of water and alcohol prevents another liquid that has no power of attraction towards water from finding any room. Perhaps because of the power of attraction water and
alcohol are mixed together. Water and paint thinner are not soluble because there is no drawing power between them (meaning water/alcohol to paint thinner). Sheila seems to have a rudimentary knowledge of the way in which a chemist might explain the solution process of two liquids: Two liquid substances can be mixed if the forces of attraction between the particles in both the solute and the solvent are of about equal magnitude. However, if the attractive forces are widely different, the solute will be insoluble in the solvent. For example, in the water/ethanol/paint thinner mixture, both the water and the ethanol molecules are attracted to each other because the strength of the forces of attractions felt among the molecules in the individual components are similar to the forces of attraction between the components. The attractions of water molecules for other water molecules are not overwhelmingly strong. However, the attraction between water and the alcohol molecules are stronger than the attraction between water-water molecules. Therefore, water molecules do not collect in a separate phase when alcohol is added to it. Water and alcohol stick together, and jointly, they repel the paint thinner because the weak attractive forces of the latter does not overcome the attractive power that exists between the water/alcohol mixture.

Both Jo and Sujatha had the idea that we normally teach in class under the notion of a saturated solution. They stated that there is insufficient amount of water to dissolve all the salt. Gary had a similar concept but he thought that there was no room in the air pockets.

4.6 Size of Solute Particles

Some students argued that the size of solute particles must be small enough for dissolution to take place. If the solute is broken into tiny bits, then it will dissolve in the solvent. In this case Ami argued that the paint thinner will not dissolve because it moved together
and it will dissolve only if the paint thinner layer is broken up by heating or stirring.

Note the following excerpt:

**Ami (29) [water/alcohol/paint thinner]**

S: ...Heat it up. That is the only way it will break down.

R: *How does heat help to break things up?*

S: It just helps. It applies pressure inside something with the oil (meaning paint thinner). It breaks down the atoms and it falls down. Heat breaks the molecules in the paint thinner. Heat breaks down the molecules that holds the paint thinner that separates the paint thinner from water....

R: *Molecules are breaking down into what?*

S: Into separate particles. Like, you know, how sticky these particles are when they are together whatever; when it is heated, it breaks. That's what happens for it to go down.

Ami explained the effect of heat on oil. Ami stated that when this oily substance is heated it will be dispersed into smaller globules of oil; then it will dissolve in the water/alcohol mixture. The foregoing explanation seemed to correspond with the idea of surface tension of water and the behaviour of oil in water. For example, oil has less surface tension than water and is drawn out into a film covering the whole surface except when the water is hot. The surface tension of hot water decreases because the faster-moving molecules are not held as cohesively. This allows the grease or oil in hot water to float in little bubbles on the surface of the water. But when the water cools and the surface tension of water increases, the grease or oil is dragged out over the surface of the water. Thus the oily layer floats on water, forming a separate layer.

Ami explained dispersion of oil in terms of the need to break it down into smaller particles. Ami figured that heat will break the oil into smaller molecules and atoms. Her explanation might have two meanings. First, with a little supply of energy, oil can be separated into molecules and atoms. Secondly, a little heat energy is enough to break the molecules and atoms of oil (transmutation).

Ami attributes a physical characteristic to particles when she stated, "How sticky these particles are when they are together." This is the primary condition which causes
"oil" to float on top and it must be altered if one wants to try and dissolve oil.

4.7 Property of Solute

Some students argued that in order for a substance to dissolve in another substance, the solute must have an element that would cause it to dissolve. Others reasoned that if the solute is pure, it will not dissolve. The following excerpt characterizes the notion of the character of element:

**Gary (30) [water/alcohol/paint thinner]**

R: *Why do you think paint thinner did not dissolve in water?*

S: Because it does not have the element that mixes with the water very well. The element does not dissolve.

Gary mentioned that the paint thinner was devoid of an element that helps to mix with water.

Some students proposed the idea that salt does not dissolve in water because of its pure, insoluble crystal state. Consider the following excerpts:

**Rosie (31) [salt/water]**

R: *Here I have salt and water. You see salt has settled at the bottom. Why does salt do that?*

S: These are crystals of salt. These are pure crystals. So it won't dissolve. This is like a salt crystal with water. It doesn't get mixed. Because water doesn't have any virtue inside it that it can get through. It can't combine with. You can't break it up. It is that it is hard. Not a normal solid.
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Ami (32) [salt/water]
R: Why has salt settled down at the bottom?
S: If it was stirred probably it will not be undissolved like any other substance.
R: I am going to shake this vigorously. Why do you think it is settling down?
S: Gee. I don’t know. I have no idea. Maybe it is because it is stuff like elements can’t break down. They are pure elements like gold. They can’t break down because they have—I don’t know what they have but they won’t break. This is in the pure state. So it won’t break down. You can’t make anything out of it just like gold. You know, try heating it, shaking it, melting, freezing it. We can’t make anything out of it. It is one of the pure stuff. You can’t.
R: Is salt a pure substance?
S: Yeah. They are crystals. You can’t change.

Candy (33) [salt/water]
R: Do you think there is salt in the upper part?
S: If there is, there isn’t much. Most of it has come down.
R: Why did most of it come down?
S: I’m not sure. But I know that when water evaporates it always evaporates pure liquid. It is always pure. So maybe that is why salt and the water separate from each other, for the same reason.

Rosie and Ami referred to the salt that was formed at the bottom of the jar as crystals. Ami used the adjective, “pure” to describe the salt crystals. Obviously, the salt crystals were hard, shining and clear.

One of the methods of obtaining pure table salt is by crystallization. As table salt crystallizes from its solutions in water, many of its impurities are left in the solution. If the salt crystal formed is repeatedly dissolved and recrystallized, salt crystal of a higher purity is obtained. Evaporation is one of the processes whereby salt can be recrystallized. The notion of water evaporating from salt solution to form pure salt crystals was given as a view by Candy why salt remained in the bottom of the jar.

Rosie considered recrystallized table salt to be an unusual solid, like semi-precious crystals, that is insoluble in water. Ami suggested that salt can be likened to a pure element, for instance, gold. This conception of purity arose because of the apparently
Table 4.1: Frequency Distribution for Pre-Instructional Outcome Space of Solubility for Systems A*, B** and C*** (n=13)

<table>
<thead>
<tr>
<th>Categories of Description</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>physical transformation from solid to liquid</td>
<td>A: 10 B: - C: 4</td>
</tr>
<tr>
<td>chemical transformation of solute</td>
<td>A: 5 B: - C: 1</td>
</tr>
<tr>
<td>density of solute</td>
<td>A: - B: 8 C: 3</td>
</tr>
<tr>
<td>amount of space in solution</td>
<td>A: - B: 1 C: 3</td>
</tr>
<tr>
<td>size of solute</td>
<td>A: - B: 1 C: -</td>
</tr>
<tr>
<td>property of solute</td>
<td>A: - B: 4 C: 3</td>
</tr>
</tbody>
</table>

*System A: Sugar/Water
**System B: Water/Alcohol/Paint Thinner
***System C: Salt/Water

pure state of the salt crystals.

According to the foregoing analysis, the outcome space for the concept of solubility comprises six categories of description. Although experts will arrive at one or more relevant theories for a particular phenomenon, the student responses were system dependent. This information is provided in Table 4.1.

4.8 Discussion of Data Analysis

Students' conceptions of dissolving contributes to two types of knowledge: (1) understandings about high school chemistry learning; and (2) understanding about high school students' chemical knowledge. The understandings about high school chemistry learning are discussed in Chapter 7. The understandings about high school students' chemical knowledge are:

1. macroscopic qualities extended to microscopic level;
2. students' chemical language and teacher meanings; and
3. confusions between pairs of concepts and processes.
4.8.1 Macroscopic Qualities Extended to Microscopic Level

The literature cites examples of students' conceptions which illustrate their extensions of macroscopic qualities or behaviour of substances to microscopic qualities or behaviour. Studies (Ben-Zvi, 1988; Hess, 1987) suggest that, for most students, a particle is a very small piece of matter; therefore, the properties of the particles are those of the matter.

This study identified several examples of explanations of solubility which consisted of students attributing macroscopic properties to the microscopic worlds. Illustrating this point are two examples: One of the student's stories was that molecules cannot be seen but if they are altogether like sugar in a sugar bowl, one can see the molecules. This explanation is parallel to Plato's theory of matter—"These unit-bodies must be thought of as being so minute that a single atom of any one form is too small to be visible to us, though a large number taken together form a mass which we can see" (Toulmin and Goodfield, 1962, p. 77).

Another student's creation for the crystallization of salt was: "The molecules cool down and they [salt crystals] re-form in the bottom." Here, the student associated the occurrence of energy change in molecules rather than in matter. In her study on Learning about Heat and Temperature, Haggerty (1986, p. 70) states that there is a distinction between the macroscopic behaviour of matter and the sub-microscopic behaviour of the particles which comprise the matter. Her example was: "when matter is heated it expands. The particles do not expand." Concerning the melting of ice, one of Haggerty's target students, Cathy, had said:

Ice melts because the particles become warmer and melt, and that warm air rises because the particles become lighter.

This finding is not surprising. In 600 B.C., Greek philosophers (Thales, Anaximander, and Anaximenes) proposed different theories while seeking an answer to the question: What is matter? They were all of the understanding that matter can be reduced to a
single universal substance from which all animate and inanimate things were formed. For example, Thales put forward the theory that the underlying principle of matter was water.

The first conception of matter held by the early Greeks was that it was continuous since it was not specified that the basic element or elements were subdivided into fundamental particles. In essence, a continuum theory of matter assumes that as matter is divided into smaller and smaller pieces, these pieces, no matter how small, will retain the properties of the bulk material. This assumption seems reasonable because it was through experimental studies that the scientists came to the realization that the continuum theory cannot account for the varieties of matter. Similar ideas held by the present chemistry students should not surprise researchers or teachers because it does sound reasonable to say that “all the molecules are going crazy because they are hot.” It seems to the researcher that students state these things without giving too much thought to what they say or the meaning which it conveys. They may not even believe that the “molecules are hot” when they talk about matter. However, the interplay between the macroscopic and microscopic levels is an important characteristic of chemistry and crucial for success in chemistry.

4.8.2 Students’ Chemical Language and Teacher Meanings

In a chemistry class, students may experience conflicts because their common linguistic expressions might be at odds with that of teacher or meanings they have gleaned from certain chemical terms. A chemistry class should become a context in which the students must be provided opportunities to understand the linguistic differences, so that social interaction or dialogue among individuals about the topic under discussion is more meaningful. Some students used the term “particles” for “granules” of sugar whereas in chemistry, the term particle refers to “atoms,” “molecules” and “ions.” In everyday
language the word "particle" refers to a very small, visible piece of solid substance such as granules of sugar.

For most individuals, language is for communicating about something in the most pragmatic sense. The thing that matters most is whether the communicators understand what is being conveyed. In school, however, importance is given to the disciplinary language. The students are expected to learn this language and be fluent in it almost immediately. This is not the case when French, Spanish or any other language is learnt.

Often, students use taught disciplinary language in their written work or tests but when communicating ideas, they bring their everyday language and meanings to understand science concepts. For most students, expressing scientific ideas with their everyday vocabulary and thinking seems to be not only sensible but also sufficient and "good enough" (Hesse, 1987). In a chemistry class, what students count as good enough may make science learning difficult.

Should the teachers strive to change the students' everyday talk in their science classes? If so, how successful will the teachers be? As argued in the previous paragraph, for some students, taught scientific ideas may be applied in stereotypical school contexts as, for example, in examination questions. Such ideas are not applied outside the formal school setting to everyday phenomena. Solomon (1983) distinguishes the symbolic and life-world domains of knowledge and documents the difficulties students have in relating to the two. Similarly, although students' imprecise use of language can be readily acknowledged, it is not ideal to expect them to immediately forget the language which is so much a part of them. Students should, however, be made aware of the differences in the meanings derived from their everyday talk and the meanings embedded in the chemists' language and why it is important to cultivate the usage of appropriate language to learn a distinctive discipline such as chemistry.

The context in which a word is used should be given some thought. When students
use the word "particle" for granules of sugar, as in this study, the meaning must not be decontextualized for communication or evaluation purposes. However, gradually a chemistry teacher ought to sensitize the students with appropriate language use in a chemistry class for proper understanding and discourse.

4.8.3 Confusions Between Pairs of Concepts and Processes

An important finding of this study was that students exhibited confusion between pairs of concepts and processes such as physical and chemical change, compound and solution, and melting and dissolving. Although these concepts and phenomena are part of the students’ world, distinctions are made between these only in a science class with everyday examples. Furthermore, chemical theories and models are taught only in the school context.

Some of these concepts are taught beginning from Grade 1. By the time students are in Grade 10, usually these concepts have been taught repeatedly, although the kinetic molecular theory and theories and models related to dissolving are taught to students at some depth only in Grade 11 chemistry. Before the unit on solution chemistry was begun, the teacher had drawn the differences between physical and chemical changes using a "Concept Attainment" (Joyce and Weil, 1986) lesson. Despite this, the students manifested problems when they had to apply the learned knowledge in the sugar/water system. They came up with all kinds of theories why they would say that sugar dissolving in water is a chemical change in a generic sense. This goes to show that, initially, understanding of students’ prior ideas are vital. Even in concept attainment lessons, students’ prior understandings of the differences between two related science concepts must be drawn out. This is one of the ways those who are concerned with teaching will know the difficulties and confusions that students have.
Chapter 4. Students’ Conceptions of Solubility

4.9 Summary

The phenomenographic research tool guided the analysis of the data. In line with findings of studies that have used this research tool, this study has yielded a limited set of descriptive categories in accounting for students’ conceptions of the phenomenon of solubility. Within the categories of description for solubility, there were some variations in the pattern of reasoning. For example, many students considered that dissolving is a process of “chemical transformation of solute.” Within this pattern of reasoning, students’ arguments featured interesting variations such as the following: there is an attraction between sugar and water and it is like elements attached in a compound; there is a compound formation between sugar and water because of either the transferring or sharing of electrons; and there is bond breaking in the sugar.

The knowledge of the outcome space of physical and chemical phenomena may be helpful to teachers. Several questions arise from this belief. What are the starting points of beginning chemistry students? What might be some of the underlying causes of the conceptions that students hold? Where can the teacher go from here (a sense of direction)? How can the teacher link students’ conceptions to the chemistry curriculum? Can the categories of description become a part of the teaching content?

It is interesting to note students’ conceptions for a given concept. What can a researcher do with the students’ conceptions other than to publish them in journals, thus confining this understanding to the community of researchers? In this study, however, the students’ prior conceptions were shared with the students’ chemistry teacher. A collaborative effort was undertaken with the teacher to teach a unit in solution chemistry together. The principle aim was to examine the factors that might facilitate or constrain the incorporation of students’ initial conceptions in a chemistry classroom.
Chapter 5

Instruction: Attempts To Incorporate Students' Conceptions

5.1 Introduction

Chapter 5 is a description of some of the collaborative efforts made by a chemistry teacher and a science education researcher to incorporate students’ conceptions of solubility when teaching a unit on solution chemistry. This description, which may be thought of as a type of story, outlines some of the most salient features of this collaborative endeavour at “conceptual change teaching” (Posner, et al., 1982; Nussbaum, J., and Novick, 1982) and examines some of the factors which served to facilitate and constrain their efforts.

In the narration of this story of collaboration, the teacher-collaborator is given the pseudonym “Jane.” Hence letter J denotes the teacher. The letters R and S (Sg=girl, Sb=boy, S1=student 1, S2=student 2) stand for the researcher and student respectively.

Chapter 5 attempts to answer the following research question:

What are some of the influences facilitating and constraining the teacher-researcher collaborative procedures in attempting to incorporate students’ conceptions in this study?

5.2 Preparations for Solution Chemistry Teaching

Jane and the researcher carefully examined the concepts and the course objectives\(^1\) that were outlined in British Columbia Grade 11 & 12 Chemistry Curriculum Guide (1987). Jane noted the dates and the content of solution chemistry that she and the researcher

\(^{1}\)See Appendix C for Solution Chemistry Unit Objectives.
would cover on each date. Altogether, they planned to have ten lessons of solution chemistry. Jane requested the researcher to take the first two lessons because she was eager to see a constructivist science researcher/teacher in action.

The implications of covering all of the content material in the given time was also discussed. Jane mentioned that since the chapter on solution chemistry is taught almost at the end of the year (according to the Curriculum Guide), in her previous years she could not give it the allotted time of 15 hours of teaching.

Concerning pedagogy, Jane expressed a desire to try different methodologies to deliver the curriculum material in interesting ways. In this way, Jane believed that the “students would learn a little bit more” than if she taught by transmission. Jane wanted her students to be “engaged.” Jane said that her technique of teaching chemistry was one “very much of verifying information” and not by “inquiry” or “chemical applications.” She wanted to know if the researcher and she could “experiment, with [her] kids actually getting involved with the experiment.”

From the beginning of the collaboration, Jane requested and expected the researcher to help her in the constructivist methods of teaching. For example, she stated:

The more you talk to me about it, hopefully, you know I will through metamorphosis ... the philosophy will come in, the more suggestions you give me as how to present the material. If it doesn’t work the first time, ... you can make comments on the way I deliver and hopefully I will incorporate the changes in my next presentation. And you know, I think, if I were an experienced teacher delivering some of this stuff I will be probably very effective. But delivering it for the first time that kind of strategy is new territory for me and it won’t be effective. I love to have a coach which is you in the classroom. (Conversation on 1989 07 30, Transcription, p. 4)

Jane asked the researcher for the scope and sequence of all the lessons in solution chemistry and the procedures that she and the researcher would follow for each lesson. The researcher did not want to give Jane a pre-packaged plan of how she would try to incorporate students’ conceptions of solution chemistry because she was in the classroom.
to understand how Jane would plan strategies to incorporate students' conceptions. During the course of the study, the researcher wanted to facilitate Jane's reflective inquiry into her chemistry teaching and pose some alternative methods of teaching. So, in the preparatory period of their study, the researcher stated the following about some aspects of collaboration:

As we go along we can talk about each lesson. We can see the effects of our lessons on student understanding. At the end of the each lesson, we should talk about the strategy we used. What kinds of understanding do students have? And we should try to elicit students' understanding and talk about these. We should ask ourselves the question, "Could we have presented the concepts differently?" We can also trace students' conceptual change. (Transcription, pp. 4-5)

The pre-planning for collaborative teaching consisted of looking at the Grade 11 & 12 Curriculum for intended objectives and outcomes of the solution chemistry unit, content coverage, time span, scheduling of lessons, pedagogy, and teacher/researcher expectations of collaboration.

Incorporation of students' conceptions of solubility was the main goal in the collaborative efforts of the teacher and the researcher. The next section describes some of their collaborative efforts.

5.3 Collaborative Instructional Components

Incorporation of students' conceptions was evident in the following instructional components:

1. researcher's attempts at constructivist teaching;
2. Jane's attempts to incorporate students' conceptions; and
3. Jane's lessons on polar and non-polar solutes and solvents.

These collaborative instructional components are described in chronological order and they provide a framework for this section. Within each component of instruction,
the concepts taught, strategies used, the researcher's reflections, students' reflections, and
teacher/researcher reflections about certain aspects of instruction are described. Because
of the large amount of data generated by a study of this nature, only selected lessons
have been chosen for more detailed analysis.

In the subsequent sub-sections, each of the above components of collaboration are
expanded. Included are examples of excerpts taken from the classroom data, and the data
gathered from the researcher's reflections, students' reflection logs, teacher/researcher
conversations, as well as reflections about the researcher's constructivist teaching and
the teacher/researcher reflections about the teacher's efforts to incorporate students'
conceptions.

5.4 Researcher's Attempts at Constructivist Teaching

The teacher/researcher collaboration journey on teaching and learning of solution
chemistry began when Jane invited the researcher to "model" a constructivist approach
by teaching the first two lessons of solution chemistry in her class\(^2\). In response to Jane's
invitation, an attempt was made to try out some of the constructivist strategies to teach
solution chemistry. At the outset it must be mentioned that the researcher makes no claim
in being an expert constructivist practitioner. Although she has had the opportunity to
examine extensively the literature on constructivist teaching and learning, this is the first
time she has had a chance to put that knowledge into practice in a secondary chemistry
class.

\(^2\)The researcher taught the third lesson as well. See Appendix D for Lesson Plans.
5.4.1 Objectives of the Researcher’s Lessons

To manifest an example of constructivist science teaching to Jane, an attempt was made to follow Driver’s instructional model\(^3\) (Driver, 1987) in the first three lessons that were taught. Thus, the following objectives were outlined:

- to orient the students to the study of solution chemistry by having them drink Orange Crush and discuss their ideas about the nature of solutions;
- to elicit and examine students’ conceptions of solution chemistry by using an everyday experience, drinking Orange Crush, and a simple system, dissolving of a cube of sugar in hot tap water;
- to provide an example to the teacher of how students’ ideas can be utilized to form the basis for curriculum development and teaching;
- to give students opportunities to elaborate and/or change their conceptions;
- to show the teacher how students’ prior conceptions can be incorporated by using a discrepant event; and
- to introduce to students a strategy for laboratory learning.

In accordance with the curricular objectives outlined on p. 46 of the Grade 11 & 12 Curriculum Guide, it was decided in the planning stages that the researcher will deal with the following topics: “the nature of solutions”; “types of solutions”; and, “general solubility considerations.”

5.4.2 Teaching Concepts Adapted From Driver’s Instructional Model

5.4.2.1 Lesson One

On the first day of the solution chemistry unit, in accordance with the first two components of Driver’s instructional model, that is, “orientation, and elicitation,” two learning experiences were provided to orient and elicit students’ prior knowledge of solution chemistry.

\(^3\)See Appendix E for Driver’s Instructional Model.
The first activity consisted of students drinking Orange Crush to elicit their understanding about the nature of solutions and to establish a working definition for “solutions.” The second activity consisted of adding a cube of sugar to hot water, which focused on the solution process. With the second activity, the students were expected to describe what might be happening to the sugar when it was added to water.

The students worked in groups consisting mainly of five students. Twenty minutes were given for their discussion of the activities mentioned above. A portion of the conversation in the first lesson is included here to give insight into how a group of students shared their ideas amongst themselves.

S1: (Reads the question on sugar and water) Describe what might be happening when a cube of sugar is added to hot water.

S3: It has particles, separating, dissolving.

S2: Bubbles that are attracted to each other. The bubbles are attracted to each other.

S1: Bubbles attached to the side of glass.

S2: Yeah, that's true. They form at the bottom and they float to the top.

S2: Stir it. This is a suspension.

S1: This is a solution.

S2: It is a suspension.

S1: I can't see it.

S3: There is nothing floating on it.

S2: Milk is a suspension. It got fat things in it. Molecules floating in it.

S1: Milk is homogenized.

S2: O.K.

S1: You can't see it.

S2: It is staying in the bottom. It is a mechanical mixture. You can physically see two things apart.

S1: Yes, you can but you can't see all of it. You can't see all of the sugar. Can you?

S2: Well, I can't because I didn't number all of them.

S1: Sugar is dissolving.

S3: What do we mean by dissolve? I mean mixed more thoroughly.

S2: They went from big thing to little thing.

S1: There, it disappeared now. Well, now, what is it?

S2: Now it is a solution.

(Lesson 1 Tape Transcription, p. 3)

In this conversation, the students proposed and justified their own ideas about sugar dissolving in water. In their conversation students were wondering what they would call a
mixture containing sugar and water. The students were advancing logical explanations as to why they would call sugar dissolving in water a suspension, heterogeneous mixture or a solution. Each of their proposals seemed plausible. At the first stage of the dissolution process, student 2 suggested that the bubbles were seen at the top, bottom, and adhering to the sides of the glass walls of the beaker and she decided she would call it a suspension or a mechanical mixture. The analogy the student drew was homogenized milk. She seemed to say that in milk there are finely divided fat globules that are suspended in water. Student 2 argued that milk is homogeneous. She stated she can't see it [fat globules]. With regard to sugar in water, student 2 argued forcefully: “Yes, you can (meaning ‘see two things apart’) but you can’t see all of it. You cannot see all of the sugar, can you?.” At the second stage of the dissolution process, student 2 agreed with student 1 in saying that it is a solution.

The students’ prior conceptions that emerged from the discussion of these two activities which touched on the curricular objectives of the solution chemistry unit are presented in Table 5.2:

In the first lesson, the students were given plenty of time to share their ideas about solutions in small groups. Then as a class, their ideas were elicited. Simultaneously, the concept of solution was introduced with their own ideas. Some understanding of the concept of solution was achieved through discussion and probing. For instance, the researcher asked questions such as the following: “Why do we call Orange Crush a solution?” “What do you understand by dissolving?—What ideas do you have?” “What do you know about solutions?” “Can you give me examples of solutions?” “Do you see any particles?—What do you mean by particles” “What different salts do you find in the ocean?—Can you name some of them?” “Can we make a general statement about the characteristics of solutions?”

Based on the two activities, as a class the researcher and the students arrived at
Table 5.2: Students' Conversations Reflecting Curricular Objectives

<table>
<thead>
<tr>
<th>Curricular Objectives</th>
<th>Students' Talk</th>
</tr>
</thead>
<tbody>
<tr>
<td>The students should become aware of the different types of solutions</td>
<td>liquid dissolved in a liquid (e.g., citric acid in water), gas dissolved in a liquid (e.g., carbon dioxide in water), solid dissolved in a liquid (e.g., sugar in water in the Orange Crush)</td>
</tr>
<tr>
<td>The students should understand the term concentration</td>
<td>Orange concentrate, being sticky because of sugar concentration</td>
</tr>
<tr>
<td>The students should understand the effect of pressure on gas solubility</td>
<td>pressure—&quot;sprayed out in our hands.&quot; &quot;It was pressure in the can. When we opened it, it went zzzz.&quot; gas solubility—&quot;There are lots of bubbles,&quot; &quot;What are those air bubbles?&quot; &quot;It must have air in it, something is in the bubble. Most likely it is an acid&quot; &quot;look at the air floating&quot;</td>
</tr>
<tr>
<td>The students should understand the effect of temperature on gas solubility</td>
<td>&quot;If you put this in hot water it is going to sh ...&quot;</td>
</tr>
<tr>
<td>Types of mixtures and examples</td>
<td>&quot;smooth,&quot; &quot;It is homogeneous or heterogeneous or whatever,&quot; &quot;Oh! you can see through (students referred to this as ‘opaque’), &quot;It cannot be a mechanical mixture. But it is not a suspension, is it? It is not anything floating in this. Like milk. Milk is a suspension because it got fat floating.&quot;</td>
</tr>
<tr>
<td>The students should distinguish the types of solution state</td>
<td>liquid state of a solution—&quot;It is in the liquid state. Well it is not a solid.&quot;</td>
</tr>
<tr>
<td>Dynamics of solutions</td>
<td>&quot;It will take forever. No, some is going to stay at the bottom if we just leave it like that. (pause) It dissolves much faster.&quot; &quot;Well, stir it up.&quot;</td>
</tr>
<tr>
<td>The students should understand the dissolving process of sugar</td>
<td>&quot;The bubbles are going to eat away the sugar.&quot; &quot;It is disappearing, right.&quot; &quot;It is just falling apart. &quot; &quot;The particles are breaking.&quot; &quot;It is boiling. It is cooking.&quot; &quot;Sugar is cooking. ...softer than usual.&quot; &quot;Dissolving is when it melts the particles.&quot;</td>
</tr>
<tr>
<td>The students should understand the chemical process of solutions</td>
<td>&quot;No, it is a chemical reaction. ...How do you know that it is a chemical reaction? Because there are bubbles. That's why it fizzes. Because there is a reaction in the pop because there are bubbles.&quot; &quot;There is carbon in it. Is that why it is bubbling? Reaction with the carbon.&quot;</td>
</tr>
</tbody>
</table>
a working definition for solution: “A solution is a mixture of two or more substances because Orange Crush consists of sugar, carbon dioxide (bubbles), orange concentrate, food colouring, and water. When sugar dissolves in water, we get a solution.” No chemical labels, such as “solvent,” and “solute” were mentioned on the first day. In order to accommodate the concept of invisibility of molecules (a problem area for students), the origin of the word “molecules” from the Greek words, “moles (lumps)” and “cules (little)” was told.

5.4.2.2 Lesson Two

In the second lesson, the concept of solutions was reviewed. Concepts such as solute, solvent, effervescence, and effect of temperature on solubility of gas were introduced and discussed, again based on the Orange Crush and sugar/water system. The fact that solutions exist in all three states of matter and can have many combinations were explained with examples of solutions such as solid in solid (tooth filling, jewellery, penny), and gas in gas (air).

In lesson two, students’ alternative conceptions formed the content of teaching rather than what was outlined in the curriculum guide.

