Chapter 1 and references from: "**An inventory for measuring college students' level of misconceptions in first semester chemistry**," by Douglas R. Mulford. Master of Science Thesis submitted to Purdue University, 12/1997.

CHAPTER 1

INTRODUCTION AND REVIEW OF MISCONCEPTIONS LITERATURE

Over the past 20 years there have been many studies of students' understandings and misunderstandings with regards to science in general and to chemistry specifically. Many of these studies have found that students hold concepts which are different than those accepted as correct by the scientific community. These alternative views have been given several names including "alternative frameworks" (Driver & Easley, 1978), "children's science" (Osborne, Bell & Gilbert, 1983), and "misconceptions" (Griffiths & Preston, 1992). For the present study, the term misconception is used to encompass both those alternative conceptions that arise from formal intervention, such as classroom study, as well as those that are a result of students' own interactions with, and observations of, their environment (Pines & West, 1986).

In the constructivist theory of learning the learner's role is taken to be an active role, not a passive role. Learners base their understanding on their previous knowledge (Bodner, 1986). Von Glasserfeld (as quoted in Bodner, 1986) said:

> ...learners *construct* understanding. They do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world even in the absence of full or complete information.

Ausubel (as quoted in Bodner, 1986) indicated one of the most important results of the constructivist theory of learning for educators in the following quote:

> If I had to reduce all of educational psychology to just one principle I would say this: The most important single factor influencing learning is what the learner already knows.

In the constructivist theory of learning, it is the knowledge and experiences that students bring with them which have the greatest influence on their learning. Therefore, an understanding of the concepts students hold prior to instruction is of paramount importance for effective instruction.

In an attempt to develop an instrument that could be used to determine the level of conceptual understanding of large samples of college chemistry students, the present study was undertaken. The Chemical Concepts Inventory, a 22 question conceptually based inventory, has been developed for the purpose of probing the level of misconceptions present for a sample of college chemistry students. This thesis reports on the process of development of the inventory as well as the data that were obtained using the instrument.

The intent of the present study was to develop a chemistry concepts inventory which could be used to probe misconceptions related to first semester college general chemistry topics. This section reviews those areas of misconceptions which relate to the topics in the first semester of general chemistry at the college level.

Phase Changes

One area of chemistry in which several studies have been done to elucidate students' misconceptions is that of phase changes. Among the common misconceptions that have been found are that when water boils it breaks into its component hydrogen and oxygen molecules or atoms (Osborne & Cosgrove, 1983), that the bubbles in boiling water are composed of air (Osborne & Cosgrove, 1983) and that in the process of evaporation of water or alcohol, the water or alcohol either disappears or is changed into something new (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993).

In 1983 Osborne and Cosgrove used clinical interviews to study the conceptions of a relatively large sample of students ranging in age from 8- to 17-years to determine several misconceptions relating to the states of water and changes between those states. These misconceptions included the belief that the bubbles in a jug of boiling water were made of air, heat, or hydrogen and oxygen (p. 827-828). They also asked about the source of the water that condensed on a jar with blocks of ice in it. In addition to the accepted explanation, students also invoked such explanations as the water passed though the glass, the coldness came through the glass to produce water and, the coldness caused hydrogen and oxygen to combine forming water (p. 832-833).

To further determine the extent of these misconceptions, Osborne and Cosgrove constructed a multiple choice survey with students' responses from the interviews as alternatives. The survey was administered to students ranging in age from 12- to 17-years. The prevalence of some misconceptions, such as the bubbles in boiling water being formed of heat or the condensation on a jar of ice being due to water coming through the glass, did seem to decrease with increasing age of the subjects. However, over 60 percent of the 17-year-olds held misconceptions in regards to the boiling of water, and over 40 percent held misconceptions in regards to the condensation of water onto a jar of ice. Even graduate students in chemistry hold misconceptions in these areas. Bodner (1991) questioned incoming chemistry graduate students about boiling water and found several of the same misconceptions found by Osborne and Cosgrove.

Osborne and Cosgrove (1983) also found misconceptions about evaporation. When asked to explain where the water had gone that had evaporated from a dish sitting on a counter top, some students used explanations such as the water is absorbed by the dish, the water disappears, and the water changes into hydrogen and oxygen in the air in addition to the correct response. The survey results for this question indicated that by age 17 almost no students responded that the water was absorbed by the saucer or that it no longer existed. Almost 30 percent of 17-year-olds did, however, still indicated that the water was converted to oxygen and hydrogen in the air.

While studying a method for modifying student's conceptions about science, Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993) chose to probe five concept areas to determine the effectiveness of their modified teaching method. In one of these concept areas, changes of state, Lee *et al.* confirmed Osborne and Cosgrove's findings as well as discovered some addition misconceptions. Lee *et al.* found that while describing evaporation some students said that the water molecules actually turned into something else; for example, alcohol turned into air (p. 264). Lee *et al.* also found that students attributed macroscopic properties to atoms and molecules. For example, students said things such as "Molecules in ice are hard and frozen" (p. 265).

Abraham, Grzybowski, Renner and Marek (1992) looked at the understandings and misunderstandings of a sample of eighth grade students in regards to several concepts found in the students' textbooks. Abraham *et al.* described a situation in which a thermometer had been frozen into a block of ice that then was allowed to melt. Several diagrams were used to show the temperature changes over time. The students were asked to explain why there was no temperature change during the phase change. Only 2 percent of the students demonstrated clear understanding of this phenomenon. Thirty four percent of the students demonstrated distinct misconceptions on this subject and 64 percent either left the question blank or had no understanding.

Gable, Samuel, and Hunn (1987) also looked at phase changes, though with a sample of preservice elementary teachers. Gabel *et al.* asked the teachers to draw diagrams of the results of various physical and chemical changes. The researchers found that some preservice teachers had inaccurate ideas about the conservation of particles, the conservation of matter, the arrangement of particles with respect to each other in various states, and the expansion of atoms as they changed from liquids to gases.

Conservation

A second area of misconceptions that has been identified is that of conservation. Both Osborne and Cosgrove (as quoted in Bodner, 1991) and Bodner (1991) looked at the concept of conservation by asking students to predict the change, if any, in weight of iron after rusting. Osborne and Cosgrove asked this question of secondary students and found that many predicted that an iron nail would weigh less after rusting when the rust was included in the calculation of mass. Bodner found a similar result among graduate students in chemistry, finding that 10 percent of the students in his sample predicted that the weight of an iron bar would be less after rusting and another 6 percent predicted that the weight would remain the same.

In looking at the nature of gases and several aspects of conservation, Furio Mas, Perez, and Harris (1987) investigated 12- to 18-year-olds' conceptions by asking a series of conceptually based questions framed in real world examples. Of these students, 43 percent did not conserve substance, 74 percent did not conserve weight, and 69 percent did not conserve mass. The researchers did find that older students were able to correctly answer a higher number of questions, though they still had difficulties with conservation: 51 percent of the 17-18-year-olds did not conserve mass as opposed to 86 percent of the 12-13-year-olds. As in the studies by Osborne and Cosgrove and by Bodner, Furio *et al.* found that 55 percent of the students incorrectly predicted the results of the mass change for the oxidation of iron.

Abraham, Grzybowski, Renner and Marek (1992) looked at conservation of atoms using the rusting iron system, though in a different manner. In their study the students were asked to balance a chemical equation and then to use that balanced equation to predict the amount of one reactant needed given an amount of the other reactant. Only 1 student in 247 was able to correctly balance the equation and use it to predict the amount of a given reactant that was needed! Twenty-three percent of the students were rated as having misconceptions and the remaining were rated as having no understanding or left the question blank. One of the misconceptions involved was balancing chemical equations by changing the formulas of compounds.

BouJaoude (1992) classified high school students as rote learners or as meaningful learners. These students were asked the rusting nail question as well as two additional conservation questions. These additional questions asked students to predict the weight change 1) when matches suspended inside a tightly closed flask are lit, and 2) when steel wool burns. BouJaoude found that of those students classified as meaningful learners, 71 percent were able to correctly predict that the weight of the flask with the matches would remain the same. Only 50 percent correctly predicted the results before instruction. For rote learners, however, BouJaoude found that the number of correct responses actually decreased from 44 percent before instruction to 28 percent after instruction. For the burning steel wool question, the percentage of correct answers for the meaningful learners increased from 13 percent to 21 percent. The percentage of correct responses for the rote learners increased from 12 percent to 16 percent.