5.4.2.2.1 Incorporation of an Alternative Conception: Air is a True Solution

Because of the ambiguous nature of air, a question was posed to students whether they would consider air as being a true solution? The researcher shared an experience of how another Grade 11 student argued with her that air is not a true solution. In class, it was argued that air can be considered a true solution if it is in the pure form.

To reinforce the idea that air cannot be really considered a true solution, the concepts of solution, suspension and mechanical mixture were developed by means of a simple demonstration. To begin with, two bottles containing clear liquid were shown. One
contained sugar dissolved in hot water and the other one contained unflavoured gelatine dissolved in hot water. Both liquids looked exactly the same. The students said that gelatin mixed with water was a true solution. The idea was proposed that every liquid that appears to be homogeneous is not necessarily a true solution. It was mentioned that some liquids are called “false” solutions—colloidal suspensions. To distinguish between a true solution and a false solution the “sunset experiment” (precipitation of sulphur when concentrated sulphuric acid was added to sodium thiosulphate solution) was shown. Colours of the sky were discussed in terms of mixture of gases, and particles in the atmosphere. In particular, the sunset experiment was shown to explain the colloidal nature of air and how air “may not” be considered a solution. This gave the researcher an opportunity to discuss the Tyndal Effect and Brownian motion, the characteristics of colloidal suspensions—not included in the curriculum.

5.4.2.2.2 Incorporation of an Alternative Conception: One Can See the Molecules of Sugar if it is in a Sugar Bowl On the first day the Greek origin for the English word “Molecules” was mentioned in class. On the second day, a five-minute video called, “Molecules,” was shown to help students accommodate the particle (molecules) nature of matter.

5.4.2.2.3 Incorporation of an Alternative Conception: Chemical Combination of Sugar and Water to Produce Sugar-Water In the interviews conducted prior to the instruction, some of the students had the notion that solutions are created by a chemical combination of sugar and water to yield sugar-water. In order to challenge this idea, the students were shown a discrepant event that consisted of a similar “disappearing act” which showed evidences of a chemical reaction. Because of the hissing noise, and the accompanying
Chapter 5. *Instruction: Attempts To Incorporate Students’ Conceptions*

flame when sodium disappeared in water, the students expressed the idea that this event was different from sugar disappearing in water. The students talked in terms of energy production. The students recognized that in this case matter has been transformed into at least two forms of energy (sound and light). The students also noticed the bubble formation. They knew that the bubble formation was due to the evolution of a gas. In fact, some of them said that there is evidence of a new substance being formed. The researcher mentioned the name of the gas in passing. After class, one student in particular mentioned that he liked the reaction of sodium with water because it helped him to distinguish between a physical and a chemical change. The researcher was not sure whether this activity created more conceptual conflicts or not in the students because of the inherent ambiguous characteristics of the activity. This is discussed in this chapter under the section “the researcher’s reflections.”

In the first lesson, students did allude to the fact that the formation of carbon dioxide in Orange Crush was because of a chemical reaction. Since it pertained to solubility and chemical equilibrium, a difficult concept to deal with on the second day, no attempt was made to talk about it. The activity on Orange Crush was also perceived by the researcher as having inherent characteristics of ambiguity, which is explored in the section on “the researcher’s reflections.”

In the second lesson, a discussion of the polarity of water molecules laid the foundation for the theoretical frameworks that chemical behaviour depends on the chemical structure of matter. An explanation of the structure of a water molecule was imperative to continuing with the solution chemistry, especially to bring out the idea about hydrogen bonding and how this becomes the basis for considering dissolving of sugar in water as a chemical phenomenon. Hence the chemical explanation of the polarity of the water molecule was given by the researcher/teacher. The concept of unequal sharing of electrons by the hydrogen and the oxygen atoms was, however, presented using a metaphor from
their personal experience (How unequal sharing often occurs between a brother and a sister).

5.4.2.3 Lesson Three

Since we talked about colloidal suspension in depth the previous day, and how the particle size is one of the determining factors whether a mixture is a true solution, a colloidal suspension or a heterogeneous mixture, it was decided to draw students' attention to paper chromatography as a method to separate components of a colloidal suspension. Each student prepared a chromatogram either using food colour or felt pen.

Practical, everyday examples of colloidal suspensions such as hair spray and shaving cream were shown. A demonstration was shown by adding detergent to a mixture of water and oil, which formed an emulsion. The above examples and the demonstration illustrated the idea that among colloidal suspensions there are different types such as sols, foams and emulsions. At the end of the period, one student asked why the researcher would say aerosols are colloids. After stating to her that sols consist of liquids or solids suspended in a gaseous dispersing medium, the researcher gave her a handout which listed many examples of colloidal suspensions. A heterogeneous mixture was also shown by adding mud to water. From students' responses to the review lesson on the third day, it seemed that they knew the distinguishing characteristics of solutions. As a means of representing their responses the researcher used a heuristic tool called a “Vee diagram” (Novak and Gowin, 1984; see Figure 1) to diagram their understanding of solutions. Figure 5.1 consists of a Vee diagram which represents students' understanding of solutions.
Chapter 5. Instruction: Attempts To Incorporate Students' Conceptions

Figure 5.1: A Vee Diagram: Students' Understanding of a Solution

My Understanding

Theory
Kinetic Molecular Theory description of a liquid is used to explain solid-liquid solutions.

Principles
A homogeneous mixture of two or more substances.
Its composition may vary.

Concepts
solute, solvent, gas, liquid, solid, solution, effervescence, pressure, homogeneous, mixture, substances, dissolve, physical change, chemical change

FOCUS QUESTION
What is a "Solution"?

My Doing

Value Claims
practical applications—food and medicine

Knowledge Claims
Solution is a mixture.
Solution is homogeneous.
Solute dissolves in a solvent
The substances are in different amounts.

Transformation
fizz carbon dioxide hear
colour orange see
sweet sugar taste

Records
fizzing sound hear
bubbly orange in colour see
orange in colour tastes sweet taste
has orange flavour
clear

EVENT

DRINKING ORANGE CRUSH
By the end of the third day, a few alternative conceptions were dealt with through demonstrations, discussions, experiences, video, and lectures. In these lessons the researcher discovered the ambiguities that might pose difficulties for students’ understanding of chemistry.

In summary, the researcher’s constructivist teaching featured the following themes:

1. orientation of solution chemistry and elicitation of students’ ideas;
2. clarification and elaboration of students’ conceptions;
3. attempt to restructure some of the alternative conceptions that the students held; and
4. introduction of a strategy for laboratory learning.

Self-reflection is a core component of constructivist teaching and learning practices. In the next section, the researcher outlines her reflections about how her lessons were carried out.

5.4.3 Researcher’s Reflections of Her Teaching

Some significant issues surfaced in the three days of the researcher’s constructivist teaching. These can be summarized in terms of two broad issues:

- the difficulty in incorporating students’ conceptions because of the ambiguous nature of chemical theories; and
- the difficulty in incorporating students’ conceptions because of confronting students with their own ideas.

These two issues are based upon the nature of chemistry content and the nature of the learner. Thus two reactants were discerned when the researcher attempted to incorporate students’ conceptions of dissolving.
5.4.3.1 Ambiguities of Chemical Theories

Incorporating students' conceptions into solution chemistry lessons was not an easy task. In every attempt at incorporating students' conceptions, the researcher was faced with the ambiguous or inconsistent nature of a particular contemporary conception of chemical theory. A few examples of these inconsistencies are examined.

5.4.3.1.1 Dissolving: A Chemical Phenomenon or A Physical Change? In the pre-instructional interview, many students were of the view that the dissolution of sugar in water was a chemical change. For instance, reasons such as changing of crystalline solid to liquid sugar, two things combining to form a single product (sugar-water), taste of water is now sweet, were given for the consideration of sugar in water as a chemical change. Some students expanded their chemical change view by explaining the process of chemical change in terms of microscopic understanding (refer Chapter 4, category of description: chemical transformations). Hence, in order to distinguish between a chemical change and a physical change, an activity (sodium disappearing in water) that would show the disappearing act and simultaneously one that would manifest external characteristics of a chemical change was shown to the students. It was thought that this activity might produce further discrepancies or inconsistencies in learning of the chemical concept "dissolving."

In chemistry there are many types of chemical reactions: (1) some show energy changes (sodium in water), (2) some indicate change of colours because of chemical equilibrium (chromate into dichromate and vice-versa), (3) some yield precipitate (potassium iodide and lead nitrate producing a yellow precipitate of lead iodide), and (4) some do not indicate any of the above visible changes (hydrochloric acid and sodium hydroxide): The danger of showing just one type of chemical reaction as was shown in
class can easily lead to misunderstandings in the minds of students. That day students may have left with the understanding that dissolution of sugar in water or salt in water is not a chemical phenomenon because there were no visible attributes of chemical changes as was exhibited by the sodium/water reaction.

An examination and understanding of the solution process such as salt, sugar, hydrochloric acid, sodium hydroxide suggests that solvation or hydration is taking place. This means that forces of attraction are set up between particles of liquid solvent and solid solute. (The existence of electrical forces can be displayed by conducting experiments on electrostatics and on conductivity—but the connection between these concepts and solution concepts are complicated). Thus the concept of dissolving poses difficulty for students because of its dual behaviour—a chemical process as well as one which does not show any outward appearance of chemical changes. In order to understand the chemical process of dissolution, students must operate in the microscopic and the symbolic worlds and these might induce complex learning difficulties. Thus it was realized that the intricate web of knowledge that was presented and the puzzles that may have been created consequently cannot be treated in a simplistic manner in a short period of time.

5.4.3.1.2 Carbon Dioxide in Orange Crush: Dissolved and in Chemical Equilibrium Orange Crush was served to get an overview of the nature of solutions. This seemingly easy, fun-type task of drinking Orange Crush and observing the properties of solutions may have caused many conceptual conflicts in the minds of the learners. Like the sugar/water system, this system can be considered a solution involving the dissolving of solids in a liquid, but this system also entails the dissolution of gas, which is more complex. On the first day of solution chemistry, the researcher dealt quickly with how temperature changes have very noticeable effects on the solubility of solutions. Notice
the discrepancies of the effect of temperature on different solution systems: Most solids are more soluble in liquid solvents as the temperature of the solution is increased. As the temperature of a solution is increased, the bonds between solid solute particles are weakened, and the substance can dissolve more easily. So solids are usually more soluble at higher temperatures. For solutions composed of miscible liquids, temperature changes generally have very little effect on their solubility. No crystalline (lattice) bonds, which need to be broken in order to cause dissolution, are present in liquids. All gases are less soluble in liquids as the temperature of the solution is increased. As the temperature of the solution is increased, the increased kinetic energy makes the particles move faster, and they can escape from the solution into the gaseous state more easily. One example of the effect of increased temperature on the solubility of gases in liquids involves warm soft drinks. The variations of the effect of temperature on solution systems can promote conceptual conflicts and such conflicts cannot be simplistically treated or resolved.

The notions of dissolving, and the effect of temperature on different solution systems are difficult. And when dissolving is understood in terms of saturation and in terms of chemical equilibrium, there can be a creation of many other puzzles. When students were served Orange Crush, one group suggested that there is a chemical reaction between carbon and water to produce carbon dioxide gas. This can mean that they had a slight inclination that there was some kind of a chemical reaction taking place. The researcher suggested that carbon dioxide gas has been dissolved in Orange Crush approximately five times the atmospheric pressure and when the lid is removed from the soft drink container, the pressure suddenly drops and some of the dissolved carbon dioxide gas bubbles out of the solution. The researcher did not get into the aspects of saturation of carbon dioxide in Orange Crush and how in a closed, pressurized container, soft drinks have an equilibrium between carbon-dioxide, water, and carbonic acid:
and how when a bottle is opened, a soft drink converts its carbonic acid into carbon
dioxide, which escapes into the atmosphere. Therefore that day the students may have
left the classroom thinking that carbon dioxide is dissolved in Orange Crush. Solutions
however exhibit dual behavior patterns (dissolution of carbon dioxide in water and
chemical transformation of it into carbonic acid) which must be dealt with. This dual
nature of solutions may indeed cause conceptual conflicts in students.

5.4.3.1.3 Air: A True Solution or A Colloidal Suspension? Air is a solution
and air is also a colloidal suspension. This dual nature of air was discussed in class
by means of an activity. First a bottle containing sugar and water was shown. Then a
bottle containing unflavoured gelatine and water was shown. The physical characteristics
of these two mixtures create sensory deceptions because they appear to be the same.
However, the mixture containing sugar and water is a solution and the mixture containing
unflavoured gelatine and water is a colloidal suspension. The colloidal nature of the
gelatine-water mixture is not obvious. Similarly, the colloidal nature of air is not obvious.
Hence, the “sunset” activity was demonstrated to help students understand the colloidal
nature of air. It can be argued that students would readily discern the colloidal nature
of air because they are aware of air pollution. However, the students may not relate air
pollution with the colloidal nature of air because the suspended particles in the air can
not be seen. So air being a colloidal suspension might pose difficulties for learners.

5.4.3.1.4 Water: A Solution or A Compound? The question whether water
is a solution or not has been a contention in the minds of many students. Interview
data, classroom observation data of high school chemistry and teaching elementary school teachers (pilot studies) suggest that students think that water is a solution because it consists of two gases, namely hydrogen and oxygen. In a science content course for elementary teachers, the researcher has attempted to show that water is a chemical compound by separating hydrogen and oxygen through electrolytic process using Hoffman's apparatus, whereas solid, liquid or gas from a solution can be similarly separated by mechanical means. Since constituents of both a sugar/water solution, and water, can be recovered (sugar solution yields sugar and water and water yields hydrogen and oxygen) by an appropriate method, the formation of a solution and the formation of a compound seem to be paradoxical.

In the pilot study, an illustration of this ambiguity occurred when some students claimed that fish have specialized organs to separate oxygen and hydrogen and that is how the fish get their supply of oxygen. In dealing with this particular situation, students actually have to distinguish between two different problems. One is whether water is a solution or a compound; the other is the solubility of oxygen in water producing a solution.

Chemistry poses many inconsistencies such as the above, even within the same system. Just one system can be argued in many ways depending on the students' experiences, and the types of questions posed in class. Sorting through the ambiguities of chemistry will not only pose difficulties for students but will also involve taking time and patience to prepare lessons to address them. But it does not mean that steps should not be taken to sort out some of the conceptual conflicts that are created by the inherent conflicts in the chemical systems. Conceptual change teaching points out the usefulness of content-based strategies that would help students to better appreciate these difficulties in understanding the language of chemistry.

In summary, then, inconsistencies of chemical knowledge induced problems and
created further difficulties for the beginning chemistry students. This was because pure concepts are difficult to teach because they are complex notions built on other complex notions. Even though theoretical ideas were expounded in class, the fundamental problem seems to be the ability of beginning students to grasp and/or differentiate among highly complex theories and articulate them using chemical language.

5.4.3.2 Confronting Students' With Their Own Ideas

Two issues surfaced when students were confronted with their own ideas. These were concerned with:

• the content of student conceptions for chemistry teaching; and
• the important role of mental comfort;

5.4.3.2.1 Content of Student Conceptions for Chemistry Teaching In the chemistry classroom, the researcher/teacher was caught between two worlds. On the one hand, she was aware of a wealth of student conceptions and a number of teaching strategies that might be used to accommodate some of these alternative conceptions. And on the other hand, there was the chemistry curriculum (curriculum guide, textbook, and lab text) that had to be covered within a specified period of time.

The intention was to address the chemistry curriculum beginning from students’ conceptions. However, when students’ conceptions were taken into consideration, many side agendas had to be accomplished. For instance, a discussion on whether air was a solution or not took a whole period. This entailed covering a content area which was not part of the solution chemistry unit. These lessons also included demonstrations and student work that were not part of the curriculum. Similarly, the demonstration (disappearance of sodium in water) to show that sugar or salt dissolving in water is not a
chemical change but a physical change in the "usual" sense was not a part of the solution chemistry unit.

Incorporating students' conceptions cannot be carried out in a linear mode because students give birth to new conceptions and often they are inconsistent with chemists' ways of reasoning. Ideally, content provided in other units should be tied in with the current concepts being addressed. This means instead of keeping with the sequence of the solution chemistry unit as laid out in the text, time has to be spent in other units of chemistry trying to relate the concepts. For example, although students had gone through the distinguishing characteristics between physical and chemical change, they could not relate these to the systems that were shown. Similarly, the students had already gone through chemical bonds (ionic and covalent) but it was very difficult for them to bridge this theoretical knowledge to the structures of chemical compounds presented in solution chemistry. Thus, bridges have to be built to various parts of chemistry. However, when chemistry is taught in a sequential manner, the students themselves have to relate their previous learning to the present learning and many do not do this successfully. This was indeed clear when students attempted to relate the concepts of chemical change and kinetic molecular theory to the systems used in the interview. Although these concepts are relevant to an analysis of those systems, they were not appropriately applied. This is a reason why conceptual change teaching is essential in a chemistry class because it emphasizes the diagnosis and uncovering of students' conceptions while the chemistry curriculum is covered. A dilemma emerges when we consider the following questions. Should the covering of prescribed content of the curriculum be the main target or, should addressing students' conceptions become an important component of chemistry teaching? In other words can we consider students' conceptions to be relevant and appropriate for chemistry teaching? In the chemistry classroom, this researcher/teacher found it very difficult to incorporate students' conceptions as well as to cover the prescribed content
of the curriculum in an effective manner in the time available.

5.4.3.2.2 Mental Comfort? In addition to the above difficulty, a second issue arises when students are probed with questions and they come to the realization that their ideas are not in line with the scientific views. How do they feel about such teaching? Are they comfortable in the classroom? Are the students being provided with a “safe” learning environment? In the three days the researcher taught, she did not follow the principle: tell them what you are going to say, tell them, and tell them what you have already told. The objectives were not clearly stated. Teacher-made notes were not given. Students were not given answers to the think-type questions that arose from the demonstrations. There were more questions raised than solutions given.

Confronting students with their own ideas did not seem to be an easy task. When the students were brought to the understanding that some of them had a different view of sugar or salt dissolving in water, the researcher wondered how the students felt about it because the expressions on students’ faces as they gathered around the safety area appeared not too happy. For some, however, enthusiasm was created when they saw the reaction of sodium in water. Having seen the demonstration, students verbally expressed why now they would not call dissolving of sugar/salt in water a chemical change. One student had written in her reflection log how she had argued about this but that others did not agree with her. This type of teaching, then, often provokes differences among students, especially when they are openly challenged with their ideas.

Another problem of conceptual change teaching is attributed to the psychological aspects of the learner. When students were confronted with their own propositions that sugar dissolving in water cannot be considered a “chemical change” because of the reasons they gave, students’ facial expressions showed an uncomfortable disposition and
they seemed non-committed and indifferent. This observation subscribes to the teacher’s concerns about certain aspects of constructivist teaching. In her opinion, students will “hate” chemistry if the students are not given the right answers to chemistry problems almost immediately, if they leave the classroom without knowing what the right answers are, if they are asked too many thought-provoking questions in tests, and if they are probed too much in group situations in case the students do not know the answers.

The researcher’s observations and the teacher’s concerns have been already expressed by Dreyfus, Jungwirth and Elovitch (1990). These authors found that applying the “cognitive conflict” strategy for conceptual change had some difficulties and problems. About some students, these authors have noted that “it is difficult to describe in writing the reaction of such students, which should be seen rather than be told about, but their main characteristics was that they were definitely neither flabbergasted, nor quite surprised. They were just indifferent.” They argued that for such type of students preconceptions may be “barriers rather than springboards” (Harlen, 1983).

How did the students view the researcher’s lessons? The following section addresses this question. Excerpts are taken from students’ reflection logs.

5.4.4 Students’ Reflections on the Researcher’s Lessons

At the beginning of the academic year Jane had introduced another teaching strategy to her students, that is, to maintain a reflection log for the chemistry course. The following classroom excerpt suggests what Jane expected of her students’ reflection logs:

...For instance as Jazlin had mentioned before it is your account of your understanding of your ideas and concepts being taught. That is, what am I learning today. Are you learning anything? That is one aspect of the log. You can also write down the changes that have happened to you as we discuss various topics. One time if you thought that the periodic elements consisted of 14 elements why do you know that it is 109 and what is the basis and why the elements are arranged the way they are? What you were thinking before and what you were thinking now. Another aspect of the log could be an account of what you did not understand.... In addition you can also
comment on the actual process with which things are delivered. Like if you work in groups to teach each other or if I had problem solving in pairs you can comment whether or not that is effective in your learning. So does concept attainment lesson (positive or negative) actually clarify some of your ideas that we taught? And you might want to comment on the technique in which the instruction is being delivered. So does small group work help in your learning? Does mind mapping help you? Do mnemonics help you with the periodic table? ... I am not marking anything wrong in a reflection log. We are just looking at what you are thinking about that day and how you are reacting to the learning process. Are you in effect learning? (Classroom Data, 1990 11 08.)

In essence, Jane expected students to reflect on three key elements which are important in any teaching/learning situation: understanding of the content of chemistry; the strategies used to promote student understanding of chemistry content; and the effectiveness of strategies used. In the remaining part of this section, the reflections of those students who took part in the interview phase of the study about the first three lessons will be elaborated.

In their reflection logs, the students had listed the concepts that they had learned and stated whether they had understood them or not; then reflected upon their attitudes toward the researcher and her approach to the lessons. The following features of a constructivist approach to teaching will be considered:

- developing students' conceptions;
- restructuring students' conceptions; and
- attitudes toward the researcher and her teaching strategies.

5.4.4.1 Developing Students' Conceptions

Of importance to a constructivist researcher is identifying, clarifying and developing student ideas and then possible restructuring. This section deals with features of
developing students' naive ideas into more sophisticated ones. Consider the following excerpts:

...I also learned that a molecule is a "little lump" (Reflection Log, Candy, November 2, 1989).

Today we discussed the molecule of water. How one atom of oxygen bonds with two hydrogen atoms to form the water molecule – the Mickey Mouse structure ... "What is a Solution"; transparent; homogeneous – same throughout; heterogeneous – not the same throughout; solutes dissolve in solvents; suspension – settle down into components; colloidal suspension – stays mixed together; false/true solutions; variable combinations; two or more substances mixed together; true solution doesn't scatter light; can apply the Kinetic Molecular Theory to solutions of liquid and solid; effervescence – gas, solid, liquid; carbon dioxide – creates bubbles. (Nila, November 6, 1989).

I have learned that there are true and false solutions. I understand the meaning of effervescence and what a colloidal suspension is. I learned that true solutions do not scatter light. How can you tell if solutions scatter light? We reviewed the meanings of homogeneous, solubility, solute and solvent. ...(Reflection Log, Candy, November 3, 1989).

Today, we elaborated on solutions, true and false, with Mrs. Ebonizer. We discussed more qualities of a solution: transparent, two or more substances mixed together, homogeneous—the same throughout, variable combinations (solid in liquid–water), (solid in solid–copper penny), (gas in liquid–carbonated pop), (gas in gas–air). We discussed solubility of solutions: solid in liquid—when heat increases the solubility increases; gas in liquid (effervescence) the release of gas—solubility decreases when heat increases. We learnt that a solvent breaks down the solute, which is something that goes into something else. Colloidal suspension (false solutions) was demonstrated. I liked the demo, it helped to explain the concept. These concepts are pretty clear, it will just take a while to fully understand them. (Reflection Log, Nila, November 3, 1989).

In spite of not having given notes in an orderly fashion, students seemed to have attended to some of the chemical concepts that were mentioned in class.

5.4.4.2 Restructuring Students’ Conceptions

A prior conception that some students revealed in the interviews was that sugar dissolving in water consisted of a chemical change. Some students seemed to have reflected upon this aspect. Consider the following excerpts:
...I thought that the sugar and water solution was a physical change because no substances were destroyed. And, also no new substances were created, the substances could be returned through distillation. Other people in my group disagreed with me, and said that it was a chemical change ... (Reflection Log, Candy, November 2, 1989).

...variable combinations; two or more substances mixed together; ...
(Reflection Log, Nila, November 6, 1989).

...We also found out that the sugar was dissolving in the hot water—physical change (Reflection Log, Al, November 2, 1989).

Today, the teacher teaches us about the relationship between solvent and solute. (Reflection Log, Willy, November 3, 1989).

...Solutions: transparent, solvent and solute, homogeneous, variable components—combinations, solid and liquid, solid in solid, gas in liquid, gas in gas (Reflection Log, Rosie, November 3, 1989).

...Understanding more about solutions—mainly from class discussion, the experiment (demonstration) demonstrations displayed physical and chemical change ... (Reflection Log, Sheila, November 3, 1989).

Note Candy’s reflections on the question of whether forming a solution is a chemical change or not. Candy had disagreed in her group that sugar dissolving in water was a chemical change. Al noted after the lesson that sugar dissolving in hot water is a physical change. Rosie expressed the same concept but used a different word sequence, “variable components—combinations.” Nila’s expression about a solution is similar to Rosie’s. Willy had understood it in terms of “solute—solvent relationships.” At first, Sheila simply stated that she had learned about the sugar cube dissolving in warm water and that the class discussions helped her to understand more. On the following day Sheila reinforced the idea that she understood more about solutions. She pointed out that it was mainly from class discussions and the demonstration that she found help in distinguishing between a physical and chemical change.
5.4.4.3 Students' Attitudes Toward The Researcher's Teaching

Constructivist teachers evaluate their teaching and their teaching strategies not in terms of "rote learning" and recalling of facts but in terms of "meaningful learning" (Novak and Gowin, 1984). What did the students have to say about the researcher's approaches? Students reflected upon the strategies used. Note the following excerpts about the Vee diagram:

... We also reviewed everything we learnt about solution on one sheet of paper. This technique helped to clear everything up and helped us to remember what we had learned, I liked it. (Nila, November 6, 1989).

We made a V-shaped chart connecting some of the things that we discussed in the previous classes. We categorized (classified) the class' theories, concepts, and principles. I learned that they are all somehow related, and that there are really no "right" or "wrong" answers, or theories etc. about how one feels about the way chemicals (substances) react. ... (Reflection Log, Candy, November 6, 1989).

Today, we did an interesting experiment again by dropping a dot of ink on the filter paper and then placed it into the water. We discovered that the ink spread out around the paper which created a beautiful colour pattern. Then we did a final report on our experiment. We had discussed in many terms such as theory, principle, concepts, records, transformation, knowledge claims, value claims, event and focus questions. Chemistry is fun and I like it. (Reflection Log, Al, November 6, 1989).

Today, we did a chart on "what is a solution?" I think I know a solution is now, a better understanding. The experiment with the paper and the felt dot "rise" was neat. (Reflection Log, Shamila, November 6, 1989).

These excerpts indicated that some of the students seemed to appreciate the Vee diagram. To Nila, the Vee diagram helped to clear up ideas and to remember what she had learned. Candy emphasized the connection and the relationship among the elements of the Vee diagram. She thought of it in terms of categorizing information. Al remembered the Vee diagram in terms of writing the final lab report. For Shamila, the Vee diagram offered a better understanding. According to these students, the Vee diagram seems to help the students to remember facts, to see the relationship of the
parts that create knowledge, and to classify information; in other words, to understand the content better.

Some students liked the activities that were done by them and by the researcher. One student noted a view of learning that is compatible with constructivist teaching. Consider Nila's reflections along this line of reasoning.

Today Mrs Ebonizer taught the class instead of Jane. We were video-taped and recorded. I liked the way Mrs Ebonizer taught the class. She gave us instructions on what to do and let us do it, but we had to keep in mind the topic—SOLUTIONS. This was a good technique, at least, I thought so, because we were able to explain and come up with our own reasons for the experiments that we did ... (Reflection Log, Nila, November 2, 1989).

Certain students stated that the experiments were interesting, fun and neat as illustrated by the following excerpts:

Today, we did a very interesting experiment of a soft drink. ... (Reflection Log, Al, November 2, 1989).

We did more research and experiments. The experiments are pretty cool. They're really interesting. We also learned some new words too and the definition. (Reflection Log, Shamila, November 3, 1989).

... Actually it is pretty interesting. I think a better understanding. (Reflection Log, Shamila, November 2, 1989).

In Shamila's mind experiments, in addition to being interesting, enabled her to understand chemistry better. Sheila is also in agreement with Shamila's view. But Sheila commented further about the researcher's teaching.

... chemistry is fun and we are all scientists. I learned about the sugar cube dissolving in warm water. The class discussions helped me understand more. I don't know if I like the tape-recorder going during the class. ... (Reflection Log, Sheila, November 2, 1989).