Basili and Sanford (1991) looked at different teaching strategies for encouraging conceptual change using conservation as one of their probes. By asking the question "When a match burns some of its matter is destroyed. Is this statement true or false? Explain your answer." Basili and Sanford were able to determine whether students believed matter was conserved. The results of this question are not directly reported in their study, but averaging over all of their questions concerning matter, Basili and Sanford found that 33 percent of the treatment group and 73 percent of the control group held misconceptions.

As mentioned above, Gable, Samuel, and Hunn found that preservice teachers demonstrated difficulties with conservation of matter.

Symbols, Equations, and Stoichiometry

Much research has been done on identifying misconceptions associated with stoichiometry. In 1985 Yarroch interviewed 14 high school students to discover how they balanced simple chemical equations as well as how they represented those equations in diagram form. All 14 of the students were able to successfully balance the chemical equations, which was not surprising given that the students selected for the interview were confident in their equation balancing abilities and had been described by their teacher as being in the upper third of the class. Of the 14 students, 12 students attempted to draw diagrams but only 5 of the diagrams were considered to be valid representations of the chemistry involved in the reactions. For students who incorrectly diagrammed the reactions, an additive view of chemical reactions was common. For example, $3H_2$ was represented as OOOOỌinstead oṭ OỌOỌOỌ and the chemical reaction

$$N_2 + 3H_2 \text{ ® } 2NH_3$$

was represented as

ÄẠ̈OOOOOỌ®̣ÄÄOOOOOO.

Several of the students who had difficulty diagramming the equations also showed a lack of understanding of subscripts and coefficients, often using the two interchangeably.

In 1990 Lythcott conducted an experiment similar to Yarroch's, also looking at high school students. In addition to being asked to answer questions about algorithmic stoichiometry questions, the students were asked to draw representations of a balanced chemical equation using labeled circles to represent atoms. Many of the students could successfully answer the algorithmic problems but they had very low understanding of the chemistry involved as measured by the drawing task. Many of the representation errors found by Lythcott mirror those found by Yarroch.

Nurrenbern and Pickering, in 1987, devised an innovative way to probe the conceptual understanding of college chemistry students. They developed a series of paired questions to examine the idea that students who could successfully complete traditional, algorithmic, questions might have low conceptual understanding. The first of a pair of questions was an algorithmic, mathematical problem that could be solved using plug-and-chug strategies. A second question matched the algorithmic question but was conceptual in nature and involved no mathematical calculation. Students were fairly successful answering the algorithmic questions, yet many had difficulty answering the conceptual questions.

The questions designed in the Nurrenbern and Pickering article have been used in several other research articles. Niaz and Robinson (1993) used the questions to probe the level of conceptual understanding of a sample of college chemistry students while looking at the roles of development level, mental capacity, and cognitive style as related to algorithmic problem solving versus conceptual understanding. Nakhleh (1993) also used the questions to classify students as high or low conceptual ability and high or low algorithmic ability. As did Nurrenbern and Pickering, Niaz and Robinson, and Nakhleh found that students had a much greater difficulty answering the conceptual questions of the pairs than the algorithmic questions.

Huddle and Pillay (1996) have recently conducted a thorough, algorithmic based investigation into the misconceptions held by students at a South African university. The university students were given the following problem:

If the mineral phosphorite ($Ca_3(PO_4)_2$) is heated to 650°C with sand (SiO_2) and coke (C) the products are calcium silicate ($CaSiO_{3(s)}$), carbon monoxide, and phosphorus ($P_{4(g)}$). Calculate the theoretical mass of P_4 produced if 6.2 kg phosphorite, 4.0 kg sand and 1.0 kg coke were heated in a furnace to 650°C (p. 67).

This question requires the students to balance an equation, determine the mole amount of each product, determine the limiting reagent, and calculate a theoretical yield. Only 38 percent of the students were able to successfully complete the question though 91 percent were able to balance the equation. Huddle and Pillay found two main misconceptions in regards to limiting reagent. First, some students believed that the lowest stoichiometry implied the limiting reagent; second, some students believed that the lowest molar amount was the limiting reagent, regardless of stoichiometry.