Directions needed to be explained clearer. I think we should not be treated as kids in grade 8. The information is interesting as well as experiments although haven't actually explained the reasons for some of them. Lab idea is good but sections should be explained for what you want in each. (Reflection Log, Sheila, November 6, 1989).
Although the experiments were interesting to Sheila and helped her to understand better, she conveyed an important message. She focused on three major issues: they were treated as Grade 8 students; the researcher did not actually explain reasons for some activities; and the sections in labs should have explanations of what is expected. Sheila seemed to say that Grade 11 students should be taught differently. She did not, however, specify "how." Furthermore, Sheila would like the teacher to give reasons rather than allow the student to construct her own reasons for the phenomena. She would also like to have clear directions on the purpose of each section of the lab.

In line with Sheila's arguments about teaching, Susan was not too clear why we did certain activities. However, she noted that it was fun. She felt that the teacher's enthusiasm is part of her learning. More importantly, she reflected upon her previous science learning and her apparent lack of understanding of the science content. Consider the following excerpt:

...I'm not too clear on why we did it, but it was fun. Mrs. Eb is so "up." It's nice to see a teacher enthusiastic about teaching instead of saying "do it." Jane is totally like that too. I hope I can answer all of those questions in my next interview. I felt 10 years of science hadn't taught me much. I couldn't explain. (Reflection Log, Susan, November 6, 1989).

Although Rosie is in agreement with Susan in stating that the approach is interesting, she pointed to another facet of the teaching she experienced, that is, the discussion is taking forever. Note the following excerpts:

Today we get a new teacher. We get to tape what is said at our groups and are getting video-taped. She teaches well. We get to discuss. ... (Reflection Log, Rosie, November 2, 1989).

More on solutions. Discussion and the class seems to take forever. But it is interesting. ...(Reflection Log, Rosie, November 3, 1989).

To Gary, the researcher's teaching seemed different. He seemed to have enjoyed the video that was shown, but he did point out the tediousness of listening to lectures. Ami had no use for the researcher's lessons. Consider the following excerpts:
We talked about solutions out loud with pop as an example and sugar that dissolved in water with a tape recorder going the whole time. It was different. (Reflection Log, Gary, November 2, 1989).

We discussed solutions in more details with a movie at the end and it was very interesting and the movie was very different and humorous. (Reflection Log, Gary, November 3, 1989).

Another lecture that was quite slow. I'm starting to dislike lectures. They're very uninteresting and dull. (Reflection Log, Gary, November 6, 1989).

We did nothing really. Was really bored today. (Reflection Log, Ami, November 2, 1989).

The students’ reflections about the researcher’s lessons ranged from being fun to boring, from understanding of concepts to not being sure of why certain activities were done, listing of the concepts learned to stating the restructured ideas, and the researcher’s personality to her teaching strategies. All of these comments have salient implications for constructivist approaches to teaching. For example, “the discussions are long” has implications for teaching chemistry in the high school where covering prescribed content, and getting prepared for provincial examinations and university learning are major goals.

What did the teacher have to say about the researcher’s lessons? The subsequent section considers the teacher’s views and reactions to the researcher’s teaching.

5.4.5 Teacher’s Sense-Making of the Researcher’s Lessons

This section describes Jane’s sense-making of the researcher’s constructivist teaching of solution chemistry. The excerpts are taken from the informal and the formal conversations the researcher had with Jane about the first three lessons during the progression of these lessons as well as during the remaining part of the study. In her comments to the researcher’s three solution chemistry lessons, Jane alluded to three primary issues:

1. students’ seriousness;
2. lesson planning; and
3. valuing, developing, and reconstructing students’ ideas.
5.4.5.1 Students’ Seriousness

The issue of students’ seriousness stemmed from the orientation phase designed to elicit students’ ideas in the first solution chemistry lesson. It was as a result of serving Orange Crush in the chemistry classroom and having said in my opening remarks that I would not be giving students any teacher-made notes.

Orange Crush was served with a definite purpose, that is, to initiate a discussion about different types of solutions. The students seemed excited about it. There was a lot of noise and laughter in the classroom as students drank the Orange Crush. The noise and laughter were produced not because of idle talk among students but as a result of discussions and conversations about the chemical concepts and principles and as well the novelty of calling themselves scientists during their discussions.

Jane talked about students’ seriousness right after the first lesson was over.

I have so much fears about the whole thing. The students were thinking that pop was given and no meaning of lesson was attached to it. Students must take notes. Insist on it. Otherwise they will never get used to it. I don’t want the students to think that they will have one month of free time. (Personal Thought Log, p. 15.)

On the 22nd of November, which was three weeks after the researcher’s lesson, when the teacher and the researcher took time to view the video on the first lesson, again Jane referred to her concern about students’ seriousness. Jane stated to the researcher that somebody in a university class that she was taking raised the question about the students’ engagement in lessons. The following interview excerpt reveals Jane’s expressions of concerns and feelings about students’ seriousness:

It was very difficult because I have never seen this approach before. So they did not know whether to take this seriously and they did not know the rationale of this particular way of presentation. It is different from the

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5 Jane wrote down her reflections for the purpose of writing a paper for a Science Education (SCED) course that she was taking at the time.

6 In this excerpt, they refer to students.
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way I present science, that is, different from every class they have ever taken. This approach is different from the routine that has been established by all other teachers in the school since their elementary education. ... I was afraid when I first heard the way it was approached. “The way you presented, I am scared,” I said, and the kids did not take it seriously. The guy that day who presented the topic on teaching strategy said that this is exactly what they found out in PEEL Project on the particular model. The teachers who documented this found that is exactly what was happening, what I had said. Regarding my discussion on how my kids reacted and how I reacted before he read the transcript of how those teachers reacted and that was pretty much the same. So the new approach not taken seriously and I guess kids will know. The new approach, I am not sure was accepted by the kids. I felt the kids were not taking it seriously. The students were not all engaged. But they had fun with demonstrations because they never had the opportunities before I think. (Reflection Tape 1 Transcription, pp. 2-3.)

From this excerpt one can conclude that Jane and the researcher viewed students’ seriousness differently.

Jane permitted the researcher to serve Orange Crush in her chemistry classroom with great reluctance. This was because Jane was very careful at the beginning of the school year to teach laboratory safety aspects according to the expectations and criteria set forth by her school district. One of the teacher/student understandings with regard to safety rules was that no one should eat in the laboratory. So when Orange Crush was served as part of the chemistry lesson, students may have thought about the safety principles.

Jane did not think that students would attach any importance or meaning to such an act in a chemistry laboratory. The noise level was more than usual since the researcher used a fun activity to introduce solution chemistry.

Another concern expressed by Jane regarding the lack of student seriousness was note-taking. Consider the following excerpt:

I like that point, you construct your own knowledge. At that you also said same time we will not be giving very much, very many notes. That’s the dramatic shift in approach to information gathering, I suppose. (Reflection Tape 1 Transcription, p. 2.)

Jane had students memorize all the safety rules and expected every student to get one hundred percent correct in the test on safety. The students studied and re-wrote the test until they all got one hundred percent correct.
In the context of Jane's teaching, Jane's fears about the teacher not giving any notes or students not taking down notes are absolutely crucial. In her chemistry class, it is customary at the beginning of the period for Jane to display notes on the overhead. The students copied the teacher's notes. Jane expected students to use notes to learn the relevant concepts. In turn, students expected their teacher to give notes. It is with these notes the students determined what was important and what was not important for the test. Students therefore depended on teacher notes to study for their tests and exams. Note-taking was an important aspect of students' learning.

5.4.5.2 Lesson Planning

Although Jane did not request them, the researcher gave her detailed lesson plans for the first three lessons. This was done for two basic reasons: to respect school policies; and to file them as research documents for future references. In addition, it was the researcher's belief that in line with Driver's model of teaching, a teacher ought to carry a mental map into the classroom. So Jane was presented with the researcher's mental map. There was absolutely no intention to cover everything that was printed on the paper which was submitted to Jane. When the researcher gave her the first lesson plan, Jane said, "It looks so professional ... it is too much to cover within a short time." The researcher's reply to Jane's comments on the lesson plan was, "I am carrying a mental map with me. Students' responses and discussions will decide what and how much will be covered." (Personal Thought Log p. 15.)

In the researcher's way of thinking, a lesson plan is organized and structured in terms of lesson management or progression. So it is not planned according to the prescribed sequence in a certain syllabus. The content can stem from the prescribed or authorized curriculum or from any other source. The lesson plan is structured in such a way that students' conceptions can be incorporated as the lesson proceeds. Furthermore, certain
activities are prepared in advance for demonstrations in the light of anticipated students' questions or in the case of detours taken by the student(s) in understanding the concept. Needless to say this requires a lot of time and commitment on the part of the teacher. In addition, the lab-technician has to respond to heavy demands in terms of preparation. Jane was indeed concerned about these aspects of the researcher's teaching.

5.4.5.3 Valuing and Developing Students' Ideas

In conversation, after listening to the video of the researcher's first lesson, Jane stated the following:

I think what you say is very good—the students valuing each others' ideas. Because I don't think that there has ever been or I don't think that I made a point of saying to the kids, "your science ideas and your science interpretations are important." I never thought about that at all. I always thought of the way I was taught. I never take their ideas into consideration. "Valuing their opinions," and "your views are just as important"—such thoughts never dawned on me before. So I guess I never thought about that perspective. I think it is excellent to value students' ideas about science because they are like scientists too. It is a very powerful technique. I think the kids feel like they are actually generating knowledge. By questioning science, they are learning. (Reflection Tape 1 Transcription, pp. 3-4.)

Jane pondered about how she was taught science. Jane compared the way she had learned science with how she is presently teaching and how her teaching departed from the way the researcher taught her classes.

Although Jane valued teaching in which students are at the forefront in generating knowledge, she felt that it takes a long time to develop students' ideas. She said that at the beginning of each year, each teacher has to give her goals and objectives of each course she is teaching. Jane felt that a teacher cannot spend more than a few hours on each of the units. The following excerpt shows the feelings of the teacher and the researcher in terms of covering the curriculum. At the end of the second lesson, Jane asked the researcher how she felt about the lesson. Their conversation went like this:
Chapter 5. Instruction: Attempts To Incorporate Students' Conceptions

R: It was rushed. I would have taken at least three days to cover this material, but since we had to cover material, I had to rush.

J: To teach like that we need at least three months to teach solution chemistry.

R: Each unit will not be dealt with separately. From solution chemistry, in fact, I can take many detours into other areas of chemistry and tie them all together.

(Personal Thought Log, p. 16.)

Within three days of her teaching, the researcher felt that she had covered a lot of material. Jane mentioned that the researcher had given "so much information to students in these three days, it was better than what she would have ever done and she was pleased with it." Although Jane gave credit for what the researcher had done in her class, the researcher was not too pleased with Jane's statement that the researcher had given so much information. The researcher was garbed in a constructivist robe and attempted to present a constructivist view of teaching but in the school context she was found to "cover a lot of stuff." In the back of her mind, on the second day of her teaching, the researcher was thinking about Jane's expectations of her. In addition, students were used to a different framework of teaching. And the researcher felt that the students were put under stress when she probed them with questions. Students were reluctant to answer in case their answers might be wrong. So on the second day of the researcher's teaching, she had no choice but to have a teacher-directed lesson and to give the students ready-made answers. Note what Jane stated about the researcher's lesson:

O.K. I guess you said here about don't talk, but show. I think it is very "constructivism" and I haven't been doing that. I think you did lots of showing and I am glad and the following day you came back and discussed the results, but are you supposed to do that? I feel it's better that you come back. One day you pose the question and listen to their ideas and the next day you come back and sort of talk about it. (Reflection Tape 1 Transcription, p. 2.)

This excerpt shows that the researcher is adapting to the school situation, to the expectations of the teacher and the students. In fact, the researcher is being political in playing the school game because she wanted to keep Jane and the students happy and
for them to like her. The researcher was looking for acceptance as a teacher. At the same time she was concerned about not being flexible enough to follow a constructivist approach which involved restructuring students' conceptions related to the phenomena considered. In essence, the researcher experienced a "discrepant event."

Students were so used to being spoon-fed for the last ten years of their schooling. Now all of a sudden to change course was too much for them. Premature closure seemed to be the only way out in these circumstances. Hence the researcher was attempting to convey this message to Jane. Consider the following excerpt:

R: I thought it was little premature in my own mind. If given more time I would prolong that period and come back to it later on as we develop. But time was such. As well, I have to meet your expectations too. So I thought I should give some answers which I shouldn't have given. I thought, "Premature Closure."
J: I felt better when you did give the answers.
(Reflection Tape 1 Transcription, pp. 1-2.)

In the light of this experience and the thoughts that went through her mind while teaching on the second day, she tried to view Jane's position as a teacher. The demands and expectations of her students are great. From her three years of chemistry teaching experience, Jane knows that the students would not be happy if notes and book answers are not given to them. She does not want students to leave her class without them learning a body of knowledge that she had prepared for that day.

However, Jane understood the value of reconstructing students' ideas. So Jane attempted a constructivist lesson. The next section describes Jane's attempts to incorporate students' conceptions.

5.5 Jane's Attempt at Incorporating Students' Conceptions

Although Jane was concerned about students' seriousness and exhibited mixed feelings about the researcher's presentations of the first three lessons on solutions, Jane showed
a desire to model the researcher. Jane mentioned to the researcher, on the phone the night before the fourth lesson, that she would like to do what the researcher did with the Block F chemistry students with her Block H chemistry students. Jane said that she could not do an "elaborate" job, the ways in which the researcher conducted the first three lessons, but would do something similar. So on the following day, Jane did the first solution chemistry lesson with her Block H students.

Likewise on the fourth day of solution chemistry instruction with Block F students, it seemed that Jane attempted to incorporate her own students' prior conceptions, "process of dissolution—a physical change or a chemical change, melting or dissolving." Wanting to incorporate students' conceptions was clearly evident as she began the fourth lesson in solution chemistry in the following manner:

We are going to work at the model today to look at the process of dissolving. To see whether or not it [dissolving] is actually a physical change or a chemical change. Is it melting or what process is it? (Lesson 4 Transcription, p. 3.)

At the beginning of the fourth lesson, as was customary, Jane had students copy notes and a diagram on the process of dissolution of table salt from the overhead ("once you copy this down, get the mind maps in front of you...").

Jane then had the students get the mind map\(^8\) that she had drawn on the first 15-20 pages of the chapter which she distributed. Jane directed students' attention to each cluster of the solution chemistry unit on the mind map. With the aid of the mind map, Jane began the lesson by reviewing the nature of solutions, the component of solution chemistry that the researcher had covered on the first three days. Jane also described "saturation," and "polar and non-polar" nature of solvents. In this section, only her attempts at incorporating students' conceptions will be described.

Drawing students' attention to the mind map, Jane tried to incorporate students' conceptions. Because the students talked about dissolving in terms of melting, she used

\(^8\)See Appendix F for Jane's mind map of the solution chemistry unit.
the kinetic molecular theory of particles to explain the process of dissolution as the following transcription shows:

Microscopic models are used to explain macroscopic observations. You have seen sugar dissolve in hot water. We are going to try to use the kinetic molecular theory of particles to explain at the microscopic level what you should be seeing or what likely is happening. That is you can see it microscopically that sugar dissolves. How does this process happen? So we are going to look at the molecular model. We are going to try to look at how water dissolves or how sugar dissolves. ... We talked about sugar or salt dissolving in the water. The salt crystals are solutes. It diffuses among the solvent particle and eventually we call it dissolving. One of you said it is disintegrating. But definitely it is dissolving or dissociation. Although some of you identified one time that it was melting, we will look at it and then you can decide whether or not it is actually melting. The two negative parts of the water molecule are attracted to the positive sodium ions. Same thing here; the positive hydrogen end of the water molecule is attracted to the negative chloride molecule, et cetera. So what happens is distinct crystals of solid sodium chloride in the solution, the water hydrates the entire salt crystal pulled apart. We call it dissociation. Not melting, dissociation or dissolving. Remember you thought that one time it is a melting process. That actually is dissolving, because water hydrated the sodium chloride solid and pulled apart individual ions. (Lesson 4 Transcription, pp. 4-5)

In this lesson, Jane mentioned what the students' prior conception was about dissolving. To explain dissolving, she described the dissociation process of salt. Finally, Jane reinforced the idea that dissolving is not melting.

On the following day, two videos (Solutions, 1969, 13 min; and Ionic and Molecular, 1983, 23 min) on solution chemistry were shown to reinforce the concepts and principles that had already been taught. In the first video, the properties of a solution were investigated. It showed several experiments including the ones using filters and light beams to determine what a solution is and how it differs from a mixture. The second video illustrated the chemical nature of a solution, what happens when it forms and the role of the electrostatic forces. Brownian movement is seen, and saturation defined, and the concept of molarity presented along with an explanation of why some substances, like oil, won't dissolve in other substances like water.
5.6 Jane's Lessons on Polar and Non-Polar Solutes and Solvents

Jane conducted three lessons on polar and non-polar solutes and solvents. These concepts were taught with labs and with a strategy called Concept Attainment (Joyce and Weil, 1986). What follows now will be a description of the lab work and the concept attainment lesson to cover the curricular objectives: Students should be able to: categorize $H_2O$ and $CCl_4$ as polar or non-polar solvents; deduce from observations involving polar and non-polar solutes and solvents, that polar solvents tend to dissolve polar solutes and non-polar solvents tend to dissolve non-polar solutes. Lab: Polar and Non-Polar Solutes and Solvents.

5.6.1 Lab Work: Polar and Non-Polar Solutes and Solvents

The formal laboratory work that Jane conducted consisted of testing the solubility of a variety of solutes in a variety of solvents. In particular, classification of polar and non-polar solutes and solvents were done according to experimental results. The procedures in Experiment 16 A, pp. 163-166, from Heath Chemistry (Laboratory Experiments) Text were followed. Two periods were allotted for the lab. One period was used for orienting students to lab work. Part of the following period was used for preliminary instructions and part of it was for conducting the experiment.

In this lab session, preparations for the lab, presenting of the final reports, following the lab procedure methodically, trying to finish the lab on time, safety aspects, and other laboratory skills were emphasized. The following excerpt denotes these characteristics:

For your lab preparation list the words to know and list the materials you have to do and data table you are going to set up here. You have to copy them all down. So when you prepare for a lab it may be that it will take you about 40 minutes to set everything up such that when you come into this class you can start right away with your goggles on, aprons on, and you can go right to the reagents to start your procedures, but I always re-emphasize safety before you start any lab, especially in chemistry. There are five pre-lab questions that you have to answer before you come into your class tomorrow.
And then I have about 5 points to mention. 15 marks for homework check. Five marks for word to know. Five marks for the data table all copied our and five marks for pre-lab questions answers. So make sure those sections have to be all done. ... Copy down the safety precaution. When we do each lab you will be given a ten mark for lab technique so that you will follow safety through the entire class. Goggles have to be on, aprons have to be on. Before you come into the lab, everything can be set up and when you do the lab, record your result in the data table. After the lab then you can answer the lab questions. And you can report your conclusions. So therefore the data table, the lab questions and the conclusions are to be done on the day of the lab or after the lab. Everything can be set up prior to coming in. For your homework check tomorrow, I am going to be looking for definitions all completed, pre-lab questions answered. Data tables are being filled out and are left with blanks to fill the data. Read over your procedure step and just make sure that everybody knows what they are doing. There will be a ten-mark quiz which you will work with your lab partner on things specifically with the lab itself because I don’t want anybody in here who has not read the lab and therefore be a danger to the other person that they are working with, all right? 10 marks quiz based on the lab itself. So read 15 thoroughly. So that is what you are supposed to do, rightly set in your mind before you come into class tomorrow. (Lab: Polar and Non-Polar Solutes and Solvents Tape)

The next day, before lab started, Jane gave explicit directions about details of safety procedures and the marks taken off for violating principles of safety. Jane’s instructions follow:

Test tube 1 consists of water. Test tube 2 consists of paint thinner and the paint thinner has been placed in glass containers. And when you pour, never put the stopper on the table. You always pull out with your finger and you pour, and when you finish cap it again. Never let this end of the stopper touch the table, otherwise it will be contaminated. You always keep it in your fingers when you pour. Wash the stopper and dry with the towels. There are two different towels right here, a white canister. There are two garbage cans, one by the back and by the front desk. Put all the extra papers in the garbage can, one by the back and by the front desk. Put all the extra papers in the garbage can. All right, in addition you need labels and sucrose and salt, iodine in your tray. You don’t have twelve rubber stoppers. You only have four of the small rubber stoppers per tray. Therefore you got to share. Two rubber stoppers per team. Wipe them off or wash them or rinse them between agitations. Where are you going to throw all these once you used it all up? You have one white container at the back under fumer no. 1, a funnel attached to that all the waste material into the white container. Then rinse out your test tube and then do part two. Part two is identical to part 1. It is at this time, your salt, sugar or iodine crystals. There are going to be unknown and you have to determine their characteristics and fill your data table, too. The last, part three, you must mix in the test tube 1 part
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of water and 1 part of paint thinner and shake it or agitate and the result you draw in the diagram. 1 quart of water and half of glycerine and again stopper agitate and draw the diagram and clean up again and everything goes in to the container at the back. All right, there are three major parts. You are sharing 2 groups per tray and working at the sides. I would suggest tables 1, 2 and 5 this side of the room and tables 3 and 4 work at that side of the room. O.K. Take precautions. No quarrel for anything. Your goggles and your (inaudible) hand over everything and I will be giving you 10 more marks for techniques. Every time I see one of the things violated, you get minus beside your name. If you are going to ask me or Jazlin any questions about the lab you have to be sure it is not already in the book. If you are not reading the procedure step and if asking us to repeat the instructions for you because you don’t know to put things, you are going to lose marks as well. All right. You have questions. We are going to start. The first part, part 1 will take no more than 10 mins. Second part, I will take no more than 10 mins and part 3, I will take no more than 5. So I would say 25 mins if you are efficient, 35 mins if you are not so efficient. I wish you would finish before that, all right. (Lab: Polar and Non-Polar Solutes and Solvents Tape)

In lab work, besides being concerned about safety procedures, Jane stressed time length for each part and student efficiency. One of Jane’s brightest students told the researcher that he couldn’t finish the lab on time so he copied the results from his partner. Some students asked the researcher for answers to fill in their data table so that they could finish the lab on time.

Students’ findings were matched with the teacher’s book answers. Any finding that contradicted with the book report was distinctly stated by Jane as “incorrect.” No explanation was given by Jane or her students why this might have happened. For example, some students reported that iodine did not dissolve in alcohol. This observation was not discussed. Marks were not given for incorrect findings.

Note the discourse that took place between Jane and her students concerning the solubility of solutes in solvents:
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J: Now what is the result for the solubility of sugar and iodine in water? So let's see. Al, what was your group's result for paint thinner, salt, sugar and iodine.

S: It (salt) didn't dissolve in paint thinner. It's (sugar) partly soluble in paint thinner. Iodine dissolved in paint thinner.

J: So how many got "no, no, yes"? You can put positive, positive, negative. Now check and make sure everybody has the same result.

A similar type of discourse transpired between Jane and her students with regard to solubility tests on known solutes, solubility tests on unknown solutes, and the mixing of two liquids.

In this manner, the purposes and the objectives of the lab session that are outlined below were accomplished:

- to determine the type of solvent that generally dissolves ionic compounds;
- to determine the type of solvent that generally dissolves polar covalent compounds;
- to determine the type of solvent that generally dissolves non-polar covalent compounds;
- to investigate the effect of adding a polar liquid solute to a non-polar liquid solvent.

The reagents used were: sodium chloride (table salt) crystals, sucrose (table sugar) crystals, iodine crystals, three unknown solid solutes, paint thinner and glycerin.

As preparation for the lab and as homework assignment, Jane had the students write the definitions of the following words: solute, solvent, solution, ionic compound, covalent compound, polar compound, non-polar compound, and solubility. She also had the students write the safety precautions, draw tables to record their observations, and answer the following pre-lab questions:

- Contrast the properties of ionic and covalent compounds with respect to solubility in water and methanol.
- Why will a dry cleaner often seek more information about a stain on a garment?
- How can covalent compounds be classified with respect to their sharing of electrons between atoms?
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• What is the purpose of using stoppers in this experiment?
• What is the purpose of using paint thinner as a reagent in this experiment?

There were five lab questions, and two follow-up questions. The follow-up questions were as follows:

• Explain which solvent from this experiment you would use to remove road salt stains from a pair of jeans.

• Some people use gasoline (a non-polar covalent compound) to clean grease stains from clothing. Although it is an effective solvent for grease, explain why gasoline should never be used for this purpose. Suggest a suitable alternative solvent.

For “conclusion,” the students answered the question: What general rule can be followed when choosing a type of solvent for a particular solute?

In the lab work, students classified covalent compounds as polar and non-polar based on experimental results. The second method of classification of covalent compounds as polar and non-polar required information about electron-sharing tendencies and molecular shapes. Jane used a concept attainment lesson to help students distinguish between polar and non-polar covalent compounds9.

5.6.2 Concept Attainment: Polar or Non-Polar

For this lesson, Jane gave students a handout consisting of structural formulas for sixteen covalent compounds. Looking at these, Jane had the students classify these compounds as polar and non-polar. Students worked in groups. While the researcher was held up working with one group of students, Jane was observed to move around among various groups. Students were heard to ask Jane questions and Jane went around clarifying students’ queries.

Later on, Jane mentioned to the researcher that she came up with this type of a lesson after much reflection when she stayed at home because of her illness. Jane said that she

9See Appendix G for the student handout consisting of molecular structures of compounds.
would have never come up with that lesson if not for the time she had to think things through.

In that lesson, some students showed feelings of disgust and frustration. There was, however, more interaction between the teacher and the students. Many students were seeking help. Some students sought help from the researcher after class hours, during lunch break and after school. It seemed to be one of those lessons that made the students think.

Chapter 6 is an account of the outcome space of solubility after instruction. Four case studies of students' changing conceptions of solubility are also presented. Students' post-instructional conceptions are linked with their pre-conceptions. Wherever possible, the influence of instructional strategies are discussed.
In Chapter 4, six conceptualizations of solubility were derived from clinical type interview data of thirteen Grade 11 students. Chapter 5 told a story about the instruction of a unit on solution chemistry which endeavoured to incorporate some of these conceptualizations. This chapter focuses on students’ conceptions of solubility after instruction. This is accomplished by focusing briefly on the outcome space of solubility for all thirteen students and by presenting case studies of four of the students in the class. The data presented in Chapter 6 address the following three research questions:

1. What conceptions of solubility are held by Grade 11 students after studying a unit on solution chemistry?
2. How do four of these students’ conceptions of solubility relate to their own prior understanding?
3. What was the influence of instruction on the students’ prior conceptions?

During the post-instructional interview, all thirteen students were again exposed to the three chemical systems which were used in the pre-instructional interview. How does the outcome space of solubility appear after instruction?

### 6.1 Outcome Space of Solubility After Instruction

Table 6.3 compares the outcome space of solubility before and after instruction for Systems A, B, and C: sugar/water, water/alcohol/paint thinner, and salt/water.

According to Table 6.3, after instruction, students had the idea that solubility is mainly attributed to the chemical structure of components. Almost all students
Table 6.3: Frequency Distribution for Pre- and Post-Instructional Outcome Space of Solubility for Systems A*, B** and C*** (n=13)

<table>
<thead>
<tr>
<th>Categories of Description</th>
<th>Frequency</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre Post</td>
<td>Pre Post</td>
<td>Pre Post</td>
<td></td>
</tr>
<tr>
<td>physical transformation from solid to liquid</td>
<td>10 2</td>
<td>-</td>
<td>4 1</td>
<td></td>
</tr>
<tr>
<td>chemical transformation of solute</td>
<td>5 2</td>
<td>-</td>
<td>1 -</td>
<td></td>
</tr>
<tr>
<td>density of solute</td>
<td>- 1</td>
<td>8 1</td>
<td>3 2</td>
<td></td>
</tr>
<tr>
<td>amount of space in solution</td>
<td>- 1</td>
<td>1 1</td>
<td>3 6</td>
<td></td>
</tr>
<tr>
<td>size of solute</td>
<td>- -</td>
<td>1 -</td>
<td>- -</td>
<td></td>
</tr>
<tr>
<td>property of solute</td>
<td>- -</td>
<td>4 -</td>
<td>3 1</td>
<td></td>
</tr>
<tr>
<td>†chemical structure of components</td>
<td>- 8</td>
<td>- 13</td>
<td>- 2</td>
<td></td>
</tr>
<tr>
<td>†solution equilibrium</td>
<td>- 1</td>
<td>- -</td>
<td>- 3</td>
<td></td>
</tr>
</tbody>
</table>

†These two categories of description appeared after instruction.
*System A: Sugar/Water, **System B: Water/Alcohol/Paint Thinner, ***System C: Salt/Water

convincingly presented the idea that two liquids are miscible or immiscible because of polarity. In the pre-instructional interview these students claimed that it is because of the density of the liquids that liquids are immiscible. Notice the drop from 8 to 1 for the conception “density of solute” under system B in Table 6.3. However, this conception can also be considered as another way of looking at the water/alcohol/paint thinner system. Instruction did not address this point.

Although the students were able, after instruction, to use the language of chemistry such as polar and non-polar, they often did not necessarily know what was meant by these terms. For instance, note what Sheila states when she was asked why she thinks water is polar:

I just understand by what someone told me and I think it is because you can’t split in half and it can’t be symmetrical because you can’t split the little oxygen atom. You can’t split it. That’s what I think she means. That’s what I understand by what she said.

An example such as this shows that just because the students are told what polar and non-polar is, it does not mean that they have an understanding of electronegativity and
dipole moments. Among the thirteen students, Nila was the only one who talked about a line symmetry for non-polar molecules (This reasoning will be dealt with in the case study).

In the pre-instructional interview most students (n=10) stated that the dissolution process was a physical transformation from solid to liquid. The post-instructional interviews suggested that most of the students had dropped this idea (n=2). Some said that the dissolution process of sugar in water was because of the polar nature of both solute and solvent. Some of them drew diagrams to represent the dissolution of sugar in water, but these diagrams were similar to those representing salt in water. This was because of repeated teaching about the model of dissolution of salt in water.

When Willi was asked to draw a model of sugar dissolving in water, his model was different from what the others had drawn. His diagram is given below:

Since the representation of sugar dissolving in water was not taught in class and the model was not diagrammatically shown in the students' text book, one might speculate that Willi may have referred to other chemistry books. While other students drew pictures representing sugar in terms of ions, Willi represented it in the form of molecules. The polar ends of the sugar were represented by a positive (+) and a negative (-). This representation shows that Willi was challenged to take on the responsibility to do more work on his own.
Consider what Tammy shares about the dissolution process of sugar:

The water molecules with the positive and negative balance pulling the molecules of sugar away from the cubes. Water is clinging to them.

Ami proposed that “It’s sort of the structures weakening. They are moving far more apart and they are not dissolving.”

According to Table 6.3, the number of students who had the conception “chemical transformation of solute” had dropped from 5 to 2. At the post-instructional interview, it was two of the same five students who interpreted the sugar/water and salt/water system in terms of a chemical transformation. For instance, Ami emphatically stated that “It’s a chemical change definitely because it has different properties.” The number of students who opted for “chemical transformation of solute” at the post-instructional interview was low. This result could be attributed to the demonstration performed for the students showing the conflict situation (sodium dissolving in water) during instruction which was intended to provide a type of cognitive conflict for those students who subscribed to the “chemical transformation” view. At the post-instructional interview, more students (6 versus 2) seemed to interpret the crystallization of salt in the salt/water system in terms of insufficient amount of space available for the salt to dissolve in the solution. Nila explained this phenomenon in terms of solution equilibrium. This concept was not addressed in class, but she had picked it up from reading the text book. Gary represented the same phenomenon in terms of an equation and arrows pointing in both directions (discussed more fully in the case study section). Willi had a sophisticated model of solution equilibrium. He did not refer to this word. However, his diagram shown below indicates that he has some understanding of what solution equilibrium is.
On the contrary, notice what Al had to say about crystallization of salt.

Al (1) [salt/water]

R: What you see here is salt. Any idea why it has come down

S: Salt dropped to the bottom. It is too heavy. Probably because when salt is used for cooking, it is added a little bit. The water around can dissolve the salt because it is more than this. This solution is saturated. That means the water cannot break it down. Or too much salt is put in and water probably cannot break it down. So the size is too big I think.

The above excerpt revealed that Al seemed to think that the concept of saturation had something to do with the heaviness or the size of the solute.

Ami likened salt crystallization to ice formation: “Outside in the morning is really cold and when the snow comes, ice is there. ... I picture this to be a large block of ice.”

What ideas did students have about the solution process after instruction? For Jo, dissolving was when solute and solvent were together: “Sugar and water are together.” Celin argued that dissolving is particles of solute mixing with particles of solvent: “The particles of sugar have mixed with the particles of water.” Candy’s idea was that “the water wraps around the sugar particle and make it dispose it to dissolve and to become uniform to the water.” She further argued that “because solute is less. It is of the lesser quantity and the solvent is a greater quantity. So the water being the solvent there is more of it so it just surrounds the sugar particles and forces it to dissolve.” Rosie contended that: “Like the two substances are mixing together. So it is breaking down and they are attracting. Like the electrons and protons are attracting each other and stuff.”

Sheila related a fascinating idea during the post-instructional interview. She said that a solution is a homogeneous mixture. Then she posed the question, “Could chalk be one because it’s homogeneous?” She followed this question by saying that the glass in the window is a solution because that is what is in the book. When queried about why she considered window glass a solution, Sheila stated that the “solution can come in
any form—solid, liquid or gas and it's a homogeneous mixture. So, like glass is uniform, chalk must be a solution." The researcher asked Sheila in turn whether she meant that anything that is uniform is a solution. She responded by stating that "I think so. That's why chalk is a solution."

In terms of microscopic particles, after instruction, at least four students had the idea that the molecules can be seen when they are together. For instance, observing the salt/water system Tammy commented thus:

Right now, no. You can’t see the molecules in the stuff you see and you can see the molecules altogether, but not each separate molecules.

Notice what Rosie stated looking at the sugar/water system: "When all the particles are together, you can see. But you can’t see it other than that. If they move too fast you can’t see it. But when they are all together you can see it." These examples suggest that after instruction, students did have difficulties in understanding particulate ideas.

The subsequent section deals with four students' post-instructional conceptions in a detailed manner to give an idea of whether or not instruction helped them to restructure and expand some of their ideas.

6.2 Case Studies

Among thirteen students, four were selected for the presentation of case studies because it was thought that more complete descriptions of a few students would be worthwhile. Nila, Gary, Sujatha, and Shamila were selected based on four criteria: (a) The range of students' prior conceptions of the solution process—Nila and Gary represent those students who said that the solution process involves a chemical reaction between the solute and the solvent. Sujatha and Shamila represent those students who stated that the solution process was that of a solid turning into a liquid. (b) The type of conversations in the interview—while some students' conversations were characterized by the use of the
language of chemistry, other students elaborated their thoughts in imaginative ways and spoke in terms of everyday chemistry. Nila and Sujatha represent the former, Gary and Shamila represent the latter. (c) The ability range of the thirteen students—Nila and Sujatha appeared to work hard and they received high marks on exams, Gary and Shamila did not appear to work hard and they received average marks. (d) The ratio of girls to boys—since nine out of thirteen students were girls, three girls and one boy were chosen. Gary was chosen among the boys because of his ability to communicate. The pre- and post-instructional interview data, classroom data, and students’ responses to selected questions on the solution chemistry unit test provide the knowledge base for the case studies.

Each of the following four main sections presents a case study. Each case study begins with an outline of pre- and post-instructional outcome space. This is followed by a description of post-instructional conceptions with selected interview excerpts and students’ responses to the solution chemistry unit test questions. This procedure attempts to answer research question 3 (b), which attempts to seek a relationship among students’ pre- and post-instructional conceptions. Then the post-instructional conceptions are related to their pre-instructional conceptions in response to the second research question. Finally, the influence of instructional procedures on each of the four students’ conceptions is examined with the purpose of answering the third research question.

What are the categories of description found in Nila’s post-instructional conceptions? How have they changed? These questions are addressed in the following sub-section:

6.2.1 Nila’s Changing Conceptions of Solubility

The outcome space for Nila’s conceptions of solubility constructed from the pre-instructional interview consisted of the following categories of description:
Chapter 6. Students' Conceptions of Solubility After Instruction

• physical transformation from solid to liquid: particle view of liquid state
• chemical transformation of solute
• density of solute
• chemical character of the dissolving substance

Were there any changes in Nila's outcome space of solubility after instruction? After instruction, two qualitatively different categories of description seemed to characterize her conceptions:

• solution equilibrium
• chemical structure of components

These categories will now be described in some detail.

6.2.2 Nila's Post-Instructional Conceptions

6.2.2.1 Solution Equilibrium

Nila explained solution equilibrium in terms of sugar and salt dissolving in water:

Nila (1) [sugar/water] When you raise the temperature of something then the dissolving process goes faster. The greater the surface area, the faster it [sugar] dissolves. It [sugar] is polar. The water is polar because of its unequal sharing of electrons. If it is dissolving, both of them should be either polar or polar and ionic. It looks that it [unstirred granules of sugar which remained undissolved at the bottom of the beaker] has stopped dissolving but it is in dynamic equilibrium. Like the solvent has accepted as many particles as it can. The rate at which the particles dissolve is the same as the dissolved particles will crystallize. So something is happening. It is just exchanging and this is what it looks like.

This excerpt revealed that Nila was concerned with three aspects of dissolving: energetics involved in the solution process, chemical structure of components, and solution equilibrium.

With regard to energetics, Nila talked about the influence of the temperature and the surface area of the solute on solubility. In the solution chemistry unit test, Nila included
stirring as one of the ways to speed up the dissolving process. Therefore one can state that Nila was of the understanding that heating the solution, increasing the surface area of the solid solute, and stirring the solution result in faster dissolution of a solid in a liquid.

Nila then touched on the chemical structure of compounds and how that could affect dissolving. (This conception is dealt with in detail in section 6.2.2.2). Now the focus is on Nila’s conception of solution equilibrium (See Nila, Excerpt 1). When encouraged to explain the principle of dynamic equilibrium with the aid of a diagram, Nila argued thus:

Nila (2) [sugar/water] That’s the sugar and then the water. I don’t know what to draw but all I know is the rate of exchange is the same. So it’s like if these particles are dissolving or you can see the other ones are appearing. That’s the water. You can’t see the water bubbles. This [sugar that had settled] can’t dissolve because the solvent has accepted as much as the solid that it can. What is left over, it’s like you think it is staying there but it’s actually in exchange, you know. I can’t draw.

It appeared Nila was of the opinion that undissolved sugar in this system was the same as the recrystallization of sugar from its saturated solution. Some characteristics of a saturated solution are revealed in the following excerpt:
Nila (3) [salt/water]

S: Water and salt. It was hot when you started it.
R: Yes.
S: So it [salt] didn't melt. It dissolved. Then it cooled down when the temperature went lower. So therefore it is saturated, right, I am right. When the temperature changes, then the amount of the solid that can be dissolved decreases. When the temperature is lowered, it precipitates out and I got it.
R: (Pointing to the upper part of the jar) Is there salt in this part?
S: There could be. That's all, but I don't know how it got up there. (meaning the salt that was on the sides of the jar because of evaporation.
R: So you think there is equilibrium between the two?
S: Well, one thing you did not put that much salt in the start, did you? You put only a tiny bit, right.
R: No, no, I put a lot.
S: Is that right? There could be. Sure. I got it. This is like a gas, right, the pressurized gas, when it has pressure on it, can't escape. When there is pressure in the can, right, there is no escape. So it's in equilibrium and there is so much gas above and below when once we open it, gas comes out. It got to be like equilibrium between these two and it [salt] is escaping.
R: O.K. Could you draw a picture for this at the microscopic level? And also write an equation.
S: ...So I know what salt looks like. ...This is the bottom layer. ...I don't know the equation. ...I don't know what it equals, salt water. I know that.

\[
\begin{align*}
\text{NaCl} + H_2O & \rightarrow \text{Salt water} \\
\text{top layer} & \\
\text{hydrated} & \\
\text{NaCl} & \text{bottom layer}
\end{align*}
\]
With regard to saturation, Nila likened the salt/water system to a gas dissolving in water in a closed system. In this system, Nila argued that excess salt had to come out to reach equilibrium just like the pressurized system reaches equilibrium by releasing the dissolved gas when it is opened.

The foregoing excerpts suggest that Nila began her discussion of the sugar/water system by talking about the influence of temperature on the solution process. Then she introduced the concept of dynamic equilibrium and in terms of this notion discussed the lack of room in the sugar-solution (see Nila, Excerpt 1). The researcher probed her understanding of dynamic equilibrium (see Nila, Excerpt 2). In the salt/water system, Nila initially focused on temperature and saturated solution. This time the researcher introduced the term “equilibrium” (see Nila, Excerpt 3) because Nila related this to “lack of room in the solution” (saturated solution) in the sugar/water system. In essence, Nila came up with the “gas pressure” metaphor to explain the notion of equilibrium between sugar in solution and the crystallized sugar and salt.

6.2.2.2 Chemical Structure of Components

Since Nila mentioned about the polar nature of water and sugar, the researcher posed Nila the following question: “Using a simple structure such as water, could you explain what you mean by ‘polar’? Nila’s response to this question was:
Nila (4) [polarity of water]

This is water. Oxygen and Hydrogen. This is carbon tetra-chloride. These here are polar bonds. This is water and this is polar because like there is unequal sharing of the electrons. That is, it is not symmetrical because if you divided like that it's not symmetrical; but this one is divided like that and like that. Either way it's like symmetrical. So this is non-polar. But these bonds are polar even though it does not act like polar.

In the solution chemistry unit exam, she drew a line across the structural formulas of cyclopentane, carbon tetrachloride and ethanol to ascertain whether a solvent is polar or non-polar. In order to determine whether a substance is non-polar, Nila tended to draw a line of symmetry. If the structural formula is symmetrical, then she concluded that a substance is non-polar.

When Nila was asked to propose a theory for the solution process of sugar, she responded with the following explanation:
Nila (5) [sugar/water]
S: The sugar has molecules. They are not like crystals. They are sort of in a circle. That is the sugar molecule. I don't know and let me see. There is hydrogen and then we have the water molecules and I know that one and then it goes like that and has to hydrate these things. So each one of these has to be hydrated.

R: Could you indicate what this negative is and what this positive is?
S: Hydrogen. Oh! I forgot carbon. Carbon has to be in there somewhere. That would be water. Carbon is not a negative, is that right?
R: Yes. (Nila however marks the carbon atom negative and positive.) (with a rising tone) It is in the middle. It is negative as well as positive.
S: It is going to be in the centre. It's going to be the positive and the negative.
R: It is interesting.

Although Nila stated that sugar was in the molecular state, her diagram is similar to that of the ionic crystal of sodium chloride. In terms of the charge, Nila figured that hydrogen is the same as sodium and oxygen is the same as chlorine. Nila wondered where the carbon atom of sugar can be placed. She put it in the center of the diagram and
assigned positive charge and negative charge because the carbon atom did not have a partner.

In the solution chemistry unit examination, Nila had the following explanations and diagrams when responding to a question about the solvation of sugar in water:

Sugar and \( \text{H}_2\text{O} \) will dissolve into each other because they are both polar, and like dissolves like.

Note Nila's continued talk about chemical structure of components. The following conversation ensued about the water/alcohol/paint thinner system:
Nila (6) [water/alcohol/paint thinner]

R: This is alcohol. Does it mix with water?
S: It mixes with water.
R: Why do you think alcohol mixes with water?
S: They are miscible.
R: What do you understand by it?
S: They are able to mix together, because they are polar. So like dissolves like.
R: Why do you say that alcohol is polar? How do you know that alcohol is polar?
S: Because they mix. If they mix they have to be like. It has to be polar or ionic and it's not ionic. So it's polar.
R: How about paint thinner, does paint thinner mix? (Nila shakes her head.) Why do you think it doesn't?
S: Because it's non-polar.
R: Now let me reverse this. I will start with paint thinner and see what happens. (At this point, a drop of blue food colouring was added to paint thinner) ... You said that this paint thinner is non-polar. Now let me add alcohol to paint thinner (the two liquids were mixed in front of her). Does it [alcohol] mix with paint thinner?
S: Yes.
R: Why does it [alcohol] mix with paint thinner?
S: It shouldn't have mixed. We did an experiment like that. We mixed three different things together. Two of them mixed and the other one didn't because, it is non-polar and the other two are polars. Alcohol is polar and paint thinner is non-polar and they are not supposed to mix.
R: Could you propose a theory why it got mixed?
S: No. I have no idea, none what so ever.
R: Now let me pour some water. See what happens?
S: They are going to be unmixed, to be separated. There is a layer in the bottom. Stir that. O.K. You got me. I have no idea with that. O.K. separated in two layers. This is the paint thinner and this is the water and alcohol.
R: Why do you say that?
S: Because food colouring is polar and it does not mix with paint thinner. We saw it when we first did it. They did not mix. Only the alcohol mixed and I don't know why. Then when we added the water, the water and alcohol mixed and the food colouring mixed with the two and turned blue. This is blue, so the water and alcohol mixes paint thinner and the food colouring in it. So then therefore the paint thinner doesn't mix. I really don't know why.

This conversation shows that Nila applied the principle of "Like Dissolves Like" to the miscibility of liquids. However, when the researcher poured alcohol into the paint thinner
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Nila was puzzled. Referring to the lab on polar and non-polar solutes and solvents, Nila argued that alcohol and paint thinner should not have mixed and they are not supposed to mix. This seemed to have been a discrepant event for her—one that was not resolved during the interview.

After instruction, Nila attributed the miscibility and immiscibility of solutes and solvents in terms of the polarity of the structure of compounds. In the solution chemistry unit test, she answered the question, “Is ethanol (alcohol) miscible in water? Explain.” by stating that “alcohol is miscible in $H_2O$ because they are both polar, like dissolves like, they have similar properties and size.”

The next sub-section is a comparison of Nila’s pre- and post- instructional conceptions.

6.2.3 Nila’s Outcome Space: Pre- and Post-Instruction

Table 6.4 shows a comparison of Nila’s personal outcome space for Solubility before and after instruction.

Nila’s pre-instructional conceptions revealed how previous learning influenced the way she discussed the systems. She brought three pieces of knowledge that she had learned in her previous chemistry lessons: kinetic molecular theory of solid, liquid, and gas; chemical change; and chemical bonding.

First of all Nila described that “sugar is not like how it started when the molecules are all tightly packed together. But when sugar molecules move freely and are spaced out it is in a different state. They are all just mixing together in the liquid state.” What Nila meant by this was that sugar was transformed into the liquid state and then liquid sugar and liquid water mix together. Nila gave a particle view of the liquid state.

In the pre-instructional interview, looking at the salt/water system, Nila stated, “salt melts in water, becoming a liquid, and these liquid salt molecules are going crazy because they are hot. Then when the molecules cool down, they slow down and reform in the
Table 6.4: Nila’s Personal Outcome Space for Solubility

<table>
<thead>
<tr>
<th>Before Instruction</th>
<th>After Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• physical transformation from solid to liquid: particle view of liquid state—“It’s not like started out with the solid, but the molecules are all tightly packed together... Then when they are moving freely but not really becoming like a gas, really spaced out, it is in a different state. ...They are all just mixing together in the liquid state.”</td>
<td>• solution equilibrium—“It looks that it [sugar] has stopped dissolving but it is in dynamic equilibrium. Like the solvent has accepted as many particles as it can. The rate at which the particles dissolve is the same as the dissolved particles will crystallize.” So it [salt] didn’t melt. It dissolved. Then it cooled down when the temperature went lower. So therefore it is saturated, right, I am right. When the temperature changes, then the amount of the solid that can be dissolved decreases. When the temperature is lowered, it precipitates out and I got it.”</td>
</tr>
<tr>
<td>• chemical transformation of solute—“...this is a new product. It has different qualities. ...You can’t get back the sugar to its original state. so it is like a chemical change. You create a new substance with new properties.” “They could form a new molecule but then it has to be like ions. They have to be like water has to give up something. ...I am sure they give or they share electrons. some sort of transfer going on. Like ions positive (+) and negative (-) and they transfer.”</td>
<td>• chemical structure of components—“The water is polar because of its unequal sharing of electrons. If it is dissolving, both of them should be either polar or polar and ionic.”</td>
</tr>
<tr>
<td>• density of solute—“The reason that it is not mixing is because the paint thinner is lighter than water that is floating on top.”</td>
<td></td>
</tr>
<tr>
<td>• chemical character of the dissolving substance—“Because its components are mizable with water. ...It’s like molecules or components are composed in such a way that they are able to mix with the components of water.”</td>
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</tbody>
</table>
bottom." She argued that the salt/water system exhibited a physical change because salt turned from a solid to a liquid and then it came back to the solid. Nila contended that when the system is really hot some of "them" (salt) could evaporate and this is why they escape. When Nila was asked whether there is anything happening between the water and the salt, she stated that the water molecules are moving around but the solid is tightly packed. In essence then, Nila appeared to use a "candle melting" depiction of salt dissolving in water and re-crystallizing from water. The knowledge about the movement of water molecules stemmed from her learning of the kinetic molecular theory. Nila's comments about the salt/system were at the microscopic level.

Although Nila argued that the salt/water system exhibits a physical change because of the recrystallization of salt, she did not have the same type of reasoning for the sugar/water system. Nila considered that the sugar/water system is exhibiting a chemical change: "You can't get back the sugar to its original state. ... You create a new substance with new properties. ... They are all mixing together in the liquid state." When asked how this combination took place, Nila came up with the following argument: "...like water has to give up something. ... I am sure they give or they share electrons. Some sort of transfer going on. Like ions positive and negative and they transfer." Nila consistently argued her points at the microscopic level and what she had learned previously had bearings on how she related to the "system."

In the pre-instructional interview, when Nila was asked why paint thinner did not mix with water, she stated, "Because it [paint thinner] is lighter than the water and it floats and the components are not in the mixable form because paint thinner does not like water." When Nila was posed the question, "Why do you think alcohol mixes with water?," Nila's response was, "Because its [alcohol] components are mixable with water. ... It's like molecules or components are composed in such a way that they are able to mix with the components of water." At the pre-instructional interview, Nila
provided three reasons as to why paint thinner did not mix with water: density of paint thinner—lighter than water; paint thinner has no affinity for water; and composition of components (paint thinner and water). This is another example of how Nila attempted to provide explanations at the microscopic level.

What are some of the changes that seem to have occurred in Nila’s thinking? After instruction Nila did not talk about kinetic molecular movement of a liquid, creation of a new substance in the sugar/water system or the density of the dissolving substance.

The category of description, “chemical character of the dissolving substance” which characterized primitive patterns of reasoning before instruction seemed to have changed into intricate patterns of reasoning after instruction. For instance, Nila argued that “water is polar because of its unequal sharing of electrons” (See Nila, Excerpt 1.). Nila has acquired some ideas about “polarity” and “non-polarity” of molecules. Her way of determining whether a substance is polar or non-polar is to draw a line of symmetry on the chemical structures of compounds.

It is important to point out that Nila did change her conceptions about the solution process. Before instruction, she thought that sugar/salt is melting in water: “What happens is when you put the salt it melts” (See Nila, Excerpt 11 in Chapter 4.). After instruction, Nila’s opening remarks about the salt/water system clearly indicated that she was attempting to remind herself about the distinction between melting and dissolving: “So it didn’t melt. It dissolved” (See Nila, Excerpt 3.). In the exam, Nila expanded on the difference between melting and dissolving:

Dissolve is the diffusion of one substance (solute) into another (solvent). Melt is the changing of state, from solid to liquid.

Nila explained the process of sugar/salt dissolving in water in terms of hydration (See the diagrams in Nila, Excerpts 3 and 5.). This showed that Nila knew the distinctions between melting and dissolving and the type of understanding she had about the solution
process.

In the pre-instructional interview Nila thought about sugar/water and salt/water solutions only in terms of dissociation, but in the post-instructional interview she envisaged solutions to consist of two processes (dissociation and dynamic equilibrium): molecular species of sugar or the ionic species of salt ($Na^+$ and $Cl^-$) separate in water to form sugar-water, and sodium-water and chlorine-water respectively—new species formed through association. Then these associated species disintegrate to form the original species—dynamic equilibrium of particles.

These concepts were not evident in the pre-instructional interview. Her earlier conception along this line of reasoning was “the molecules cool down and they reform in the bottom ... All the molecules are going crazy because they are hot and when they are cooling down, they are slowing down” (See Nila, Excerpt 11 in Chapter 4.). Contrasting Nila’s pre- and post-instructional interviews, it is clear that her conceptions about the sugar/water and salt/water have changed.

6.2.4 Influence of Instruction on Nila’s Conceptions

At the end of instruction, Nila viewed the addition of sugar/salt in water as dissolving rather than as melting. This changed conception is evident in the post-instructional interview as well as in the solution chemistry unit test. How did Nila change her conception? On the fourth day of solution chemistry instruction, the teacher exposed the students’ conception of dissolving by stating, “Although some of you can decide whether or not it is actually melting, we will look at it and then you can decide whether or not it is actually melting.”—The word “it”refers to salt. Then she confronted them with the solution mechanism of salt in water:

The two water molecule negative parts of the oxygen are attracted to the positive sodium ions. Same thing here, the positive hydrogen end of the water molecule is attracted to the negative chloride molecule, et cetera. So
what happens is distinct crystals of solid sodium chloride in the solution, the water hydrates the entire salt crystal pulled apart. We call it dissociation. Not melting. Remember you thought that one time dissolving is a melting process. That is actually dissolving because water hydrated the sodium chloride solid and pulled apart individual ions. (Lesson 4 Transcription, pp. 4-5.)

In a sense, for the sugar/water and salt/water systems, the idea of dissolving became clear to Nila and by the end of the instruction, she discarded the concept of solution process to be analogous to melting.

The second major conception of solubility that Nila had before instruction was that an ordinary chemical change is taking place when sugar/salt is added to water. In the post-instructional interview Nila did not talk about dissolving of sugar/salt in water as a chemical change. This could be as a result of the researcher using a discrepant event to show the differences between a chemical and physical change (For detail, see Chapter 5 under Section: Incorporating Students’ Conceptions.).

Nila discarded her conception of dissolving as melting and a chemical change. After instruction, she attempted to explain the process of dissolution in terms of polarity and chemical structures. First of all, there is an indication from her reflection log and her notebook of how she began learning about the structure of water, which the researcher presented on the second day of solution chemistry instruction. In her reflection log Nila noted: “Today we discussed the molecule of water. How one atom of oxygen bonds with two hydrogen atoms to form the water molecule—the Mickey Mouse structure.” With regard to the structure of water, observe what Nila had written in her note book (See Diagram 1.). Nila had extended the learning of the structure of water molecule to see how an iodine molecule forms (See Diagram 2.). She used this knowledge to understand the dissolution process of salt in water and ethanol in water (See Diagram 3.).
In the post-instructional interview Nila explained the miscibility and immiscibility nature of substances in terms of polar and nonpolar. She acquired this knowledge in seven different ways: (1) teacher notes; (2) homework assignment; (3) notes taken from textbook; (4) mind maps; (5) lab on polar and non-polar compounds; (6) concept attainment lesson; and (7) Teams/Games/Tournament.

Teacher Notes

First of all, there is evidence in her notebook that the teacher had asked the students to distinguish between polar and non-polar compounds by classifying four different liquids.

polar and nonpolar

\[ \text{H}_2\text{O} - \text{polar} \]
\[ \text{CCl}_4 - \text{nonpolar} \]
\[ \text{CH}_3\text{CH}_2\text{OH} - \text{polar} \]
\[ \text{CH}_4 - \text{nonpolar} \]

Read pp. 439-445 HW.

Homework Assignment

Nila had done an assignment that included the following question on polarity of substances: "Describe why water \[ \text{H}_2\text{O} \] and glycerin (glycerol) are miscible. Sketch this miscibility at the microscopic level, refer to ch 16 and lab 16 a." Nila's answer to this was:

"Miscibility of \text{H}_2\text{O} + \text{glycerin}

Polar + Polar

like dissolves like

mix together."
Nila seemed to have taken down copious notes from her textbook. Concerning solvation Nila stated thus:

Solvation determined by the compatibility of the solute and solvent charges. 

= if both are nonpolar or both polar solvation occurs.

Mind maps

The students were asked to design a mind map which included key words such as polar solutes, non-polar solutes, polar solvent and non-polar solvent.

Lab 16a: Polar and non-polar solutes and solvents pp 163-166

For a detailed description of this lab, see Chapter 5. Nila's lab report indicated the following conclusions:

The type of solvent that generally dissolves ionic compounds is a polar covalent solvent. 
The type of solvent that generally dissolves polar covalent compounds is a polar covalent solvent. 
The type of solvent that generally dissolves non-polar covalent compounds is a non-polar covalent solvent. 
When adding a polar liquid solute to a non-polar liquid solvent it forms two distinct layers, polar and non-polar covalents are immiscible. 
A general rule is that in solutions components with similar properties and size will dissolve each other, like dissolves like.

Concept Attainment

For a review on polar and non-polar solutes and solvents, after the lab session, the teacher gave the students a teacher-made handout consisting of structures of many compounds. The students had to come up with the reason for their classification into polar and non-polar.