Macroscopic Versus Microscopic Properties

Ben-Zvi, Eylon, and Silberstein, in their 1986 article entitled "Is an atom of copper malleable?," looked at the problems many students have in differentiating macroscopic versus microscopic properties. Tenth grade students in Israel were presented with a list of three properties of a metallic wire and three properties of the gas resulting from the evaporation of the wire. The students were then asked to predict which of the six properties would remain the same for an individual atom obtained from the wire and which would remain the same for an individual atom from the gas. Forty six percent of the students did not make any distinction between the properties of the bulk and the properties of an individual atom. Further, 66 percent of the students explicitly stated that the single atom obtained from the solid would have different properties than the single atom obtained from the gas. These students were unable to distinguish those characteristics of the macroscopic realm from those of the microscopic realm.

Solutions

Lee *et al.* (1993) found that several middle school students held a destructive view of dissolving, using the term disappear synonymously with dissolve. In talking about sugar dissolving into water, one student was quoted as saying "It dissolves into nothing...It means it disappears" (p. 263). Some students also held a transmutation view of dissolving stating that "The sugar eventually becomes water" (p. 263). Several of the students also predicted that if sugar were added to water it would settle onto the bottom and not mix because sugar molecules are heavier than water molecules or because the sugar is in a solid form and the water is a liquid.

In an effort to probe the effectiveness of a modified teaching unit involving the collaboration of a researcher and an experienced teacher, Ebenezer and Gaskell (1995) looked at grade-11 and -12 students' conceptions of solutions. Ebenezer and Gaskell asked similar sugar/water questions as Lee *et al.* as well as questions about water/alcohol/paint thinner and salt/water systems. In the salt/water study, the students were shown a jar of water which had some solid salt recrystallized on the bottom of the container and were asked to describe what they felt had happened as well as to describe the solution over the salt. In an interview conducted after the implementation of a modified teaching unit, one of the students stated that the crystals in the bottom were likely due to recrystallization due to a lowering of the temperature of the solution. The student did imply that there was salt remaining in solution, but seemed to believe that for this to be the case, the solution part of the jar had to be at a higher temperature than at the bottom of the jar where the crystals were found.

Abraham *et al.* (1992) also studied the concept of dissolution. Students were asked what happens when salt is added to water, as well as to explain why sand does not dissolve in water. More of the students were able to answer this question than the phase change or conservation questions mentioned above with 32 percent of the students showing an understanding of dissolution. Thirty four percent had specific misconceptions and 34 percent showed little or no understanding. The misconceptions found were similar to those found by Lee *et al.* (1993) as well as by Ebenezer and Gaskell (1995). Abraham also reported the misconceptions that students invoked a phase change to explain dissolving saying that the sugar was changing from solid sugar to liquid sugar.

Size of the Atom

Griffiths and Preston (1992) conducted a study to determine the misconceptions present in a sample of grade-12 students regarding the characteristics of atoms and molecules. Misconceptions were found in students' ideas about the structure, composition, size, shape, weight, bonding, and energy of molecules as well as about the structure, shape, size, weight, and animism of atoms. Of these categories, misconceptions relating to the size of atoms are most pertinent to the present study. Many of the subjects responded that atoms were large enough to be seen under a microscope, and a few reported that atoms were larger than molecules. Several students held the belief that atoms could change size, most saying that heating an atom would cause it to expand. Another interesting finding was that over half of these grade-12 students believed atoms to be alive.

Other Areas of Misconceptions

Much work has been done in many other areas of misconceptions which are not directly related to those topics found in the first semester of a typical college chemistry course. This additional misconception research includes work done on the particulate nature of matter (Novick & Nussbaum, 1978), electrochemistry (Garnett & Treagust, 1992 and Garnett and Treagust, 1992), chemical equilibrium (Gussarsky & Gorodetsky, 1988, 1990, Banjeree, 1991 and Qu'lez-Pardo & Solaz-Portolés, 1995), the mole concept (Staver & Lumpe, 1995 & Yalçinalp, Geban, & Özkan, 1995) the geometry and polarity of molecules (Furio Mas & Calatayud, 1996), and chemical bonding (Peterson, Treagust & Garnett, 1989). For a more complete review of the chemical misconceptions research, refer to Pfundt and Duit (1994), Duit (1993), Nakhleh (1992) or The Handbook of Research on Science Teaching and Learning (Gable & Bunce, 1994).

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