Teams/Games/Tournament

Teams/Games/Tournament (Joyce and Weil, 1986) game was played in class to review for the test. In this game, question 8 gave the structures for benzene and carbon tetrachloride molecules. The students had to decide whether the two compounds will dissolve or not. Note Nila's answer to this problem:
As shown, the concept of polar and non-polar was taught in a number of ways. While attending to students' conceptions, the intended learning outcome for Grade 11 based on the general solubility considerations (polar and non-polar solvents) was also accomplished.

During instruction Nila also picked up the concepts of saturation, and dynamic equilibrium. On the fourth day of instruction, in passing, the teacher mentioned what a saturated solution was. This concept came again in Nila's mind map of the solution chemistry unit. Her extensive notes from her textbook indicated at least three similar descriptions for the concepts of saturation and dynamic equilibrium. An example of her notes on these concepts is as follows:

Saturated solution shows constant interchange between dissolved and undissolved solute which is the dynamic and equilibrium rate at which dissolved crystallizes equals the rate at which solid solute dissolves. As a result there is no observable change in the amount of undissolved solute. =
It can be argued from Nila's post-instructional comments that she depended not only on the teacher's notes but also on the textbook for learning chemistry. For example, the concept of dynamic equilibrium was not discussed in class. But at the post-instructional interview, Nila attempted to examine the sugar/water system in this manner. Another example is that the dissolving of sugar was not discussed either in class or in the textbook. So she attempted to discuss the dissolution of sugar in water from what she was taught in class (on the fourth day of solution chemistry instruction, in Teams/Games/Tournament, and in her mind map) and from what she had read about the solution process of salt in water in the textbook.

The foregoing evidence shows that Nila's conceptions of dissolving were influenced by many instructional strategies.

6.3 Gary's Changing Conceptions of Solubility

The outcome space of Gary's conceptions for solubility constructed from the pre-instructional interview consisted of the following categories of description:

- chemical transformation of solute
- property of solute
- amount of space in solution

After instruction, are there changes in Gary's outcome space of solubility? His post-instructional categories of description are as follows:

- physical transformation from solid to liquid
- combination between solute and solvent
- chemical structure of components

These categories of description are elaborated in the next sub-section.
6.3.1 Gary's Post-Instructional Conceptions

6.3.1.1 Physical Transformation from Solid to Liquid

Gary did not talk about transformation from solid to liquid in the pre-instructional interview. This notion came through when he discussed the salt/water system in the post-instructional interview:

Gary (1) [salt/water]
R: Could you describe this system? What ideas do you have about it after going through solution chemistry?
S: The salt is at the bottom. The water is on top. The salt has crystallized and that means it has reached its original state.
R: So you don't think there is any salt on top?
S: Maybe some of it still remains in the water. Most salt is crystallized at the bottom.
R: Why do you think most of the salt has come down?
S: The low temperature causes crystals.
R: Why would low temperature cause crystals?
S: Less particle movement which cause the stop and it [salt] starts crystallizing.
R: Now if you were to wear your microscopic lenses, how would you view this part?

\[ T \downarrow = \text{crystallization} \]

\[ \text{H}_2\text{O} \quad \text{NaCl} + \text{H}_2\text{O} \rightarrow \text{Na}^+ + \text{Cl}^- \]

R: These are the particles of salt, right? (referring to dots in the above diagram). In terms of these particles, where is the water?
S: Around it.
R: Could you write an equation to represent what has happened here?
R: (pointing to the equation) Which form is the upper part? Is it in this form or is it in this form?
S: In this form (circling the ionic form of NaCl).
R: The upper part is in this form and the lower part is...
S: In this form (circling NaCl, which appears on the left side of the above equation).
R: Do you think there is anything happening between the two parts?
S: Between the crystals and the solution. Starting to break apart.
R: Why do you think it is breaking apart?
S: Because the temperature is rising here.
R: How do you think the temperature rises? We have not done anything to it.
S: I know, but the crystals are probably froze, I guess. The temperature is lower.
R: It is because of the freezing nature, the salt has come down?
S: Right.
R: When it gains room temperature, it goes back to the other state?
S: Yeah, like snow.

Thus, in the post-instructional interview Gary attributed crystal formation to the lowering of temperature. The lowered temperature, he stated, caused the movement of salt particles to “stop,” resulting in the formation of crystals. Almost at the end of his discussion, Gary paralleled crystallization to the formation of snow. He suggested that the salt crystals are in the frozen state and like snow, the salt crystals would go back to the liquid state when the temperature rises. It appeared that Gary thought about this system as existing in two different temperatures: the upper part containing salt solution is at a higher temperature and the lower part containing salt crystals is at a lower temperature.

In the pre-instructional interview, Gary talked about the same salt/water system in terms of lack of room in the solution: “Because there is no room in the air pockets for them to be.” He further stated that salt is “Like a kind of crystals. Like ice.”

In summary then, in both pre- and post-instructional interviews, Gary likened salt crystal formation to ice and snow formation. Rather than speaking about crystal formation in terms of saturation, at the post-instructional interview, Gary spoke about it in terms of influence of temperature and kinetic molecular theory of solids and liquids.
6.3.1.2 Combination of Solute and Solvent

Viewing the sugar/water system, Gary said that sugar and water are combining. Consider the following excerpt from the post-instructional interview:

Gary (2) [sugar/water]
R: What do you mean by dissolving?
S: The sugar is combining.
R: With what does sugar combine? How does it combine?
S: They come together.
R: Would you draw a picture to show how they combine?
S: I don't know how sugar looks like. (Draws)

Gary probably tried to represent each grain of sugar in the cubic form, but he drew squares. This may be because of the big cube of sugar that was immersed in water. Each sugar grain is magnified and drawn separately. Gary's second diagram indicated the invasion of the sugar molecules by the water molecules. For the same system, in the pre-instructional interview, Gary argued, "sugar goes to the molecules of air that are empty and then reacts with water." Compare Gary's post-instructional interview diagrams (above) with the pre-instructional interview diagrams in Chapter 4, Excerpt: Gary-15.
Surprisingly, Gary has represented sugar grains in the cubical form in both instances. However, after instruction, as indicated by the diagram, sugar “combining” or “joining” with water took a different meaning for Gary.

6.3.1.3 Chemical Structure of Components

Like Nila, Gary described the behaviour of the water/alcohol/paint thinner system in terms of polar and non-polar nature of substances. About alcohol mixing in water, Gary remarked, “They are both in the polar state.” In the case of immiscibility of paint thinner in alcohol/water mixture, Gary stated, “Because it is non-polar. It [paint thinner] makes it [water] immiscible. So it [paint thinner] won’t combine.” This phrasing is interesting in terms of the implied causality between the solute and the solvent.

Since Gary talked about the polar and non-polar nature of alcohol and paint thinner, he was shown the structural formulas of ethanol and acetone, which are respectively the constituents of alcohol and paint thinner, to explain the polar and non-polar nature of substances. Looking at the structural formula of ethanol, Gary suggested that the water molecules will go “Right here. Wherever there is some space for them to go.” Note in the following diagram where the water lodges:

Examine what Gary stated about the non-polar nature of paint thinner:
Gary (3) [water/alcohol/paint thinner]
R: This is the structural formula of paint thinner. (The structure in the right) Can you suggest why you think paint thinner does not mix with this mixture [alcohol/water]?
S: According to this (referring to the above structure in the right) there are double lines.
R: Is it because there are two lines it does not get mixed?
S: No. Like this is not symmetrical. It does not even out (referring to the structural formula of water given below). This is left behind. It won't dissolve. This is part of the compound.

R: Why would you say that this is a non-polar substance?
S: There is an unequal sharing of electrons.
R: Where do you see the unequal sharing of electrons?
S: Every place where you have a single bond.
R: But in this formula [ethanol] also you see single bonds. So don't you think alcohol also should behave like paint thinner.
S: No, it is not because of the single bond. It is because of double bond that changes the polarity.

According to Gary, the non-polar nature of paint thinner is due to the presence of a double bond in its structure. His argument suggested that double bonds influence the shift from polar to non-polar nature of the substance. Gary noted that the part of acetone which contains the double bond does not dissolve in the alcohol/water mixture.

In contrast, during the pre-instructional interview, Gary commented about miscibility in terms of the constituent elements of the compound that acts as the solute (See Gary, Excerpt 30 in Chapter 4.). Although Gary was not knowledgeable about the underlying principles of polar and non-polar nature of substances, he reasoned that it is this distinction that determines why certain substances mix with certain solvents while
others do not. For example, Gary’s response to the question, “Explain why paint thinner is immiscible in water” in the solution chemistry unit examination was, “Paint thinner is non-polar and water is polar. Therefore polarity is opposite and there is no dissolving. Therefore immiscible.” This statement showed that Gary was of the understanding that for substances to dissolve, they should exhibit the same polarity. However, to a discrepant event, adding paint thinner to alcohol, Gary’s immediate response was, “I have no idea.”

The following section responds to the questions: What conceptions does Gary have after instruction? Are there any changes from his pre-instructional conceptions?

### 6.3.2 Gary’s Outcome Space: Pre- and Post-Instruction

Table 6.5 presents Gary’s personal outcome space for solubility before and after instruction.

Gary’s ways of representing “combinations” seemed similar in both the prior and after instruction interviews. However, the meaning he attributed to the word combination was not the same. His imagination or mental image was that there are spaces in the solvent for the solute to settle into. Notice, this was his conception even when he said that water molecules will occupy the spaces in the molecular structure of ethanol.

Gary talked about the polar nature of substances, but he is still not too sure what he exactly means by polar. Presently, “symmetry” and “single or double bond” seem to determine whether a compound is polar or non-polar.

During both interviews, Gary spoke about solutions in terms of the microscopic levels. However, his microscopic depictions gave the impression that he viewed matter as being continuous. For example, Gary’s depiction of water was continuous. Although sugar is drawn by means of dots [particulate view] or salt in squares, it may be that it is a representation of the appearance of sugar and salt in their actual forms.
### Table 6.5: Gary’s Personal Outcome Space for Solubility

<table>
<thead>
<tr>
<th>Before Instruction</th>
<th>After Instruction</th>
</tr>
</thead>
</table>
| • chemical transformation of solute—  
  “It will react with water and join with it. Going to the molecules of air that are empty.” | • physical transformation from solid to liquid—  
  “The salt has crystallized and that means it has reached its original state. ... The lower temperature causes crystals. ... Less particle movement which cause the stop and it starts crystallizing. ... the crystals are probably froze. ... like snow.” |
| • property of solute—  
  “Because it does not have the element that mixes with the water very well.” | • combination between solute and solvent—  
  “The sugar is combining”  
  Refer to diagram in excerpt Gary (2) [sugar/water] |
| • amount of space in solution—  
  “Because there is no room in the air pockets for them to be.” | • chemical structure of components—  
  “Because it is non-polar. It [paint thinner] makes it [water] immiscible. So it [paint thinner] won’t combine. ... double bond that changes the polarity.” |
6.3.3 Influence of Instruction on Gary’s Conceptions

Gary’s notebook consisted of two pages of solution chemistry notes. These were homework assignment, and Teams/Games/Tournament questions. Both assignments indicate questions that required categorization of solutes and solvents into polar and non-polar. For instance, Gary had written the following for glycerin and water.

\[
\text{glycerin } + H_2O \quad \text{ "like dissolves like"}
\]

\[
\text{pol } \quad \text{pol } \quad \text{mix together.}
\]

Gary’s answers to the lab questions also shed light in terms of his post-instructional conception of solubility. Note the following selected pre-, during, and post-lab questions that pertain to polarity and non-polarity of molecules and Gary’s responses to these:

1. Why will the dry cleaner often seek more information about a stain on a garment?
   He will seek info so he will know exactly what to get rid of and what to use (chemically) to remove stain.

2. What’s the purpose of using paint thinner as a reagent in this experiment?
   The purpose of using paint thinner is because it doesn’t mix with $H_2O$.

3. Explain how many layers you would expect to see if water, paint thinner, and glycerin were combined in one test tube.
   Paint thinner, glycerin, and water would be two (2) layers because the water/glycerin combination formed one and the water/paint thinner combination formed two layers.

4. Explain which solvent from this experiment you would use to remove road salts from a pair of jeans.
   Paint thinner would be used to remove road salt stains because it’s more chemically effective.

Although Gary’s answers to questions 2 and 4 seem contradictory, he seemed to have learned the general principle, “Like Dissolves Like.” His post-instructional interview excerpts seemed to characterize conceptions of dissolving in terms of chemical structure of the components. The above questions suggest the application of these concepts to everyday examples. Since an opportunity was given in the form of after-lab questions, Gary seemed to have translated what he had learned in class to everyday chemistry.
The discrepant event shown in class to distinguish between chemical and physical change may have helped Gary to drop the idea of considering dissolving as ordinary chemical change by the end of instruction.

The post-instructional interviews characterized some of Gary’s pre-instructional alternative conceptions. For example, Gary had a continuous picture of matter as described earlier. In the pre-instructional interview, Gary seemed to picture air molecules are like "alveoli" in the lungs that they have to be empty for something else to occupy the space. Gary’s conception in the post-instructional interview had similar statements about water occupying empty spaces of the alcohol structure. Instruction did not take such rooted conceptions into consideration. Conceptual change teaching, which usually rationally analyzes some of these alternative conceptions, might help to alleviate Gary’s difficulties.

6.4 Sujatha’s Changing Conceptions of Solubility

The outcome space of Sujatha’s conceptions for solubility constructed from the pre-instructional interview consisted of the following categories of description:

- physical transformation from solid to liquid: particle view of liquid state
- density of solute
- amount of space in solution

After instruction, the following categories of description were conceptualized:

- chemical structure of components
- chemical transformation of solute
- amount of space in solution

Each of these conceptualizations will be discussed in detail in the subsequent sub-section.
6.4.1 Sujatha's Post-Instructional Conceptions

6.4.1.1 Chemical Structure of Components

Sujatha viewed the sugar/water system in terms of the chemical structure of components. Her depiction of sugar dissolving in water is given below:
Sujatha’s explanations with regard to the sugar/water system are contained in the following excerpt:

Sujatha (1) [sugar/water]

R: Could you explain to me at the macroscopic level as well as at the microscopic level what might be happening to the sugar when it is added to water?

S: Looks like it [sugar] is melting.

R: I am interested to know what you mean by sugar melting.

S: It’s becoming a liquid, that’s what I mean by melting.

R: Looks that it is becoming a liquid. Could you give me another example of melting?

S: Ice in the water. It looks like it [sugar] is melting. I know it’s not. I know it is dissolving.

R: Ice into water.

S: Ice turning into water.

R: When you put ice in water and sugar cube in water, do you say that just like ice turns into a liquid, sugar will also melt into a liquid.

S: Just the fact the ice is solid, sugar is solid. If you put ice in water and you put sugar in water, they both dissipate. They mix into it, but I know it’s not the same process. It’s just that looks like microscopically. I know it’s not the same as ice moving, changing from one state to another state, but here sugar in the water I know that is because that’s polar and polar. I know water is polar, maybe ionic. I don’t know what the sugar is. That was one of the questions that I could not get on the test.

R: O.K.

S: If it is polar or if it is ionic then you know or both the part of $H_2O$ that is negative is attracting the positive part. So it’s breaking apart and they are mixing. All the particles are mixing in hydration.

R: Hydration is the word you use. Could you draw a picture for me?

S: I can do for salt, I can’t do for sugar, though.

R: Why don’t you represent sugar with circles? Show me how water gets attracted to sugar.

S: (Draws and explains the polar nature of water.) This part is partially positive and this part is partially negative. These ones here get attracted to this or attracted to that. It is kind of hard to explain.

Sujatha was convinced that sugar “looks” like it is melting, but she stated that it was actually dissolving. When Sujatha was asked to give an example of melting, she talked about ice becoming water. She further stated that ice and sugar are both solids but when they are added to water, each is going through a different process. Sujatha
explained, “because both water and sugar are polar, they mix.” Although Sujatha did not differentiate between polar and ionic, she stated that mixing of the components is due to the attraction that exists between the opposite charges of the solute and the solvent. For this process, Sujatha used the term “hydration.” The researcher was curious to see how Sujatha would represent diagrammatically what she meant by hydration. This was when Sujatha stated that she knew how to represent salt and not sugar. The researcher used the conductivity probes in sugar solution and salt solution to see whether Sujatha could distinguish between the solvation process of salt and sugar. She responded, “This is the part that I did not understand and this is the way how you explain it to say polar dissolves polar and non-polar dissolves non-polar, but I don’t know how to explain that. So when I asked Miss (the teacher) she said that this is partially negative and partially positive.”

Note how, in her test, Sujatha differentiated between the dissolving of sodium bromide and sugar in water:

1) Explain the solvation of sodium bromide in water (microscopic & macroscopic levels). Draw a diagram to illustrate this process. (3 marks)

Microscopic - The solvation of sodium bromide in water is by dissociation. The Na and Br are separated by the water molecules into their ions.

Macroscopic - We see a clear colorless liquid, does not scatter light.

Macroscopic

Sujatha has a pictorial representation of the ionic nature of sodium bromide. She explained the dissociation of sodium bromide in water. In the case of sugar dissolving in
water, she stated the following:

The solvation of sugar in water is explained by the saying “Like dissolves like.” Like dissolves like because the partially positive side of the sugar attracts the partial negative side of the water and vice versa. Both the solute and the solvent are polar. Macroscopically, the sugar dissolves into the water leaving a clear liquid.

Sujatha drew the following diagrams to support the above answer:

Sujatha seemed to have remembered what her teacher said about partial charges. So Sujatha brought this piece of knowledge to explain the solution process of sugar. Her diagram of the polar compound, sugar, is fascinating.

Now consider what Sujatha said in the pre-instructional interview:

Like the solid is dissolving into a liquid. The molecules are reacting and everything. It is a physical reaction, but it’s turning into a solution. They are colliding. The molecules are colliding and they are separating and they are like moving further apart and it is turning into a liquid. Sugar is turning into a liquid form of sugar which is mixing with water. It looks like it anyway.
Although Sujatha stated in the pre-instructional interview that sugar is turning into a liquid form of sugar, she used words such as “like” and “looks.” Later on in the conversation, Sujatha mentioned that “it [sugar] becomes a liquid like water.” However, it seemed to her that sugar is turning into a liquid. Sujatha expressed the same view at the post-instructional interview. In fact she used the very word, “looks,” in both interviews. After going through a unit on solution chemistry, Sujatha was able to discuss sugar dissolving in water in terms of the polar nature of sugar and water, and how hydration of sugar occurs.

In the following excerpt we get some notion of Sujatha’s mental picture of the solution process of sugar:

Sujatha (2) [sugar/water]

R: Could you show me in the form of a diagram what you have in your mind about the solution process of sugar in water?

S: It’s looking enlarged or something. Like looking at it closely, here’s the water. Here’s the sugar. We’ll call this one sugar and that the water. These are colliding like that and they mix around and then they dissolve. I know that it is like \( H_2O \) mixing around. I don’t know how to draw mixing around. Running mixing around dissolving. (Pause) I don’t know what to draw.

Sujatha drew the following diagram to show the solution process of sugar in water:
Chapter 6. Students' Conceptions of Solubility After Instruction

Among all thirteen students originally interviewed, Sujatha was the only one who stated in the post-instructional interviews that alcohol does not dissolve in water. However, she talked about solubility in terms of chemical structures of components. Consider the following excerpt:

Sujatha (3) [water/alcohol/paint thinner]
R: What do you think will happen when I pour alcohol into water. Will it dissolve in water?
S: It doesn’t. Water and alcohol don’t mix.
R: Why do you say it won’t?
S: Because I read in the book. I think I remember.
R: (poured the alcohol into the water) Any reasons for that?
S: Because they only partially dissolve. The negative particles and the positive particles don’t quite join. So it depends upon the nature of solute and solvent. They don’t mix.
R: So you think it hasn’t completely mixed then.
S: I don’t think so. Looks like it’s gone. Looks like there is a layer on top.
R: This is paint thinner. Do you think this will get mixed?
S: No.
R: Why do you say that?
S: Because paint thinner is non-polar. Polar and non-polar don’t mix at all.
R: How about alcohol? Is it polar or non-polar?
S: It’s polar.
R: If it is polar it should have mixed with water, right.
S: It dissolves actually.
R: Why do you say that? I am curious.
S: I don’t know why? I only read.
R: Let me give you the structural formula for alcohol. You said it doesn’t mix completely, right. Looking at this, could you propose a theory why it didn’t mix completely?
S: Certain fluids (inaudible). So it will dissolve a little bit, but some of these will still stay, because it is not equal.
R: What is not equal?
S: Technically, I think electrons are moving around. I don’t think numbers are equal. This polar.
R: If it’s polar, it should dissolve, right?
S: Sure. ...This is what I read.

Sujatha did not trust what she observed when alcohol was poured into water. Her argument seemed similar to that of the sugar/water system, when she stated “It looks like sugar is melted into liquid sugar.” Sujatha again stated: “Looks like it’s [alcohol] gone.” Actually, according to Sujatha, alcohol had not mixed with water. For this claim
her source of authority was the book because she said, “This is what I read.” Sujatha tried to remember what she thought she had read in the book.

Sujatha was shown the addition of paint thinner to alcohol and was asked to respond to it.

**Sujatha (4) [water/alcohol/paint thinner]**

R: *I am going to pour paint thinner in alcohol. Is alcohol mixing in paint thinner?*

S: Not really. Well, I don’t know, but there is still some not mixed.

R: *You say that some didn’t mix.*

S: Looks like it.

After an extensive discussion about the water/alcohol/paint thinner system, Sujatha was asked to summarize her observations of the system.

**Sujatha (5) [water/alcohol/paint thinner]**

Polar and non-polar don’t mix. Alcohol is partially polar. So it sort of mixes with polar, that is the water, but it doesn’t really mix at all. It sort of mixes with. It actually mixes with both and the food colouring dissolves totally in water, totally in alcohol and not totally in paint thinner and that’s why you get the line at the bottom, because it dissolves better in alcohol and water than it does in paint thinner. I don’t know why it is moving around like that, though.

In the solution chemistry unit test, for the question, “Is ethanol (alcohol) miscible in water? Explain,” Sujatha stated the following:

**Sujatha (6) [water/alcohol/paint thinner]**

Yes, ethanol is miscible in water, but only partially. Both are polar, but alcohol does not dissolve fully in water.

Sujatha was of the understanding that alcohol is partially polar. She used this reasoning to justify that alcohol does not completely mix with water.

In the pre-instructional interview, with regard to the water/alcohol/paint thinner system, Sujatha stated that alcohol “looks” like it is mixing with water. Concerning the behavior of paint thinner in the alcohol/water mixture, Sujatha stated, “It [paint
thinner] is like oil. It is a different texture. It is a different density. It doesn’t sound right either.”

Sujatha did not talk about either texture or density of paint thinner in the post-instructional interview. She concentrated on the polar, partially polar, and non-polar nature of water, alcohol, and paint thinner respectively.

6.4.1.2 Chemical Transformation of Solute

As opposed to what Sujatha mentioned about dissolving, note what she stated about the difference between dissolve and melt in her unit test:

Sujatha (7) [exam question: difference between “dissolve” and “melt”]

Dissolve is chemical and changes the positions of the particles creating new elements. Melt simply is the kinetic movement making the particles go faster and become liquid.

6.4.1.3 Amount of Space in Solution

In examining the salt/water system, Sujatha was of the understanding that the system contained a saturated solution:
Sujatha (8) [salt/water]

R: Now looking at this, could you describe what has happened and what this is? Could you relate what you studied in solution chemistry to this system?

S: This is a simple saturated solution.

R: What do you mean by that?

S: A few crystals are added and it's saturated when we added more crystals.

R: Do you think there is any salt in this part?

S: Once the temperature goes down that's what happens. It's saturated.

R: Could you draw a picture for me?

S: No, I couldn't. I could draw for this part, but I don't have any idea what to draw for that.

R: Is there anything happening between the two parts microscopically?

S: Not right now. I don't think so, nothing.

R: Could you represent this with an equation?

S: I don't know, but I'll try.

\[
\text{NaCl} + \text{H}_2\text{O} = \text{NaH}_2\text{O} + \text{Cl}
\]
6.4.2 Sujatha’s Outcome Space: Pre- and Post-Instruction

Now compare the above post-instructional interview excerpt with the conversation that ensued between Sujatha and the researcher in the pre-instructional interview.

Sujatha (9) [salt/water]

R: Could you describe this system which contains water and salt?
What ideas come to your mind when you look at something like this?

S: Isn’t it the same thing with sugar? ... I don’t know whether heating does that but if you mix, it will become a solution.
... I don’t know. I don’t want to use the word react. They didn’t mix. The water and whatever it is. Maybe it was dissolved so much that it can’t accept anymore. But it doesn’t make any sense. Maybe it has accepted too much salt.
I don’t know.

R: Is there anything taking place between these two parts? You can not see things happening.

S: Oh, I think it is dissolving slowly. Yeah I think there is some kind of action going on. It is moving around like salt moving and mixing around with rest of the water, I think. I’m trying my best. I don’t know what I’m talking about.

Although Sujatha was not sure whether her statements were right, the pre-instructional comment about the salt/water system implied that she had the idea that since there was too much salt in the solution it cannot accept anymore. At the post-instructional conversation, Sujatha attached a label (saturated) for this process.

With regard to the question whether there was anything taking place between the solution and the salt crystals, Sujatha was of the opinion in the post-instructional interview that there was nothing taking place, whereas, in the pre-instructional interview, she discussed a one-way action. That is, salt was dissolving slowly and it was mixing with the rest of the water. Table 6.6 presents Sujatha’s personal outcome space for solubility before and after instruction.

Both in the pre-instructional interview and the post-instructional interview, Sujatha seemed to cast doubt on what she said. In the post-instructional interview, Sujatha used words such as “saturation” and “hydration” to explain the dissolving process.
Table 6.6: Sujatha’s Personal Outcome Space for Solubility

<table>
<thead>
<tr>
<th>Before Instruction</th>
<th>After Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• physical transformation from solute to liquid: particle view of liquid state—“Sugar is turning into a liquid form of sugar which is mixing with water. ... I guess its elements or whatever when they are far apart, it becomes a liquid like water. ... When it is in a runny state, they are fairly far apart and they are always moving because they are farther apart. They are not like together. ... So we can’t see it. Because they are so farther apart, they are moving, moving quicker and it takes up a bugger space and makes up a liquid.”</td>
<td>• chemical structure of components—“If it is polar or it is ionic then you know both the parts of $H_2O$ that is negative is attracting the positive part. So it’s breaking apart and they are mixing. All the particles are mixing in hydration.”</td>
</tr>
<tr>
<td>• density of solute—“It is like oil. It is a different texture. It is a different density.”</td>
<td>• chemical transformation of solute—“Dissolve is chemical and changes the positions of the particles creating new elements.”</td>
</tr>
<tr>
<td>• amount of space in solution—“Maybe it was dissolved so much that it can’t accept anymore. But it doesn’t make any sense. May be it has accepted too much salt.”</td>
<td>• lack of room in the solution—“This is a simple saturated solution. ... A few crystals are added and it’s saturated when we added more crystals.”</td>
</tr>
</tbody>
</table>
6.4.3 Influence of Instruction on Sujatha’s Conceptions

A perusal of Sujatha’s notes showed that she, like Nila, had all the teacher-given notes. However, Sujatha did not have any personal notes. The following examples will characterize how Sujatha came to hold school science conceptions of solubility.

Like Nila and Gary, one of Sujatha’s conceptions was “chemical structure of components.” How did she acquire this concept? As pointed out in Nila’s and Gary’s case, Sujatha was also able to distinguish between polar and non-polar compounds because of the various instructional activities such as demonstrations, lectures, textbook reading, lab, construction of mind maps, taking part in Concept Attainment and Teams/Games/Tournament lessons.

In order to acquire a “chemical structure of components” conception, like Nila, Sujatha had classified four liquids, namely, $H_2O$, $CCl_4$, $CH_3CH_2OH$, and $CH_4$ into polar and non-polar. In her study sheet, there was an indication of how she had learned to distinguish between ionic and covalent bond.

Ionic: transfer of electron to form $+ -$ attractions. – metal & non metal
Covalent bond: sharing of electron between two elements – non-metal & non-metal.

\[
\text{Na}^+ \quad \text{Cl}^- \quad \rightarrow \quad \text{Na}^+ \cdot \cdot \cdot \text{Cl}^-
\]

In her solution chemistry assignment, Sujatha had responded thus to the question: “Explain why water is miscible in glycerin and not paint thinner.”

Like dissolves like. The characteristics of the 2 liquids determine whether the
mixing will occur.

Sujatha's notes also consisted of the following statement:

The solutes molecules are pulled from the "molecular lattice" by the solvent molecules PDB molecules diffuse through the solvent.

Examining the structural formulas of para di chloro benzene crystals and carbon tetra chloride, Sujatha had identified these as non-polar covalent solute and non-polar covalent solvent. Then she stated, "Like dissolves Like."

Sujatha had explained the solvation of $NaCl$ in $H_2O$ by means of macroscopic and microscopic representations. Teacher-given notes on the dissolution of sodium chloride in water, its corresponding ionic equation, formula and pictorial representation of hydration of ethanol (see Nila's case study for these notes) were included in her notes.

This evidence shows how Sujatha might have discarded the conception "physical transformation from solute to liquid" and adopted school science conceptions of dissolving of a solid in a liquid and a liquid in a liquid. The former conception does not re-appear in her post-instructional interviews.

After learning about the polar and non-polar nature of solutes and solvents, Sujatha's answer to a lab-question based on this topic was as follows:

**Question:** Some people use gasoline (a non-polar compound) to clean grease stains from clothing. Although it is an effective solvent for grease, explain why gasoline should never be used for this purpose. Suggest a suitable alternative solvent.

**Sujatha's Answer:** Gasoline should never be used as a stain remover because it is so highly flammable. If the piece of clothing were to come in contact with anything of a high temperature, it would burst into flames. An alternative cleanser could be lemon juice or vinegar.

It seemed Sujatha naturally thought of "ordinary" household stain removers that she might have used.
As indicated earlier, Sujatha continued to hold that alcohol does not dissolve or it is only partially soluble in water. This could be because of her understanding that certain compounds show both characteristics of being polar and non-polar.

While answering an examination question on the difference between dissolve and melt, Sujatha had the notion that dissolving is a process of ordinary chemical change. Sujatha did not exhibit this conception of dissolving in the pre-instructional interview. As mentioned earlier, the researcher used a discrepant event to create doubts in the minds of students who had previously thought sugar/salt dissolving in water was a chemical change. Furthermore, the teacher taught them the solution process of salt by means of molecular models, and lectures. It is obvious, however, why Sujatha was confused, because in her notebook, she raised the question, “Can solutions dissolve into single molecules?” This question seemed to have connotations of chemical change. These types of conceptions that students hold remain hidden and intact if they are not accounted for during instruction. Conceptual change teaching conscientiously attempts to expose students’ conceptions and deal with them in some form.

6.5 Shamila’s Changing Conceptions of Solubility

The last case study is on Shamila. What kinds of conceptions did Shamila hold after instruction? How do they relate to her pre-instructional conceptions? What influence did the instruction have on Shamila’s earlier conceptions? These questions will be answered in this section. The outcome space of Shamila’s conceptions of solution chemistry constructed from the pre-instructional interview consisted of the following categories of description:

- physical transformation from solid to liquid: continuous view of liquid state
- density of solute

After instruction, the following categories of description for solubility were constructed:
Chapter 6. Students' Conceptions of Solubility After Instruction

- chemical structure of components
- amount of space in solution
- density of solute
- chemical reaction

This sub-section describes the post-instructional categories of description constructed from Shamila's interview data.

6.5.1 Shamila's Post-Instructional Conceptions

6.5.1.1 Chemical Structure of Components

Shamila discussed the solution system in terms of the structure of components. This was evident from the following discussion in the post-instructional interview:
Shamila (1) [sugar/water]

R: Can you tell me what is happening to the cube of sugar?
S: (laughs) Oh, we just did this in our test. (pause) What is the formula for sugar?
R: I'll get the structural formula for sugar.
S: Isn't it, it is like NaCl has Na and Cl. It breaks into Na, positive and Cl, negative. Since water is polar and sugar is polar, polar and polar dissolves.
R: How about salt? Is that polar as well?
S: Yes, it dissolves into water.
R: This is the structural formula for sugar. (Sucrose decomposing into glucose and fructose was shown from a chemistry book.)
S: What is this arrow going into glucose?
R: It [sucrose] breaks into glucose and fructose.
S: That's like unequal sharing, isn't it. Isn't that polar? O.K. I only know that water is a polar. Polar and polar dissolves with each other and it is attracted by molecular lattice and that $H_2O$ is attracting the particles of sugar and that's why it is breaking apart.
R: How would you represent table salt dissolving in water at the microscopic level?
S: (drawing) Isn't it something like that?

\[ \text{Na}^{+}\text{Cl}^{-} \]

R: What does that negative indicate and what does the positive indicate?
S: Since NaCl is positive and negative that will be the sodium and that will be chloride.
R: This is the case with table salt. How do you think sugar dissolves?
S: The only problem I am having is how would you separate that into like that?
R: Do you think sugar dissociates into ions like table salt does?
S: I think so because it dissolved.
R: You think sugar will break into ions.
S: (does not sound sure) Well, there are numbers down. When you break it down there will be carbon. I don't know. That is the formula for sugar, right? Then you have to. Is that like covalent compound? Like sharing of electrons?
R: You said that sugar is a covalent compound. What type of a compound is sodium chloride?
S: Thinks. That's ionic. I think it is ionic.
R: What mechanism would you propose for the dissolving of sugar? Would it be like dissolving of an ionic compound or would it be different? Can you predict? Make an intelligent guess.
S: I don't think so because each element has different properties. Isn't that right? So it got to be different.

Shamila talked about the solution process in terms of the chemical character of sugar and salt. First of all, Shamila wanted to know the formula for sugar. While the researcher was going through a chemistry text for the structural formula of sugar, Shamila likened the dissolution of sugar to that of table salt. The reason why Shamila asked for the formula of sugar may have been because in class the teacher explained the dissolution of table salt by a previously drawn diagram of solvation of sodium chloride. Because sugar dissolved in water, Shamila thought sugar has to break into ions. It was this notion that may have prompted her to ask the researcher the formula of sugar. When she said, "When you break it [sugar] down there will be carbon," there is doubt created in Shamila's mind. It occurred to her that sugar is a covalent compound. Shamila knew that salt is an ionic compound. So the researcher asked Shamila to propose a solution mechanism for sugar. Shamila thought since each element has different properties, the solution process of sugar has to be different to the dissolution of salt. While Shamila argued about the dissolution process of sugar by means of formulas, the underlying reasoning that she gave was: "Since water is polar and sugar is polar, polar and polar dissolves." Furthermore, to overcome describing the dissolution of sugar with its formula because of its complexity, Shamila states, "I only know that water is polar. Polar and polar dissolves with each other and it is attracted by molecular lattice and that $\text{H}_2\text{O}$ is attracting the particles of sugar and that's why it is breaking apart."

Once again in the solution chemistry test, Shamila presented the following argument for the dissolution of sugar in water. Note what Shamila wrote in her exam:
"Microscopically you can see that sugar breaks down into + & -, thus like dissolves like. The charged ends are attracted by 'ionic lattice'."

2) **Explain the solvation of sugar in water (microscopic & macroscopic levels).** Draw a diagram to illustrate this process. (3 marks)

Macroscopically, you can see the sugar dissolving in $\text{H}_2\text{O}$.

Microscopically, you can see that sugar breaks down into $+$ & $-$, thus like dissolves like.

This indicated that Shamila talked about the dissolution of sugar in terms of the chemical structure and character of components. The conception of chemical structure was revealed in her explanation about the miscibility of alcohol in water as well. For example, in the solution chemistry test, for the question, "Is ethanol (alcohol) miscible in water? Explain." Shamila wrote the following:

There is a sharing of electrons w/ethanol + $H_2O$? ethanol must be polar, since water is polar. Like dissolves like. Sharing of electrons attracted by their charged ends by molecular "lattice."
Shamila was logical in her reasoning when she wrote, "ethanol must be polar, since water is polar." The piece of information about the formation of covalent compounds by the sharing of electrons was borne in her statement about the miscibility of water and alcohol.

Consider Shamila's response for another similar question in the test.

"Suppose you have a spot on some clothing and water will not take it out. If you have available cyclopentane and ethanol, which would you choose as the more promising solvent to try. Explain."

I would use ethanol to take the stain out because "like dissolves like" & since water is polar and you need another polar to make a reaction. The spot on some clothing and the water can't take the stain out, it concludes that the stain is an unequal sharing of electrons. Maybe if you use ethanol on the stain it would be attracted by the "ionic lattice."

Shamila argued that for water to be an effective solvent, ethanol has to play a part. She reasoned that water and alcohol have to react first. Since they are both polar, Shamila thought that water and alcohol would react and dissolve the stain. Then she argued that if water cannot take the stain out, the stain is different from water in that it has "unequal sharing of electrons." "Ionic lattice" and "unequal sharing of electrons" seemed to be identical concepts to Shamila because she concluded that "if you use ethanol on the stain it would be attracted 'by the ionic lattice'."

Shamila viewed the water/alcohol/paint thinner system also in terms of chemical structure of components.
Chapter 6. Students’ Conceptions of Solubility After Instruction

Shamila (2) [water/alcohol/paint thinner]

R: Now let me reverse the process. Added food color to paint thinner. What happened? Did it dissolve?
S: No. That’s neat.
R: Why didn’t it dissolve?
S: No ideas. Mm ah. Has it got anything to do with uneven number of particles or molecules? or whatever. That’s what comes to my mind. It has an uneven number of electrons or molecules.

Shamila seemed to have remembered what was discussed in class with regard to the chemical nature of substances in terms of polarity. So she applied that knowledge by using words such as “polar,” “uneven number of electrons, or molecules.”

6.5.1.2 Amount of Space in Solution

Shamila’s views of dissolving had also to do with the relative amount of components available in the system. This conception was similar to what Nila, Gary, and Sujatha talked about in terms of “lack of room in the solution.”

Shamila (3) [water/alcohol/paint thinner]

R: Did it get dissolved?
S: Yes. But if there is more of the solvent [sic] it won’t mix. If there is more solute [sic] then it will mix.
R: How about the paint thinner?
S: It is immiscible. It is like oil and water.
R: Why is it immiscible?
S: It is like I think there is less water than the other.
R: Let me pour alcohol into this. You remember alcohol dissolved in water. Look at this now.
S: Hm (laughs).
R: Why do you think it [alcohol] dissolved in paint thinner?
S: I guess it is mixed in because there is more water [alcohol] in this than this one. There is more solute [sic] than solvent [sic].

Shamila argued that “if there is more of the solute, it won’t mix.” It seemed that she was reminded about the sugar/water and salt/water systems in which no more sugar and salt will dissolve when the solution becomes saturated. This was why Shamila’s present conception of dissolving was conceptualized as “lack of room in the solution.” Although Shamila attributed the immiscibility of paint thinner in water to oil and water, she
concluded by stating, “It is like I think there is less water than the other [paint thinner].” This meant that for Shamila, paint thinner is the solute and there is more of solute than the solvent water, again, substantiating the notion of “saturation.” When paint thinner was added to alcohol, Shamila observed the mixing of the components. Again Shamila argued that this mixing was because there was more solvent than the solute. In every case, Shamila held the view that if there was lack of room in the solution, there will be no further dissolving. This pattern of reasoning was clearly revealed in the following excerpt.

Shamila (4) [water/alcohol/paint thinner]

S: But it does depend on the property, though.
R: What is this property? ... 
S: Because there is more solvent [sic] than there is solute [sic]. That’s why it didn’t really mix. In spite of like I said about my Tang crystal, with water you form a paste then you make enough to make the juice. It has to have more water than you will. It might be an after effect though. Like after it settled.
If you leave like a day or two it comes back. That’s all I know.

To make the above point clear, Shamila related the water/alcohol/paint thinner system to an everyday example. She argued that if there is too much Tang crystals dissolved in the solution, they settle down after a day or two, thereby indicating the notion that dissolving is possible when there is more room in the solution.

6.5.1.3 Density of Solute

The following excerpts give evidence for another category of description: “density of solute.”
Shamila (5) [water/alcohol/paint thinner]
S: ...It got to be denser than water. I don't know.
It is like oil or grease.
R: Why do you think grease does not dissolve?
S: Grease is slippery.
R: That's why it does not dissolve?
S: It can be one property, too.
R: Are there any other properties?
S: Density.

Shamila likened the water/alcohol/paint thinner system to the immiscible character of oil in water (See Shamila, Excerpts 4 and 5.). Therefore, Shamila figured that solubility also has something to do with density of the substance being dissolved. Typically, less-dense substances will not dissolve. She corresponded the system to the dispersion of oil in water. “Grease is slippery,” Shamila argued.

6.5.2 Shamila’s Outcome Space: Pre- and Post-Instruction

Table 6.7 presents Shamila’s personal outcome space for solubility before and after instruction.

What ideas did Shamila have about the sugar/water system before instruction? In the pre-instructional interview, Shamila contended that sugar had melted into a syrup and that hot water made the sugar softer. She also suggested the idea that sugar is in liquid form. These statements represent a continuous view of matter.

After instruction, Shamila tried to explain solution processes in terms of chemical structures. Hence, she is representative of those students whose conceptions continue to characterize macroscopic pictures. Excerpts 3 to 5 show such an inclination. The following is another good example of how Shamila described the salt/water system in macroscopic terms.
### Chapter 6. Students' Conceptions of Solubility After Instruction

#### Table 6.7: Shamila’s Personal Outcome Space for Solubility

<table>
<thead>
<tr>
<th>Before Instruction</th>
<th>After Instruction</th>
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- physical transformation from solid to liquid: continuous view of liquid state—"It liquefies like the water." "It [salt] melted and it stuck together."
- density of solute—"Because it is heavier than water. It seems like there are bigger crystals, too."
- chemical structure of components—"Isn’t it [sugar] like NaCl, has Na and Cl. It breaks into Na positive and Cl negative. Since water is polar and sugar is polar, polar and polar dissolves."
- amount of space in solution—"...there is more of the solvent [solute] it won’t mix. If there is more solute [solvent] then it will mix." "I guess it [alcohol] mixed in because there is more water in this than this one."
- density of solute—"It got to be denser than water. I don’t know. It is like oil or grease."

Shamila (6) [salt/water]

R: What ideas come to your mind when you look at this?
S: It didn’t melt it down. It has been left for a long time. I don’t know. It didn’t mix with anything really. It is a heterogeneous mixture. Like in our book it says it segregates when at rest. That’s why two substances are not mixed together.

R: You think there is salt in this part?
S: Oh, I don’t really. Maybe there is a little bit, but they are all down there. Because I think salt is heavier than water, of course.

R: Do you think there is something going on between this part and the upper part...?
S: I think the water is trying to get through the salt for it to break apart, trying to force it. It is my interpretation. Like the water is pushing it. Like the sugar, how it was melting. But this is cold water.

Observing the salt crystals at the bottom of the jar, Shamila gave reasons such as “It has been left for a long time,” “It is a heterogeneous mixture,” “Like in our book it says it segregates when at rest,” “the water is trying to get through the salt for it
to break apart, trying to force it," "Like the water is pushing it," and "Like the sugar how it was melting." These seven statements portray salt/water system in macroscopic terms. Her natural inclination and preference in chemical explanations was to explain the observable. This aspect is illustrated in Shamila's concluding thoughts:

Shamila (7) [Concluding Comments] ...Science is too complicated. There are too many definitions. The key words in this chapter, I memorized all that. Then you see you memorize all that, you get out of school, what is solvent, then you sort of forget. Most schooling is like that. ...Just like if you use it a lot. If you use a term a lot then the more you learn. It is like learning a different language, too. If you use all the time you understand it. But memorizing it, it is like you memorize it for one day and that will be it. Science is complicated. Too many scientific words like molecules and atoms. Can't tell which is which. I guess that tends to get too complicated.

In the post-instructional interview, Shamila retained the idea of sugar melting (see Shamila, Excerpt 6). Furthermore, she likened the dissolving of sugar to be that of the dissociation of salt into ions. Shamila applied what she had processed about the salt/water system to the sugar/water system.

The next subsection will address the influence of instruction on Shamila's conceptions.

6.5.3 Influence of Instruction on Shamila's Conceptions

Shamila's ideas about how dissolving is influenced by considerations of chemical structures of compounds began on the first day of solution chemistry instruction when the researcher attempted to examine the water molecule as a foundation of theoretical views of dissolving. For example, Shamila had the following notes about her understanding of the water molecule. The mind map that she drew on solutions also portrays her understanding of the structure of the water molecule. See the following page for Shamila's notes and a portion of her mind map.
Chapter 6. Students' Conceptions of Solubility After Instruction

$H_2O$ is a solvent

It is exposing its protons making water dipole

$H^+$

Oxygen becomes more negative in nature.

Shamila's Notes

Shamila's Mind Map
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The teacher-given notes indicated an expansion of the theoretical ideas to sodium chloride and ethanol dissolving in water. As indicated in the case studies of the previous students, Shamila had attempted to answer all the questions based on polarity and non-polarity of substances.

Noteworthy were Shamila’s answers to two questions (pre-lab and post-lab). These substantiate the researcher’s earlier arguments about how Shamila inclined to look at chemical processes in macroscopic properties.

- **Pre-Lab Question:** Why will a dry-cleaner often seek more info. about stain on garments?
  **Shamila’s Answer:** Dry-cleaners often seek more info. about a stain on garments so they can take different approaches to go upon it, to determine what solvent they should use.

- **Post-Lab Question:** Some people use gasoline (a non-polar compound) to clean grease stains from clothing. Although it is an effective solvent for grease, explain why gasoline should never be used for this purpose. Suggest a suitable alternative solvent.
  **Shamila’s Answer:** Gasoline should never be used to clean stains off clothing because it is flammable and fumes are toxique [sic].

Whenever a chemistry question was asked in class or in an interview, Shamila explained or would answer with the help of everyday examples. She drew parallels to her experiences. Although she scored average marks in her chemistry tests, she linked school chemistry to everyday chemistry.

6.6 Summary

Chapter 6 examined the conceptions of dissolving held by four students after instruction in solution chemistry. It compared and contrasted students’ post-instructional conceptions with their pre-instructional conceptions. As well, this chapter connected some conceptions to the instruction offered.

The outcome space of the post-instructional interview consists of eight categories of description:
1. physical transformation from solid to liquid

2. chemical transformation of solute

3. chemical structure of components

4. amount of space in solution

5. solution equilibrium

6. density of solute

7. property of solute

8. size of solute

A look at the post-instructional outcome space suggests that one category (size of solute) is dropped and two categories (chemical structure of components and solution equilibrium) are added. Although the first five categories of description are similar, the nature of each of the post-instructional categories that correspond to the pre-instructional categories is much more detailed and complex and sometimes different. Some of the students' pre-instructional alternative conceptions do not resurface per se, but frequently appear as more complicated ones overlaid with some technical language.

Nila attempted to always talk in terms of chemical language, whereas Shamila was at the other end of the continuum and desired to use everyday reasoning in her chemistry learning. Gary's comments were technical, but he continued to have a continuum theory of matter. Sujatha's remarks characterized doubts. At times she did not believe what she observed.
Chapter 7

Conclusions, Discussions, Implications, and Recommendations

7.1 Introduction

Chapter 7 consists of an overview of the study, the conclusions of the study, a discussion of some of the broader issues that originated from the interpretations of the research data presented in earlier chapters, implications of this research for instructional practice and collaborative research, and recommendations for further inquiry.

7.2 Overview of the Study

Prior to drawing conclusions from this study and examining some of the general issues arising from the study, an overview of the work undertaken will be presented. This overview includes a review of the rationale, the theoretical assumptions, and the methods of inquiry.

7.2.1 The Rationale

Some studies have examined students' understanding of the concept of dissolving within the general framework of matter and its changes. There has been, however, no study conducted on students' conceptions of solubility which deals explicitly with the chemical processes and energetics of dissolving. Furthermore, no reported study has yet indicated how students' alternative conceptions of solubility can be dealt with in a classroom. This study sought to examine ways in which students' alternative conceptions in solution
chemistry might be treated in a chemistry classroom.

This exploratory study is unique both because it considered the teacher as a collaborative researcher, and because it offered an opportunity for the teacher to make sense of her own students' conceptions of solubility and how those conceptions might affect the teaching of a unit on solution chemistry. A further collaborative feature in this study was the researcher's endeavours to model constructivist teaching in the first three lessons. These features were additional to the researcher's more conventional role of identifying the students' conceptions of solubility before and after instruction by using a clinical interview methodology. This study, therefore, used a combination of conventional and somewhat novel methods of research to examine some of the difficulties entailed in the learning and teaching of solution chemistry.

7.2.2 Some Underlying Assumptions

Some of the assumptions which frame aspects of this dissertation are derived from the previous empirical research on alternative ways of thinking about the learning and teaching of science content. It has been argued by some (e.g., Driver, 1987 and Hills 1988) that this perspective is in harmony with contemporary views of the nature of science. Two of the most critical assumptions include: the belief that children come to class with some understanding of the phenomena under study; the belief that it is important to consider and incorporate students' prior conceptions in science instruction by using rationally based strategies to bring about changes in the conceptions held by students. In line with these assumptions, students' conceptions of solubility before and after an instructional unit on solution chemistry were grouped into a set of categories of description using a phenomenographic perspective.
7.2.3 Methods of Inquiry

In accordance with the first step (elicitation) of conceptual change teaching, the study consisted of interviewing individually thirteen Grade 11 students who were enrolled in the science class taught by the teacher collaborator. The students' conceptions were elicited by having students respond to questions about three chemical systems based on solubility. Each interview was audio-taped and subsequently transcribed. The data thus obtained were organized into a set of distinct categories which qualitatively portrayed different conceptions of dissolving phenomena. This means that the "outcome space" (Marton, 1981) of students' conceptions of solubility was established without casting judgement on the rightness or the wrongness of the responses provided by the students. These categories based on students' conceptions of solubility were discussed with the teacher prior to commencing the instructional unit.

The teacher invited the researcher to teach the first two classes of solution chemistry. The researcher ended up teaching an extra period. The researcher attempted to incorporate students' prior conceptions in all of her lessons. To obtain the teacher's reflections on these lessons, the teacher and the researcher carried out informal conversations whenever time permitted. The students wrote their perceptions about the researcher's lessons in their reflection logs. The researcher also maintained a personal thought log.

The teacher taught the rest of the solution chemistry lessons and the teacher and the researcher informally talked about her teaching of chemistry in view of constructivist practices. The classroom instruction was either video-taped or audio-taped. The recordings were transcribed for the purpose of describing more accurately the instruction of solution chemistry. The informal discussions between the teacher and the researcher in and out of the classroom were documented in the personal thought log. Students' labs,
Chapter 7. Conclusions, Discussions, Implications, and Recommendations

Note books, mindmaps, and examinations were photocopied.

After the instructional phase of the study, the same thirteen students were interviewed using the same chemical systems that were used in the pre-instructional interviews. Again, each interview was audio-taped and transcribed. Case studies were done on four students. Nila, Gary, Sujatha and Shamila were selected because they were representative of the thirteen students who took part in the study. The selection criteria were: the range of conceptions of the solution process; the levels of explanations (chemical versus everyday talk); the ability range; and the ratio of girls to boys. The students' post-instructional conceptions of solubility were compared with their pre-instructional conceptions.

7.3 Limitations of the Study

With regard to the issue of generalizability in this study, the students' outcome space was the major knowledge claim. The pre-instructional outcome space consisted of six categories of description. These categories of description for solubility can be replicated in future studies with a high degree of confidence. For instance, when System A (sugar/water) was shown to students, there were two distinct categories of description, namely, "physical transformation from solid to liquid" and "chemical transformation of solute." These two categories were found in the interview responses provided by thirteen students. These conceptions have also been reported in previous studies where sugar is dissolved in water. Thus it can be said with some confidence that the students' outcome space obtained in this study can be generalized to other students responding to the same systems. Being able to generalize the outcome space of this study is significant in terms of lesson planning and curriculum development.

The boundary conditions of this study consist of scope of content and a case of one chemistry teacher and one chemistry classroom. In terms of content, this study is
Chapter 7. Conclusions, Discussions, Implications, and Recommendations

confined to the chemical concepts, models and theories presented as school chemistry. It has considered the concept of solubility and its associated concepts. It did not deal with problems based on concentration.

With regard to context, it must be borne in mind that the conclusions drawn from this study are necessarily tentative and serve to point the way for future inquiry. That is, the conclusions arrived at in this study are those of a naturalistic type characterized by their applicability to similar situations and experiences (Hammersley, 1980; Hammersley and Atkinson, 1983; Lincoln and Guba, 1985; Woods, 1977). Thus the conclusions drawn from this case study of collaboration can be generalized to other teacher-researcher collaborative studies which might be conducted in similar educational governance, situations and circumstances.

7.4 Conclusions of the Study

This section presents the conclusions under five headings corresponding to the five research questions: the students' prior conceptions of solubility; factors influencing the incorporation of conceptions; the students' conceptions of solubility after instruction; the relationship of pre- and post- conceptions; and the influence of instructional procedures on conceptions.

7.4.1 Conclusion 1: Students' Prior Conceptions of Solubility

The students' prior conceptions of solubility were discussed in depth in Chapter 4. In this section, the conclusions which address research question one will be presented. The question is:

What are the most common conceptions of solubility found in Grade 11 chemistry students before an instructional unit on solution chemistry?
Chapter 7. Conclusions, Discussions, Implications, and Recommendations

The most common conceptions of solubility found in Grade 11 chemistry students before an instructional unit on solution chemistry can be grouped into the following set of categories. The students' conceptions of the solution process are given first; the factors influencing solubility follow.

- Solubility may be described as a physical transformation from solid to liquid (n=10).
- Solubility may be described as a chemical transformation of solute yielding a new product (n=6).
- Solubility depends upon the density of the solute (n=10).
- Solubility depends upon the amount of space available in the solution (n=4).
- Solubility depends upon the properties of the solute (n=4).
- Solubility depends upon the size of the solute particles (n=1).

7.4.2 Conclusion 2: Factors Influencing Incorporation of Conceptions

Instruction incorporating students' conceptions of solubility was described in Chapter 5. It concluded with an analysis of factors influencing the teacher-researcher collaborative procedures in attempting to incorporate students' conceptions. The question pertaining to this research interest is:

What are some of the influences facilitating and constraining the teacher-researcher collaborative procedures in attempting to incorporate students' conceptions in this study?

There were two types of influences on the teacher-researcher collaboration, those that were facilitating and those that were constraining. In terms of conceptual change teaching perspective, there were some influences that facilitated the teacher-researcher collaborative procedures. For instance, elements of conceptual change teaching (strategies used in Driver's conceptual change teaching model) were found in at least two of the teacher's lessons. In one of her lessons, the teacher "exposed" the students to their own conception about the solution process. Then she confronted the students directly
with the chemists’ model of the solution process of salt dissolving in water. Another conceptual change teaching strategy that she used was “cooperative learning.” In her concept attainment lesson on polar and non-polar compounds, the teacher gave students time to interact with one another to distinguish between polar and non-polar compounds.

Another factor that facilitated the teacher-researcher collaborative procedure was the teacher’s openness about evaluating her own methods of teaching at the end of lessons. With the help of the researcher, she examined teaching strategies such as mind mapping, concept attainment lesson, laboratory instruction, and cooperative learning in accord with the assumptions of conceptual change teaching.

The teacher’s reflection about the researcher’s constructivist teaching constitutes the third factor that facilitated the collaborative process. The teacher pointed out that the researcher did not take seriously enough the students’ learning outcomes in the elicitation phase of the lesson. During the intervention phase, the researcher’s lessons were perceived by the teacher as unstructured in style, exhaustive and exhausting in terms of teacher preparation, and demanding in terms of the teacher as well as the lab-technician. The teacher agreed that developing children’s ideas was valuable, but when she contemplated both the amount of time it took to incorporate students’ conceptions and the expectations of the administration, she felt that in a Grade 11 class, covering the curriculum was more important.

Collaboration was further facilitated in the teacher’s classroom because the researcher was actively involved with the teaching, helping students with their work and answering their queries at school, after school, some marking, writing certain parts of the solution chemistry examination, sharing relevant articles, doing some peer coaching, helping the teacher with a project that she did for a science education course called “issues of teaching and learning”, and by being her “research subject.”
There were also a number of constraints to the collaborative process. The efforts to link student's conceptions with formal chemistry were seriously constrained by the time available to devote to the topic of solution chemistry. Hence there was frequently insufficient opportunity to engage the students in discussion or to encourage reflection on their own conceptions as compared with those concepts identified as important by the text and curricular materials.

There were other "situation-specific" constraining factors. Because of her busy schedule, the teacher did not have time to plan lessons together with the researcher in order to incorporate students' conceptions. This factor greatly restricted the collaborative effort. Another situation-specific constraining factor was the lack of practical experience on the part of both the researcher and the teacher in developing specific teaching strategies which acknowledged students' prior belief in this content area.

Since the instructional period was fairly short, it was not possible for the researcher and the teacher to develop common perspectives and a shared language and this inability placed further restrictions on collaboration.

### 7.4.3 Conclusion 3: Students' Conceptions of Solubility After Instruction

The students' outcome space of solubility after instruction was examined briefly in Chapter 6. The research question is:

What conceptions of solubility are held by Grade 11 students after studying a unit on solution chemistry?

The conceptions of solubility held by Grade 11 chemistry students after studying a unit on solution chemistry can be grouped into the following set of categories. The students' conceptions of the solution process are given first; the factors influencing solubility follow.

1. Solubility may be described as a physical transformation from solid to liquid ($n=2$).
2. Solubility may be described as a chemical transformation of solute yielding a new product \((n=2)\).

3. Solubility depends upon the chemical structure of components \((n=13)\).

4. Solubility depends upon the amount of space available in the solution \((n=6)\).

5. Solubility depends upon solution equilibrium \((n=3)\).

6. Solubility depends upon the density of the solute \((n=2)\).

7. Solubility depends upon the properties of the solute \((n=1)\).

8. Solubility depends upon the size of the solute particles \((n=1)\).

After instruction, two more categories (3 and 5) were evident in students' understanding of solubility. While the number of students who held the first two categories diminished, the number of students who held the fourth category increased.

7.4.4 Conclusion 4: Relationship of Pre- and Post- Conceptions

From the data obtained for all thirteen students, a comparison of the students' pre- and post-instructional conceptions was made in Chapter 6. Four case studies were presented in detail to examine the linkage between the pre- and post-instructional conceptions. The question pertaining to this concern is:

How do these students' conceptions of solubility relate to their own prior understanding?

After instruction, the set of categories of description was comprised of eight qualitative differing conceptions of solubility. The students' post-instructional conceptions characterized qualitatively different conceptions in relation to their prior conceptions. Although some of the students expressed their understanding of solubility in terms of chemical structures of compounds after instruction, they retained some of their original conceptions. The newly acquired conceptions of solubility reflected insufficient explanatory power and were merely overlaid with the chemical language. Thus it can be
argued that although instruction provided new ways of thinking about solubility, it mainly helped the students in developing the language of solution chemistry. The students were therefore able to express their ways of understanding with an appropriate disciplinary language, which is an important aspect of chemistry learning. Learning the language of solution chemistry and acquiring some theoretical understanding of it reflect the change in pre- to post-instructional conceptions. This conceptual change can be considered as evolutionary rather than revolutionary.

7.4.5 Conclusion 5: Influence of Instructional Procedures on Conceptions

The influence of instructional procedures was carefully studied by examining the changing conceptions of four students in some detail. This in-depth analysis is presented in Chapter 6. The question that pertains to this topic is:

What was the influence of instructional procedures on each of these student’s prior conceptions?

Case studies were done on Nila, Gary, Sujatha and Shamila. As a result of instruction, all four students’ post-instructional conceptions could be characterized as being qualitatively different to those conceptions they expressed in interviews prior to instruction. The students’ rudimentary knowledge of solubility was expanded in some aspects. They did retain some of their original conceptions despite instruction. In spite of the conceptual change strategy that was used to create cognitive conflicts, two of the four students continued to maintain that dissolving is a chemical combination. This is not surprising because other studies point out that alternative beliefs persist in spite of instruction (Driver and Easley, 1978; and Osborne and Wittrock, 1983) and “alternative conceptions often outlive the instruction that was meant to supplant them” (Hess, 1987).

It was also concluded that students came up with new ideas that are inconsistent with contemporary chemical concepts because instruction was at the surface level and some
aspects were not discussed in class at all. While some students were aware of certain ideas such as saturation and equilibrium, others were not because they had not gathered such ideas from their textbooks. Conceptual learning can occur by reading the textbooks meaningfully. Since in this Grade 11 class the chemistry textbook was frequently used, it is important that "teachers understand when and how the [textbooks] can be [effectively] used to promote students' conceptual learning" (Roth and Anderson, 1988, p. 140).

A discussion of some of the major issues emanating from the study will be undertaken in the next section.

7.5 Issues on Nature of Chemistry Learning and Inquiry

An analysis of the conclusions arrived at for each of the research questions generates a number of issues pertaining to the nature of chemistry learning. Issues pertaining to chemistry learning arise from students' conceptions of solubility and conceptual change teaching. Issues pertaining to inquiry into the problems of teaching and learning emanate from teacher-researcher collaboration. These issues will be discussed in turn.

7.5.1 Chemistry Learning

A careful analysis of the students' conceptions of solubility revealed important factors influencing the nature of student learning in this area of chemistry. These factors include: chemistry learning is influenced by (a) explanations of the observable; (b) difficulties in understanding the particulate model; (c) inappropriate links to previous learning and (d) students' chemical language. Each of these factors is discussed in more detail.
7.5.1.1 Explanations of the Observable

Students' conceptions suggest that their explanations of chemical systems are frequently supported with reasons in the light of what they see and what they experience. Their inclination, therefore, is to focus on the seen and not on the unseen. For example, since from mixing sugar and water, the sugar solution is observed to be in a liquid state, the students proposed the idea that solid sugar is converted into liquid sugar. This conversion was compared to the process of melting, for which the heat energy supplied was hot water. This might be because students have had the experience of seeing substances such as wax and ice melting from their solid state to liquid state in the presence of heat. This finding is consistent with a finding of the Cosgrove and Osborne (1981) study, which stated that over 25 percent of students used the words ‘melt’ and ‘dissolve’ synonymously.

A second example of not being able to theorize about the unseen was evident in the students’ diagrams. Water was depicted as a continuum, whereas sugar was depicted in the particle form because that is the way these substances appear to be. Hence it can be concluded that students’ representations in the form of diagrams were often guided by what they had literally seen.

The third example was found when students in this study argued that dissolving of sugar was a chemical combination of sugar and water to produce sugar-water in which the product is different from its constituents in taste and physical appearance. This claim is similar to the findings of Stavridou and Solomonidou (1989), and Prieto, Blanco and Rodriguez (1989).

Such speculations about chemical phenomena are extrapolations made from students’ experiences, such as that of sugar dissolving in water. For most students, visible characteristics of the change seem to be the standard that governs their reasoning (Cosgrove and Osborne, 1981; Driver, 1985; Hess, 1987; Piaget and Inhelder, 1974).
These studies also indicate that students of different ages and backgrounds hold similar conceptions, or that there are commonalities in students' ideas regardless of their background. In addition, in school, students are expected to abandon their perceptually sensible model in favor of an abstract one developed by scientists. Accordingly, a particle picture sometimes contradicts one's sensory perception of matter and therein lies the difficulty (Novick and Nussbaum, 1978; Nussbaum, 1985).

7.5.1.2 Difficulties in Understanding Particulate Model

Nussbaum (1985) has noted from the history of the theory of matter that internalizing the particle model requires a difficult accommodation for people to overcome their direct perceptions of matter; hence it is not a model which is likely to be constructed quickly or eagerly by children. Ben-Zvi, Bat-Sheva, and Silberstein (1986) have pointed out that the difficulties that students have in adopting the particulate model should not be surprising since it took scientists 2000 years to develop the model. Butts and Smith's (1987) results have suggested that the interpretation of macroscopic observations in terms of atomic and molecular properties may be more difficult for many students than teachers anticipate. Driver (1985) has pointed out that from about age 13, students use particulate ideas in their explanations. The students in this study who were sixteen and seventeen years old also attempted to explain the transformation of solid sugar to liquid sugar at the microscopic level but they encountered difficulties. Their explanations and diagrammatic representations corresponded with what was apparent.

7.5.1.3 Inappropriate Links to Previous Chemistry Learning

Students make inappropriate links between present and past learning (Viennot, 1979). In the researcher's pilot study (Ebenezer, 1989), solution chemistry was taught right after the chapter on chemical reactions. The students related their chemical reactions'
knowledge to the formation of solutions. In this study, solution chemistry was taught after a unit on solids, liquids and gases, kinetic theory, and bonding. Consequently, the students attempted to relate what they had learned about these topics on the formation of compounds to solutions.

Explanations of solutions and solubility at the microscopic level consisted of what the students had learned in their previous lessons. For example, some students applied the kinetic molecular theory of liquids to explain dissolving. One student argued that since the molecules of sugar are in movement when sugar is added to water, sugar has to become a liquid like liquid-water. Another student argued similarly, but she went a little further by stating that both "liquid-sugar" and "liquid-water" are able to mix because liquid-sugar is spaced out to accommodate the liquid-water. These students' responses suggest that when students are asked to give reasons they depend not only upon their senses, but also upon their prior knowledge and learning to interpret or give meaning to their observations and the new problem situation. The above examples of reasoning about dissolving indicate that students sometimes make inappropriate links to their prior knowledge.

7.5.1.4 Students' Use of Chemical Language

Among students, there was confusion in the usage of the term "molecule." For example, the term "molecule" was often used to describe the granules of sugar. This usage is somewhat like using the word "particle." For the student, particles of sugar means granules of sugar, whereas for the teacher, the particles of sugar means molecules of sugar. Thus there is confusion in the chemical language. As some students mentioned in the interview, they find it difficult to remember the difference among particles, molecules, atoms and ions. This finding supports the view that the students' use of language is imprecise.
Chemical concepts, chemical knowledge and understanding can be elaborated, differentiated, and articulated precisely only if the student becomes conversant with the chemists' language. Only when students are shown how to perceive chemical phenomena in the appropriate manner (based upon the structure of the discipline and the related language) does the meaning of these phenomena become clear (Brauner, 1985).

The above discussion reiterates the concerns expressed by science education researchers who have called for a closer examination of the assumptions underlying teaching and learning in science (Driver, 1987). One proposed reconceptualization of teaching and learning outcome associates learning with a form of conceptual change (West and Pines, 1985).

7.5.2 Conceptual Change Teaching

Significant to this study is the discussion about the conceptual change and conceptual expansion strategies that were used to respectively restructure students' conceptions and to expand students' ideas so as to draw consequences of such methods for science teaching.

The two most important alternative conceptions that were found in this study and in previous studies about dissolving were:

1. the process of melting denoted as the process of dissolving; and
2. chemical combination of sugar and water to yield sugar-water.

In order to create dissatisfaction in the existing conceptions of the solution process the teacher-researcher collaborators used two strategies:

1. discrepant event; and
2. direct confrontation.
Chapter 7. Conclusions, Discussions, Implications, and Recommendations

7.5.2.1 Conceptual Change Strategy: Discrepant Event

Some science education researchers have used discrepant events to challenge students' conceptions (Anderson and Smith, 1983; Hess, 1987; Nussbaum and Novick, 1982). These authors have studied the effectiveness of specific discrepant events in terms of student understanding. For example, consider what Hess (1987) noted about using a discrepant event: after instruction, over 25 percent of the ninth-grade students demonstrated an understanding of chemical knowledge, conservation reasoning and explanatory preferences that would be acceptable to a chemist. Many more responded in ways that suggested a transitional state. The best ninth graders regularly chose chemical substances for reactants/products, introduced invisible gases when appropriate and indicated a preference for explanations based upon the atomic-molecular theory over non-chemical kinds of explanations. His grade eleven students' results for the same instrument were poor contrasted with his grade nine students because they were not taught using the conceptual change method. Hess concludes that traditional teaching techniques are not capable of promoting conceptual changes in many students.

7.5.2.2 Conceptual Change Strategy: Direct Confrontation

The teacher directly confronted the students by stating that “melting” is not “dissolving.” She taught the students the solution process of sodium chloride in water by drawing the related diagram given in the chemistry textbook. Di Sessa (1987) would tend to argue that the confrontational method the teacher used was not a conceptual change method. According to Di Sessa, confrontational method is when an expert theory replaces naive theories, whereas the conceptual change view consists of reshaping the core naive ideas with more than one activity. However, it may be argued that confrontational method can be considered a suitable approach if one believed that the theoretical explanations
of phenomena have to be simply told. For example, note what Laurillard (1988) stated about confronting students with scientific theories:

Students may never arrive at appropriate experiments to enable them to learn the right form of conception. These have to be provided, and students have to work through them in order to experience the necessity of changing their original conceptions. If the teacher allows the student to be the author, there is little hope that he or she will learn Newtonian physics.

Similarly, in this study, the students may have never learnt the process of dissolution and hydration and how the solution process differs from melting if the teacher had not simply told them with the aid of the book what dissolving was.

Despite the use of this direct method, at the end of the solution chemistry unit, some students did not know the difference between melting and dissolving. In addition, most of the students thought that dissolution of sugar is the same as the dissolution of sodium chloride in water. This is because the students memorized the text and the diagram for the dissolution of salt, and attempted to apply this knowledge to other solution processes incorrectly. It is therefore essential that the conceptual bridges are built from concept to concept by creating situations wherein the students can think about their own conceptions in terms of what the teacher wants them to learn. Students might take a long time to realize the discrepancies between their ways of thinking and the formal chemical knowledge that they are exposed to in class. The teacher's intervention in exposing the student's alternative conception and providing appropriate strategies to restructure his/her ideas must be accompanied by sufficient time for student creation, reflection, sharing and clarification of his/her ideas of science concepts.

Most of the students' knowledge on solubility seemed primitive or rudimentary. For example, some students stated that because of the type of element present in the solute, it does or does not dissolve in a solvent. This limited understanding of dissolving was based upon the character of the dissolving constituents. Furthermore, students said that because of the difference in the densities of the two liquids, one does not dissolve in
another. In order to expand students' knowledge about dissolving, a lab on polar and non-polar nature of the solute and solvent compounds and a concept attainment lesson to distinguish between polar and non-polar compounds were used by the teacher. As a result the students had an opportunity to learn about the structural aspects of some solutes and solvents. They also attached the language of solution chemistry to their conceptions.

7.5.2.3 Conceptual Expansion Strategy: Laboratory Activity

The laboratory activity on polar and non-polar compounds was conducted for the very purpose of expanding on students' conceptions. As a result of doing this lab, the students learned how to distinguish between polar and non-polar solutes and solvents as evidenced in the solution chemistry unit examination.

This laboratory activity emphasized following the lab procedures methodically, presenting of the final reports in a neat package, trying to finish the lab on time (Jane stressed time length for each part and student efficiency—one of Jane's brightest students told the researcher that he could not finish the lab on time so he copied the results from his partner. Some students asked the researcher for answers to fill in their data tables so that they could finish the lab on time.), safety aspects and other laboratory skills. Students' findings were matched with the teacher's book answers. Any finding that contradicted with the book report was distinctly stated by the teacher as "incorrect." No explanation was given by the teacher or the student why iodine did not dissolve in paint thinner. Marks were not given for incorrect findings although the results were written according to their observations.

The students did their experiments in small groups, but the lab activity turned out to be teacher directed, confirmatory and one that emphasized finishing the task within a short period of time. Current research on laboratory teaching favors the notion that
students conduct experiments in small groups because the students will then have a
greater opportunity to share, justify, and negotiate their ideas so that they may eventually
come to consensus in line with scientific thinking. Such procedures appear to influence
sense-making as students engage in solving problems that are created by their laboratory
observations (Driver, 1987; Tobin et al., 1990).

7.5.2.4 Conceptual Expansion Strategy: Concept Attainment

Prior to instruction, students did not know that dissolving had to do with chemical
structure of compounds. They had different conceptions (refer Chapter 4) prior to
instruction. Students were now exposed to the structures of various compounds, some
polar and others non-polar through a concept attainment lesson. The students found
this lesson difficult and they expressed remarks of frustration. Transition from the
macroscopic observations (lab) to visualizing and reasoning at the microscopic level why
some compounds are polar and others are non-polar was difficult for these students. So
learning chemistry for beginning students is a great challenge. This argument is in line
with the Butts and Smith (1987) survey report, which indicated that students experience
difficulty with some of the fundamental concepts related to atomic, ionic, and molecular
structure. These authors concluded that macroscopic observations in terms of atomic and
molecular properties may be more difficult for many students than teachers anticipate.
Ben-Zvi et al. (1987) has indicated that difficulties will occur when students are asked to
conceptualize chemical changes on the atomic-molecular level and the phenomenological
level almost simultaneously. In this study, although conceptual change and expansion
strategies were used to help students to restructure their alternative conceptions and
build their conceptions of dissolving, students' difficulties were exposed when they had
to conceptualize solution process at the microscopic level.
7.5.3 Phenomenography: A Method to Assess Conceptual Change

Conception research literature has been consistently arguing for conceptual change in students. It is desired that, using conceptual change instructional strategies, students be taken from their naive conceptions to an appropriate theory presented by textbook authors, science teachers or the scientific community. The present study attempted to follow this tradition by initially looking at a set of categories of description of solubility using a phenomenographic approach. In this study, phenomenography was used as a methodological framework because it is acknowledged as a branch of constructivist world view. The main point of departure from this framework is that constructivists believe that students have well-established mental structures or schemes that need to be accounted for in instruction (Marton, 1984). Marton argues that “the most fundamental images of our world are always taken for granted and they are mostly not present in individual consciousness, but they are reflected in the way we organize society,” (Marton, 1984, p. 45). He goes on to claim that we must also look “beyond the individual” in our search for the various ways in which we can come to understand phenomena.

From this point of view, it can be argued that the concept of solubility is embedded in the cultural language as well as in a more specialized chemical language. It is the latter which is given a special place in the chemistry classroom. Initially this concept is culturally acquired and one might argue that it is in the conscious level before a student studies solution chemistry. An introduction of solution chemistry to a student, in the science classroom, one might argue, is an induction of him/her to the language of the scientific community, a presentation of a qualitatively different way of understanding solution phenomenon. From this stance, it appears that the concept of solubility occurs in two domains of knowledge: everyday knowledge (Claxton, 1983) and chemical knowledge. For example, in this study it was found that students thought of dissolving as melting.
This stems from their everyday knowledge. But when dissolving is thought of as a chemical phenomena and it is depicted and explained in terms of macroscopic and microscopic language of chemistry, then the student is dwelling in the chemical language domain. So, as Linder (1990) points out, it is out of social necessity that students construct different modes of knowledge (Solomon, 1983) and different modes of perception (Brauner, 1988).

This study shows that at the end of conceptual change instruction using a "discrepant event", some students still retained the idea that "solubility may be considered as a transformation of a solid to a liquid", thereby indicating that it is a process of melting (see Table 6.1 in Chapter 6). This everyday "socialized knowledge cannot ever, by its very nature, be extinguished" (Solomon, 1983, p. 50). Consequently one tends to see some light in Linder's work on students' conceptions of sound. In his recent paper, "Is conceptual change something science teaching should be striving for?", Linder argues that conceptual dispersion is a "naturally occurring phenomenon" (Linder, 1990) because of a student's movement into different social frameworks. According to Linder, conceptual dispersion is a characterization of the set of conceptualizations which a person may have regarding some phenomenon—a person's private outcome space. The same phenomenon viewed in different contexts may evoke different conceptualizations of that phenomenon (Linder, 1989, p. 16). Linder proposes that the science teacher's efforts should be "aimed at adding new knowledge that is recognizably more appropriate from our particular perspective for particular contexts" (Linder, 1990, p. 6).

Accepting Linder's point of view, I would like to propose that since chemistry instruction is a context or another province which is meant for further social enculturation into the chemical world of knowledge, the student must be provided with a qualitatively differing conception about solubility for his/her consideration. This is deemed important for the school context especially if the students' everyday knowledge structure or ways
of expressing and understanding solubility is variant with the understanding put forward by the community of chemists. For example, as shown by this study, if the students understand solution process to be a chemical reaction rather than a chemical phenomenon (the formation of two new electro chemical species), teachers ought to take the effort to show them a qualitatively differing and a more plausible idea. On the other hand "density of the solute" (experience based) and "chemical structure of components" (school based) are appropriate competing theories for the characterization of solubility of a liquid in a liquid.

Although phenomenography encourages one to look for qualitatively different conceptions for a given phenomenon, Marton (1988, p. 15) states that the "differing understandings of various phenomena are not specific to particular contexts" ... but "they are specific to the particular phenomenon". However, the students' conceptions are specific to particular contexts even if the phenomenon is the same. This is why, from his study, Linder termed this property as "conceptual dispersion". And the phenomenon of conceptual dispersion is evident in this study as well because students' conceptions were specific to the three individual chemical systems as shown in Table 4.1 in Chapter 4. Chemistry instruction must address this issue: that some systems are more likely to evoke specific conceptions and students should be made aware of the fact that for the same phenomenon regardless of the independent systems there are usually one or more appropriate differing conceptions. In conclusion, the claim made in this section is that a chemistry classroom is a context for chemical knowledge construction. Therefore, conceptual change strategies should address chemical constructs in the appropriate manner. However, in the everyday social context students saying "sugar is melting in tea" can be considered appropriate. The qualitatively differing ideas deriving from everyday social context and chemical social context may be brought to students' understanding in the study of chemistry. The chemistry classroom then becomes a place where students'
qualitatively differing ideas are initially considered, but chemists' ways of looking at the same phenomenon are presented for the students' consideration with the aim of bringing about some form of conceptual change in the students.

7.5.4 Seeds for Conceptual Change Teaching

Observations of the teacher's chemistry class revealed that the teacher used many novel meta-cognitive instructional procedures. For example, mind mapping, concept attainment, games/teams/tournament, and cooperative learning. Some of these strategies appear in the conceptual development and change literature (Baird et al., 1987). In Jane's class, however, these strategies were used in a traditional sense. For example, with regard to mind mapping, Jane commented, "Basically the mind map that I have them [students] use is not based on their pre-conceived notions or their concepts of what I am talking about. I have them map out a chapter in the textbook of the overview of their work." In Jane's class, a mind map serves as an organizational tool and not as a tool for conceptual understanding or reflecting (Ault et al., 1984).

Since Jane is already using some of the meta-cognitive strategies which "might be useful in making chemistry learning more meaningful" (Ebenezer, 1990), it will not be difficult for her to re-think her use of these tools to fit more closely with the ideas of constructivist teaching. For instance, have the students draw a mind map of solutions from their own points of view and then compare and contrast this with the chemical understandings of the concepts used. For teachers like Jane who are willing learners, in the course of time, when conceptual change of professional knowledge occurs, the strategies that she is presently employing to teach chemistry would be more meaningful and fruitful.
7.6 Implications for Instructional Practice

The research on conceptual change science teaching posits tentative implications for instructional practice in four major areas:

- analysis of students' conceptions for instruction;
- development of curriculum materials;
- teacher education; and
- teacher-researcher collaboration.

7.6.1 Analysis of Students' Conceptions for Science Instruction

This study showed that students did not come to the solution chemistry class with "blank minds." Their conceptions of solubility were both rudimentary, alternative to accepted views of dissolving, and exhibited qualitative differences. The students viewed the phenomenon of dissolving in terms of their prior learning. An analysis of the students' conceptions helped the teacher-researcher collaborators to examine the content of the solution chemistry unit in terms of building conceptual linkages between students' understanding and chemists' understanding. As well, a conscious effort was put forth to match teaching strategies with students' conceptions. While some conceptions were replaced with qualitatively different conceptions, new alternative conceptions were born. These insights reveal that teachers must constantly analyze students' conceptions of physical and chemical phenomena and think about the sources for their conceptions so as to plan effective strategies.
7.6.2 Development of Curriculum Materials

It was realized in this study that a teacher's day can become very long when he or she wishes to take part in extra work related to teaching. For instance, the teacher collaborator was engaged in many other professional activities such as science associations and strategy development. Although the teacher collaborator was excited about alternative methods of teaching, she was bogged down with excessive work. As a result, she did not have time for deliberately planning strategies for conceptual change teaching or experimenting with them. So ultimately, the teacher did not feel comfortable in experimenting with incorporating students' conceptions in her lessons. She acknowledged that her preferred way of experimenting with conceptual change strategies was following well-planned conceptual change lessons and the accompanying resource materials. This implies that it is important not only to make the teacher aware of students' conceptions but also to develop curriculum materials within the framework of constructivist principles. In this study, curriculum development of solution chemistry entails the preparation of two types of materials:

1. a summary of students' prior alternative conceptions and why the students have such alternative conceptions; and

2. matching activities and teaching strategies that would focus on students' prior conceptions.

Classroom materials using students' conceptions have been written in the past on a few topics by some researchers (for example, see McFadden et al., 1986; White and Horwitz, 1988; Zietsman and Hewson, 1986). While such efforts are greatly appreciated, the researcher believes that the prepared curricular materials can only act as a springboard, and that on site, the teacher should have the presence of mind to be sensitive to his/her students' thinking, and to be creative, with appropriate questioning and reformulating students' thoughts towards appropriate conceptions. Furthermore, as theoretical studies
(Driver, 1987; Hewson, and Hewson, 1987) indicate, a teacher ought to be conceptually ready to follow the conceptual change teaching strategies. How can this be wrought in both in-service and pre-service teachers?

7.6.3 Teacher Education

Many studies have argued for science teaching and learning that would promote conceptual change in students. Few teachers, however, are sufficiently informed of this literature. From this study it can be argued that teachers whose conceptions about the nature of science and about the nature of science teaching and learning are not harmonious with conceptual change principles will find it fruitless in implementing conceptual change strategies effectively in their classroom.

Since most science teachers are of the view that learning is a process of acquiring and memorizing scientific facts rather than a process of conceptual change, in professional development sessions, and in advanced science education courses, they should be introduced to the principles and theories of conceptual change teaching. As well, the teachers should be directed to the findings of students' conceptions of natural phenomena that have been documented from an array of empirical studies in various topics. This information will enable the teachers to know what to expect from students from a particular unit of study, and will give them an incentive to prepare appropriate curricular materials.

Experience dictates to this researcher that these alone are not sufficient to help teachers to undergo a conceptual change. As the first condition of conceptual change theory teaches, the teacher must perceive a need or find the present teaching to be unsuccessful to change his/her ideas to accept that the alternative model of teaching is more powerful. Such changes take time, sometimes years. The researcher's personal experience shows that it is a struggle to grapple with the theoretical and practical issues.
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7.6.4 Teacher-Researcher Collaboration

It was the personal struggles and hurdles that the researcher experienced which convinced her to collaborate with a chemistry teacher to do a study of this nature on students' conceptions. Although in reality it was not easy to do a study of this nature, the few theoretical aspects that the teacher and the researcher considered when practical issues surfaced, and some things that they did together with their teaching of a solution chemistry unit seemed to foster conceptual changes. Such a collaborative venture prompted both the teacher and the researcher to contemplate on the complexity of teaching and learning, the kinds of knowledge and facilities that are specifically needed to teach effectively for conceptual change, and the factors that constrained practising the approach.

More specifically, the teacher-researcher collaborators had the opportunity to look in detail at the students' conceptions of solution chemistry. The knowledge of and incorporation of students' conceptions in instruction gave them an idea to what depth and to what range a teacher ought to know about the content matter of solution chemistry. In addition, the study gave them insights into the preparation of teaching strategies that would match with content.

From this study, the researcher would argue that her interactions with the teacher helped her to understand the teacher's situation with greater understanding and appreciation. The teacher expressed more than once that the researcher's presence in her class added more than what money could provide. The teacher acknowledged that the researcher's interventions illumined, or helped her to re-think, her understanding of science teaching and learning. Science educators must, therefore, find ways to facilitate, support, and guide teachers in undergoing conceptual change towards the principles of conceptual change science teaching.
Experiences with the collaborating in-service teacher in this study can be applied to the pre-service teachers as well. Recent studies indicate that the pre-service conceptions of the nature of science and teaching/learning are alternative to the current conceptions of teaching/learning (Aguirre et al., 1989; Aguirre, 1990; Gurney, 1990; Price-Meyer, 1990). Studies also indicate that teachers do not readily accept the principles of conceptual change teaching in their methods classes (Haggerty, 1990; Parsons-Chatman, 1990).

In teaching methods courses as well as in supervision of pre-service teachers, especially in traditionally oriented classrooms, science educators and faculty advisors should play a collaborative role and through modelling help their students to begin to think of an alternative model of teaching. As they continue to undergo conceptual changes, science educators should coach, support and guide them (MacKinnon, 1989). In addition, assignments, tests and exams should reflect conceptual change theories and methodologies. For example, in the researcher's science education methods class, during the first four weeks, the researcher modelled conceptual change instruction of a unit on mixtures. As one of the major assignments, the students were required to go through the process of eliciting students' prior ideas on a topic of their choice, and proposing curriculum materials and strategies bearing students' ideas in mind, and writing a mini-report. An example of one such report is "A Constructivist Approach to 'Floaters and Sinkers': What Do Children Think?" In science content courses, conceptual change strategies such as Vee diagrams that provide a visual representation of the interaction between the conceptual and the methodological sides were used extensively. In doing a lab activity, the student usually constructed two Vee diagrams. One was to examine their own conceptions. Then, after class discussions and further activities that challenged their ideas, they constructed another Vee diagram to represent their accommodation of the new learning. These were done in groups.

Also, science educators should help pre-service teachers to build a repertoire of
curriculum materials that will match with students' conceptions that have been found for various topics of study.

7.7 Recommendations for Further Research

Three major areas of study emerged from this study that would be useful for potential researchers:

- **A Study of the Effectiveness of Selected Activities and Strategies that would Promote Conceptual Change in Students about Solubility.**

Since the study in hand made the first probe in searching for content-based activities and strategies that would foster conceptual changes, such a topic could be considered as a continuation of this study. It requires the researcher to initially develop curriculum materials for a unit on solution chemistry bearing in mind students' prior conceptions from this study as well as from previous studies. Then examine the effectiveness of the strategies used by measuring conceptual changes through clinical-type interview. Since most teachers rely heavily on textbooks for teaching, such an effort can result in writing textbooks that would facilitate the incorporation of students' conceptions.

- **Issues in Following Conceptual Change Science Teaching in a Traditional Classroom**

Many issues surfaced as the teacher-researcher collaborators attempted to employ conceptual change science teaching. For example, cognitive and physical demands were experienced. An in-depth study of such issues will have implications for potential teachers and collaborative researchers.

- **Influence of Researcher Interventions for Teacher Development in a Teacher-Researcher Collaboration Study**
In the study in hand, the teacher and the researcher formally and informally talked about many issues with regard to teaching. Some examples: the researcher helped the teacher with re-thinking of the strategies that she used (how a mind map can be used for conceptual change in a student; extension of wait time), the lab work that was done on polar and non-polar solutes and solvents (emphasis on the understanding of content rather than procedures and skills), and the inclusion of questions for understanding rather than eliciting memorized facts. A study of the recommended type can indicate the impact of a researcher working with a teacher in the teacher's classroom to examine the practical problems arising with theoretical solutions, thereby promoting the concept of teacher and researcher working collaboratively and cooperatively on educational endeavours.
Bibliography


Bibliography


Bibliography


Appendix A

Letters of Consent

Researcher's Letter to Students

Dear Student,

With the permission of the School Board, I am doing a study on students' ideas about chemistry. Your ideas will be helpful to teachers to develop methods of teaching. The study is being conducted as part of my dissertation for the doctoral degree.

You will be interviewed individually at least twice at a time convenient to you. You will not be involved in the interview process for more than 30 minutes. The interview will consist of questions pertaining to your understanding of chemistry. I will be also observing your interaction with the teacher in the chemistry classroom. Your written work will be also examined.

Your responses will be kept confidential giving different names. Since this study is a study done by me as well as your teacher, your responses will be shared with the teacher as well as the persons conducting the study.

Your participation or non-participation in the study is voluntary. It will not affect your marks, class standing or access to any school programme. You may withdraw at any time from this study. Again this will not affect your grades, class standing, and access to school programmes.

Please indicate your consent, or refusal, to participate in the attached form. It would be helpful if you return the form as soon as possible. If you have any questions, you may contact me at . I appreciate your consideration of this request.

Jazlin V. Ebenezer
Graduate Student
Department of Mathematics and Science Education
University of British Columbia
STUDENT CONSENT FORM

I do/do not agree to help Jazlin Ebenezer in investigating "Students' Conceptions of Solution Chemistry: A Teacher-Researcher Collaborative Study" by offering myself as informant in a series of clinical interviews. I understand that my agreement or rejection will not in any way affect my status in classroom interaction or in academic assessment.

Signature __________________________________________

Date _______________________________________________
Dear Parent or Guardian,

With the permission of the School Board, I am eliciting students' conceptions of solubility. The information thus obtained may be helpful to teachers to develop instructional strategies. This study is being conducted as part of my dissertation for the doctoral degree. The title of the study is: Students' Conceptions of Solution Chemistry: A Teacher-Researcher Collaborative Study.

Participating students will be interviewed individually at least twice after school hours. However, no individual student will be involved in the interview process for more than 30 minutes. The interview protocol will consist of questions pertaining to students understanding of solution chemistry. I will be also observing teacher-student interaction in the chemistry classroom. As well, students' written work will be examined.

All student responses will be kept strictly confidential by arranging pseudonyms. Since this study is a collaborative study, student responses will be shared with the teacher as well as the persons conducting the study.

Participation or non-participation in the study is voluntary, and will not affect a student's marks (grades), class standing or access to any school programme. Students may withdraw at any time from this study, with similar assurances as to their grades, class standing, and access to school programmes.

Please indicate your consent or refusal to participate in the study in the space provided below. It would be helpful if you could return the form as soon as possible. If you have any questions, you may contact me at

I appreciate your consideration of this request.

Jazlin V. Ebenezer
Graduate Student
Mathematics and Science Education
University of British Columbia
PARENT CONSENT FORM

Student's Name: ____________________________________________

I DO/do not give permission for my child to take part in the study described above.

Signature of Parent or Guardian __________________________________

Date: ______________________ 1989
Appendix B

A Sample of a Complete Interview Transcript

System A: Sugar/Water

R: I have hot water here. I am going to add a cube of sugar. Could you tell me what is happening?
S: It is dissolving.
R: What do you mean by dissolving?
S: It's combining with water. It is mixing. It's not like it started out with the solid, but the molecules are all tightly packed together and when you mix it with the water, it mixes with water, something like that.
R: You said combining. What do you mean by combining?
S: Oh combining is they are not like two separate things. They are mixed up together. Like they are moving throughout the molecule.
R: What types of molecules are there?
S: Well molecules are molecules. They are all molecules. Even the water are molecules. The way they combine. They are not tightly packed together. So then that's a solid, right. Then when they are moving freely but not really becoming like a gas, really spaced out. It is in a different state.
R: How many different types of molecules are there in this system?
S: Well, there is oxygen, hydrogen and other stuff in the water like nitrogen. No oxygen and hydrogen. Then sugar. There is sodium chloride. But sugar, there are molecules in there like hydrogen I am not sure but different molecules.
R: When you said combining what do you understand by it? There is sugar. There is water. Do they combine to produce a new substance?
S: Well.
R: Or they don't produce any new substance? What ideas do you have?
S: It is a physical change. I guess, this is a new product. It has different qualities. No it is a chemical change. You can't get back the sugar to its original state. So it is like a chemical change. You create a new substance with new properties.

R: Could you illustrate with a diagram, how this combination has taken place? You have some kind of a picture?

S: Okay, sugar and the water.

R: How do you visualize? Maybe you have a model that comes to your mind when sugar and water are together. Nicki draws the picture and then she explains.

S: These are the water molecules. They are Mickey Mouse ones.

![Diagram of water and sugar](image)

S: These are the water molecules. They are Mickey Mouse ones. Hydrogen and the two oxygens like $H_2O$. I am not sure that could be like a clump of sugar. One molecule of sugar because it got all different elements in it. They are all just mixing together in the liquid state.

R: You remember, you said that they are combining together. In this picture, how would you show the combination? Or is there a combination between the two? Maybe this is what you mean by combination.

S: Well, they could form a new molecule but then it has to be like ions. They have to be like water has to give up something. I don’t know. I am not sure. I am sure they give or they share electrons. Some sort of transfer going on. Like ions positive and negative and they transfer.
Appendix B. A Sample of a Complete Interview Transcript

R: What does water and sugar form?
S: (pause) (laughs) sugar water.
R: Could you suggest a term that is used to describe what is happening?
S: (pause)
R: Can you give me another example?
S: It can be ionic bond. It can be ionic or covalent bond.
R: Now what happens when you put sugar in tea?
S: It melts. It doesn't melt. It dissolves because of the heat.
   I bet it melted when it was very hot. I am being inventive here.
R: That is how I want you to be.
S: You wanted me to explain.
R: I was wondering whether there was any other examples that you can
   give that are similar to this from daily life.
S: Oh, like you put bath crystals in the bath, sugar and coffee.
R: You think same thing is happening?
S: Yeah, I do. If you put sugar and cold water would it dissolve?
   I think it would dissolve, but it would dissolve faster because
   the molecules are moving out faster.

System B: Water/Alcohol/Paint Thinner

R: This is alcohol. What happens to the alcohol in water?
S: It mixed.
R: Why do you think alcohol mixed with water?
S: Because it mixes. Because its components are mixable with water.
R: I am going to add paint thinner into this. Can you explain to me
   what happened?
S: It did not mix.
R: Why do you think it did not mix?
S: Because it is lighter than the water and it floats and the
   components are not in the mixable form because paint thinner
   does not like water. Some things do and some things don't.
R: Why some things do and some things don't?
S: It is like molecules or components are composed in such a way
   that they are able to mix with the components of water.
System C: Salt/Water

R: *Could you describe what you see here?*
S: That is salt and water. Salt does not dissolve in water. Oh no, salt does. When you started with this, was the water hot or cold?
R: *It was hot.*
S: What happens is when you put the salt it melts. Then when it cools, the molecules cool down and they reform in the bottom. So that is just a physical change from a solid to a liquid. Then it came back to the solid and then because (long pause) I don't know why, I guess some of it escaped and they came down.
R: *Why do you think some of it escaped?*
S: I think it was melted. Well, it was a liquid, right. Now that it is cooling. It's all (did not complete) All the molecules are going crazy because they are hot and when they are cooling down, they are slowing down, I think. And when it is really hot some of them could evaporate, because they escape they move so fast. They get pushed away by all the other molecules. And they get out and cools off right away. They call it cool air.
R: *Do you think there is any salt in this part of the jar?*
S: No.
R: *You think all the salt has come down?*
S: I think it has gone back to the original state. Some of it out of the water. Some of it in the water.
R: *Is there anything happening between the water and the salt?*
S: Oh yes, there is water. The water molecules are moving around just like the solid. They are still moving but so tightly packed, not like moving freely.
Appendix C

Solution Chemistry Unit Objectives

CHEMISTRY 11

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X. SOLUTION CHEMISTRY</td>
<td>Students should be able to:</td>
</tr>
<tr>
<td>A. The Nature of Solutions</td>
<td>1. define a solution as a homogeneous mixture;</td>
</tr>
<tr>
<td></td>
<td>2. classify the solution phase as a system distinct from solid liquid and gas;</td>
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<tr>
<td>B. Types of Solutions</td>
<td>1. identify the several types of solutions according to the phases of the components of the solution;</td>
</tr>
<tr>
<td></td>
<td>2. identify the solute and the solvent as the components of a solution.</td>
</tr>
<tr>
<td>C. General Solubility Considerations (Polar and Non-polar Solvents)</td>
<td>1. describe the causes of molecular polarity;</td>
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<td></td>
<td>2. categorize H₂O and CCl₄ as polar or non-polar solvents;</td>
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<td>3. deduce from observations involving polar and non-polar solutes and solvents, that polar solvents tend to dissolve polar solutes and non-polar solvents tend to dissolve non-polar solutes;</td>
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<td></td>
<td>4. compare the prevalence of water as a solvent to the prevalence of other liquids.</td>
</tr>
<tr>
<td>D. Concentration of Solutions</td>
<td>1. give a general description of the term, &quot;concentration&quot;;</td>
</tr>
<tr>
<td></td>
<td>2. differentiate in terms of the relative amount of solute and solvent, between a dilute and a concentrated solution.</td>
</tr>
<tr>
<td>E. Saturated, Unsaturated Solutions</td>
<td>1. describe and compare a saturated and unsaturated solution;</td>
</tr>
<tr>
<td></td>
<td>2. describe how to determine the solubility of a particular solute in water.</td>
</tr>
</tbody>
</table>
Appendix C. Solution Chemistry Unit Objectives

<table>
<thead>
<tr>
<th>Text</th>
<th>Lab</th>
<th>Notes &amp; Supplemental Refs.</th>
<th>Video and Software Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Suggested Supplemental References for this topic are: 28, 30.</td>
<td>Molecular Spectroscopy</td>
</tr>
<tr>
<td>439</td>
<td></td>
<td></td>
<td>CH0044.RV Video 18 mm</td>
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<tr>
<td>440</td>
<td></td>
<td></td>
<td>MLA 1963. 23 min</td>
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<tr>
<td>440</td>
<td></td>
<td>The film covers infra-red light absorption and its relation to molecular properties.</td>
<td>Solutions</td>
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<td></td>
<td>CH0080.RV Video 4′</td>
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<td></td>
<td>CH0080.RU Video 4′</td>
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<td></td>
<td></td>
<td>The properties of a solution are investigated in this program. It shows several experiments including ones using filters and light beams to determine what a solution is and how it differs from a mixture.</td>
<td>BFA. 1969. 13 min</td>
</tr>
<tr>
<td>440</td>
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<td></td>
<td>Chemistry: Solutions (Ionic and Molecular)</td>
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<td></td>
<td></td>
<td>CH0040.RV Video 4′</td>
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<td>CH0040.RU Video 4′</td>
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<td>Solutions are an intimate part of our planet's life. We illustrate the chemical nature of a solution, what happens when it forms and the role of the electrostatic forces. Brownian movement is seen and saturation defined, and the concept of molarity presented along with an explanation of why some substances, like oil, won't dissolve in other substances, like water. CHEMISTRY Series.</td>
<td>COR. 1983. 23 min</td>
</tr>
<tr>
<td>355–357</td>
<td></td>
<td>• A simple definition for molecular polarity would be: &quot;A dipole results when electrons are displaced to one side of the molecule (as in H₂O).&quot;</td>
<td>&quot;Reaction Time&quot;</td>
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<td>Chemistry of Water</td>
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<td></td>
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<td></td>
<td>CH0032.RV Video 4′</td>
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<td>CH0032.RU Video 4′</td>
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<td>The program is designed to teach the properties of water, using the theory that water molecules are angular and bound to each other by hydrogen bonds. Evaporation and dissolution are explained and reactions of water are demonstrated.</td>
<td>CH0032.RV 16 mm</td>
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<td>CH0032.RU 16 mm</td>
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<tr>
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<td></td>
<td>Many of the physical and chemical properties of water are illustrated. The water's molecular structure is examined to help explain its unique properties.</td>
<td>BFA. 1973. 20 mm</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Physics and Chemistry of Water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lab: Polar and Non-polar Solutions and Solvents.</td>
<td>Suggested activity or demo.</td>
</tr>
<tr>
<td>444</td>
<td></td>
<td>Evaporate a known volume (and mass) of saturated solution to dryness or Calculate solubility using Fig. 16-8.</td>
<td>Solution Preparation</td>
</tr>
<tr>
<td>444–445</td>
<td>16a</td>
<td></td>
<td>CH00108.RV Video 4′</td>
</tr>
<tr>
<td>440</td>
<td></td>
<td>• Lab: Factors Affecting Solubility.</td>
<td>CH00108.RU Video 4′</td>
</tr>
<tr>
<td>440</td>
<td></td>
<td>Suggested activity or demo.</td>
<td>ITE. 19 min</td>
</tr>
<tr>
<td>440</td>
<td>16c</td>
<td>Evaporate a known volume (and mass) of saturated solution to dryness or Calculate solubility using Fig. 16-8.</td>
<td>Demonstrates the preparation of four different solutions and illustrates how to choose appropriate equipment and techniques. The film examines common pieces of volumetric equipment.</td>
</tr>
<tr>
<td>441</td>
<td></td>
<td></td>
<td>Spectrophotometric Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CH00107.RV Video 4′</td>
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<td></td>
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<td>CH00107.RU Video 4′</td>
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<td>The film clearly illustrates the use of a calibrated spectrophotometer to obtain a spectrum of absorbance vs. wavelength; a Beer's Law plot of absorbance vs. concentration, and the absorbance of an unknown sample at known wavelength.</td>
<td>ITE. 19 min</td>
</tr>
</tbody>
</table>

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### Appendix C. Solution Chemistry Unit Objectives

#### CHEMISTRY 11

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X. SOLUTION CHEMISTRY — (Continued)</td>
<td>Students should be able to:</td>
</tr>
<tr>
<td><strong>F. Molarity of Aqueous Solutions</strong></td>
<td>1. describe molarity (mol/L or M) as the preferred way to specify concentration in chemistry;</td>
</tr>
<tr>
<td></td>
<td>2. describe the necessary steps to prepare a solution of a given concentration;</td>
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<td>3. calculate the molarity of a solution when given the number of moles of solute dissolved in a given volume solution (mL or L);</td>
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<td>4. calculate the concentration of a solution given the volume of the solution and the mass of the solute;</td>
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<td>5. calculate the volume of a solution of known concentration which would contain a particular mass of solute;</td>
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<td>6. produce a given volume of working solution from a standard stock solution;</td>
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<td>7. calculate the resulting concentration when a given volume of a solution of known concentration is diluted with water to a given volume;</td>
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<tr>
<td></td>
<td>8. calculate the concentration of ions resulting when two solutions of known concentration and volume are mixed, assuming no reaction.</td>
</tr>
<tr>
<td><strong>G. Conductivity of Aqueous Solutions</strong></td>
<td>1. use laboratory observations to describe the relative conductivity of several solutes in aqueous solution;</td>
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<tr>
<td></td>
<td>2. summarize the results of a conductivity experiment as to the types of solute that conduct electricity when dissolved in water;</td>
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<td></td>
<td>3. propose a mechanism which explains the conductivity of soluble salts in water;</td>
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<td>4. outline the non-conducting behaviour of a salt in the solid phase;</td>
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<td>5. explain the existence of ions in an aqueous HCl solution;</td>
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<td>6. write dissociation or ionization equations for several substances that dissolve to give conducting solutions;</td>
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<td></td>
<td>7. calculate the concentration, in mol/L, of each ion in a salt solution, given the molarity of the solution (and all other required calculations described above);</td>
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<tr>
<td></td>
<td>8. calculate the concentration of ions resulting when two solutions of known concentration and volume are mixed (assuming no reaction).</td>
</tr>
</tbody>
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<tr>
<td>117-118</td>
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<tr>
<td>118-119</td>
<td>16b</td>
<td>• Lab: Preparation of a Standard Solution (Using a Spectrophotometer).</td>
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<tr>
<td>119-120</td>
<td></td>
<td>• See &quot;Chemistry &amp; Society&quot; p. 117.</td>
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<td>120</td>
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<tr>
<td>446</td>
<td></td>
<td>• Use an activity that requires students to dilute a known solution to produce a new solution of a lower specified concentration.</td>
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<td>446</td>
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<td>31-32</td>
<td></td>
<td>• An experiment or demonstration is recommended.</td>
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<tr>
<td>31-32</td>
<td></td>
<td>• Lab: Differences Between Ionic and Covalent Compounds (use the conductivity portion of the lab).</td>
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<td>32</td>
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<td>559-560</td>
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<tr>
<td><strong>X. SOLUTION CHEMISTRY</strong>&lt;br&gt;—<em>(Continued)</em></td>
<td>Students should be able to:</td>
</tr>
<tr>
<td><strong>H. Precipitation Reactions and Net Ionic Equations</strong></td>
<td>1. state that a precipitate may form when two ionic solutions are mixed;</td>
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<tr>
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<td>2. infer that the precipitate of such a reaction is a substance of low solubility;</td>
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<tr>
<td></td>
<td>3. predict the identity of the precipitate when two solutions are mixed, given a list of compounds of low solubility, and write the full ionic and balanced net ionic equations for the reaction.</td>
</tr>
<tr>
<td><strong>I. Arrhenius Acid-Base Chemistry</strong></td>
<td>1. gather qualitative data to identify the properties common to all acids (bases);</td>
</tr>
<tr>
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<td>2. write an operational definition of an acid (base);</td>
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<td>3. write a conceptual definition of an acid (base);</td>
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<td>4. relate acidic properties to the presence of H⁺ (aq) and basic properties to the presence of OH⁻ (aq) in solution;</td>
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<td>5. write equations to represent the formation of ions for several common strong acids and bases;</td>
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<tr>
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<td>6. determine the acidic/basic characters of many household substances.</td>
</tr>
<tr>
<td><strong>J. Acid-base Titrations</strong></td>
<td>1. predict the result when an acid and base are mixed;</td>
</tr>
<tr>
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<td>2. balance the formula and ionic equation of an acid-base reaction;</td>
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<td>3. describe how to perform an acid-base titration in order to determine the concentration of an acid or base (intended as a qualitative description);</td>
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<td>4. perform several titrations; e.g.,</td>
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<tr>
<td></td>
<td>—HCl with NaOH</td>
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<td>—determine the [CH₃COOH] in vinegar.</td>
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<tr>
<td>Text</td>
<td>Lab</td>
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<td>454</td>
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<td>454–455</td>
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<td>455–457</td>
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<td>16d</td>
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<td>13b</td>
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<td>560</td>
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<td>20c</td>
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<td>20c</td>
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</tbody>
</table>

"Experiments in Chemistry"

Use of a Pipet
CH00109, VH Video "b" CH00108, VU Video "a"
ITE, 14 min
Emphasizes correct techniques for using the volumetric or transfer pipet. The pipet and its markings are carefully examined and the steps involved in manipulating are thoroughly demonstrated.
Appendix D

Lesson Plans

Lesson 1

1989 11 01

Group Discussion

Task A

Think about the soft drink that you are drinking presently. What ideas come to your mind about the soft drink?

Task B

Describe what might be happening to the cube of sugar when you place it in a beaker containing hot water.
Lesson 2

1989 11 02

Solutions and Solution Process

Solutions

1. a brief review of students' ideas about solutions
   (a) characteristics of solutions
   (b) components of solutions—solute and solvent

2. examples of solutions in three states of matter—a handout

3. demonstration on colloids

4. examples of colloids—a handout

Incorporating Students' Conceptions of Solution Process

1. melting

2. turning into a liquid

3. combining? physically combining or chemically combining

"Melting" and "Turning into a Liquid"

Heat a cube of sugar in an evaporating dish. Allow the students to observe and have them express their ideas. Connect students' experience with the molten state of sugar to the solution process. Then place a watch glass on top. Heat it further. Allow the students to observe and have them express their ideas. What has happened to the sugar?

Combining

Show students the following "disappearing acts".
1. NaCl with water

2. sodium with water

3. zinc with dilute hydrochloric acid

What are students' understandings about these disappearing acts? Can they differentiate? If so, what are their explanations? What connection do they make from this experience to the sugar/water system?

Elaboration on Solution Process

1. conductivity (sodium chloride crystals, sodium chloride solution and sugar solution)—a handout—“water drill”

2. ionic representation of NaCl/water system

3. chemical representation of sodium and water, and zinc and hydrochloric acid

4. microscopic models—building of water molecule (Do students have ideas about polarity just by looking at the model? How can we represent the attraction between sodium chloride and water, and sugar and water? What are students' models? Explain scientists' model—solvation process

Structure of Knowledge

Vee diagram—sugar/water system

Teacher Expectations
Lesson 3

1989 11 06

1. Water: Universal Solvent?

2. Solutions/Colloids/Suspensions—visuals and handout

3. Vee Diagram—Characteristics of a Solution

4. Video—molecules and atoms

5. Reminder: Reflection Logs—one entry for each day we meet

## Appendix E

### Driver’s Instructional Model

<table>
<thead>
<tr>
<th>PHASE</th>
<th>PURPOSE</th>
<th>METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I ORIENTATION</td>
<td>Arouse interest and set the scene.</td>
<td>Practical activities of real problems to see how teacher demonstrates film clips, videos, newspaper cuttings.</td>
</tr>
<tr>
<td>II ELICITATION</td>
<td>To enable pupils and teachers to become aware of prior ideas.</td>
<td>Practical activities of small group discussion followed by reporting back.</td>
</tr>
</tbody>
</table>
| III RESTRUCTURING OF IDEAS | To create an awareness of an alternative viewpoint - the scientific one - to:  
  a) modify  
  b) extend  
  or c) replace with a more scientific view. | Small group discussion and reporting back. |
| (1) Clarification and exchange | Recognise alternative ideas and critically examine own. | Teacher demonstration of performing personal experiments, work. |
| (11) Exposure to conflict situations | Test validity of existing ideas.                                         | Discussion, reading, teacher input. |
| (111) Construction of new ideas | Modify, extend or replace existing ideas.                                      | Practical work, personal work, experimental teacher demonstration. |
| (1v) Evaluation | Test validity of newly constructed ideas.                                  | Personal writing, practical activity problem solving, project work. |
| IV APPLICATION OF IDEAS | Reinforcement of constructed ideas in familiar and novel situations. | Personal writing, discussion, personal diaries, reviewing posters etc. |
| V REVIEW       | Awareness of change of ideas and familiarisation with learning process to allow the pupils to reflect upon the extent to which their ideas have changed. | Personal writing, discussion, personal diaries, reviewing posters etc. |

**Figure 1**: Phases in the teaching schemes
Appendix G

Concept Attainment Lesson—Polar and Non-polar Compounds

1. Octane (gas)
2. Boron trichloride
3. Paradichlorobenzene (mothballs)
4. Carbon disulfide
5. Carbon dioxide
6. Carbon tetrachloride
7. Carbon tetrahydride
8. 2-propanone (paint thinner, acetone)
9. Iodine
10. Nitrogen trihydride
11. Glucose
12. Sucrose (sugar)
13. Propanetriol (glycerol, glycerin)
14. Citrate (citric acid)
15. Water
16. Sodium chloride
17. Hydrogen chloride
18. Potassium permanganate
A TRUE SOLUTION is a mixture (liq., solid, gaseous) in which the components are uniformly distributed throughout the mixture (homogeneous). The proportion of the constituents may be varied within certain limits.

1. The SOLUTE is the component of the solution which is considered to be dissolved in the other called the Solvent. It is present in the lesser quantity.

2. The SOLVENT is the component of the solution which is present in the larger amount.

3. SOLUBILITY is the amount of a solute which dissolves in a particular amount of solvent at a specified temperature. e.g., 100 g solvent

The Solubility of a solid increases with increase in temperature, while the Solubility of a gas decreases with increase in temperature.

5. A solution is SATURATED if it contains at given temp. as much of a solute as it can retain in the presence of an excess of that solute. That is, a solution that will not dissolve any more solute at that given temp. Any additional solute added will remain as Crystals.

6. A SUPER SATURATED SOLUTION is a solution with more dissolved solute than a saturated solution at the same temp. It is formed when a solution is cooled below the temp. at which there are no particles for the solute to crystallize around, so the "extra" solute remains dissolved. This solution is unstable if crystals are added or dust enters, the "extra" solute forms crystals and thus falls "out of solution".

Chap 16 - Solution Chemistry - In Review Reflection

Hydration Solution
Appendix G. Concept Attainment Lesson—Polar and Non-polar Compounds

SOLVATION is the process of solvent molecules interacting and combining with solute molecules as the solute dissolves. When the solvent is water, the process is called hydration. Whether or not solvation (dissolution, dissolving) occurs depends on how much the molecules of the solvent and solute attract each other.

POLAR SOLVENT (H₂O, alcohol) is a liquid with polar molecules and generally dissolve ionic compounds (Na⁺Cl⁻, K⁺MnO₄⁻) and polar covalent compounds (glucose, sucrose, glycerin). Solvation occurs because the charged ends of the solvent attract the ions of the ionic lattice (Na⁺Cl⁻ — see fig —) or the individual molecules of sucrose.

A NONPOLAR SOLVENT (paint thinner, acetone) is a liquid with nonpolar molecules and generally dissolve nonpolar covalent compounds (mothballs, PDB, CO₂, CC₁₄, I₂). The solute molecules are pulled from the "molecular lattice" by the solvent molecules and diffuse through the solvent. Many organic liquids are non-polar solvents.

An IONIC COMPOUND is a compound whose components are held together by ionic bonding. There is no electron sharing but electrons are transferred from the metal to the non-metal and thus cations (⁺) and anions (⁻) are formed in an "ionic lattice" ex Na⁺ Cl⁻. Ionic compounds have high melting & boiling points and in aqueous solution, they conduct electricity because the ions are moving through.

<Figure>
A COVALENT COMPOUND is a compound where the atoms share electrons so that each atom acquires a stable outer shell. Most covalent compounds are usually liquids or gases at room temp. Covalent compounds have low melting and boiling points and don't conduct electricity because there are no charged ions present.

A POLAR COVALENT MOLECULE shows unequal sharing of electrons between the atoms so that the electrons are nearer to one atom's nucleus than the other. This causes polarization or a dipole to occur.

ex. \( \text{H}_2\text{O} \)  

\[
\text{H} \quad \text{O} \quad \text{H}
\]

Recall: polar covalent solvents dissolve ionic compounds and other polar covalent cmpds "LIKE D Dissolves LIKE"

A NONPOLAR COVALENT MOLECULE shows polar bonds as well but due to symmetry around the molecule, the molecule acts like a nonpolar molecule although it's a polar molecule. Consequently it will not dissolve in a polar solvent but will dissolve in a nonpolar solvent.

ex. \( \text{CS}_2 \)  

\[
\text{S} \quad \text{C} \quad \text{S}
\]

Recall: nonpolar solvents dissolve nonpolar cmpds "LIKE Dissolves LIKE" caplyn tetra chattle propane propane...