ABSTRACT

FORBES, TONYA PAIGE. Alternative Conceptions Held by Community College Chemistry Students about Physical Properties and Processes: Density, Solubility, and Phase Changes. (Under the direction of Dr. John C. Park).

The purpose of this study was to determine what alternative conceptions about density, solubility, and phase changes are held by community college chemistry students and to determine if traditional lab activities aid in promoting conceptual understanding of these three topics. The setting for the study was a large community college in North Carolina. The subjects were 38 students enrolled in a college-level general chemistry course.

Students in the study were given a pre-test consisting of 10 multiple-choice questions and 10 definitions they were to provide. They then completed three lab activities, one per week for three weeks, and were post-tested in the sixth week. The post-test was identical to the pre-test except for the order of the questions. The multiple-choice items on the pre- and post-tests were compared using t-tests. Comparisons were done for each item, for each subjects area, and for the test overall. The pre- and post-test definitions provided by the students were compared and analyzed for trends. Finally, based on the responses to the multiple-choice items and the definitions, six students were selected to be interviewed for each subject area.

The community college students were found to hold similar alternative conceptions about density, solubility, and phase changes as those cited in literature for high school and college students. Links of alternative conceptions to the particulate nature of matter and use of language were noted. The traditional lab activities did not enhance the students’ conceptual understanding of the three subject areas.
Alternative Conceptions Held by Community College Chemistry Students about Physical Properties and Processes: Density, Solubility, and Phase Changes

by

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BIOGRAPHY

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. REVIEW OF THE LITERATURE</td>
<td>5</td>
</tr>
<tr>
<td>Knowledge Acquisition</td>
<td>5</td>
</tr>
<tr>
<td>Cognitive Development</td>
<td>5</td>
</tr>
<tr>
<td>Alternative Conceptions in Science</td>
<td>8</td>
</tr>
<tr>
<td>Alternative Conceptions in Chemistry</td>
<td>22</td>
</tr>
<tr>
<td>Addressing Alternative Conceptions in Chemistry</td>
<td>29</td>
</tr>
<tr>
<td>Summary</td>
<td>36</td>
</tr>
<tr>
<td>3. METHODOLOGY</td>
<td>38</td>
</tr>
<tr>
<td>Purpose</td>
<td>38</td>
</tr>
<tr>
<td>The Setting</td>
<td>38</td>
</tr>
<tr>
<td>The Population</td>
<td>40</td>
</tr>
<tr>
<td>Pilot Study – Subjects</td>
<td>41</td>
</tr>
<tr>
<td>Pilot Study – Instrument</td>
<td>41</td>
</tr>
<tr>
<td>The Instrument for the Study – Pre-test</td>
<td>42</td>
</tr>
<tr>
<td>The Subjects for the Study</td>
<td>43</td>
</tr>
<tr>
<td>The Laboratory Activities</td>
<td>44</td>
</tr>
<tr>
<td>The Post-test</td>
<td>46</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1. Number of Lab and Testing Participants .............................................. 51

Table 2. Breakdown of the Written Test Items by Topic and Response Type.......................................................... 52

Table 3. Means and Standard Deviations of Pre- and Post-test Scores for the Ten Multiple-choice Items .......................................................... 53

Table 4. Breakdown of Means and Standard Deviations on Multiple-choice Items by Topics .......................................................... 55

Table 5. Analysis of Number of Correct Answers by Item and Tests.............. 56

Table 6. Item Analysis of the Multiple-choice Test .............................................. 59

Table 7. Breakdown of Most Common Responses for Terms to be Defined..... 60

Table 8. Alternative Conceptions about the Density Concept from Interviews .......................................................................................... 68

Table 9. Alternative Conceptions about the Solubility Concept from Interviews......................................................................................... 72

Table 10. Alternative Conceptions about the Phase Change Concept from Interviews.......................................................................................... 75

Table 11. Alternative Conceptions about Particles from Interviews ................. 80

Table 12. Summary of Alternative Conceptions .................................................. 82
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1. Classification of Multiple-choice Test Items</td>
<td>52</td>
</tr>
<tr>
<td>Figure 2. Comparison of Pre- and Post-test scores by Individual Items</td>
<td>57</td>
</tr>
<tr>
<td>of the Multiple-choice Test</td>
<td></td>
</tr>
<tr>
<td>Figure 3. Density Question about Compressed Air</td>
<td>66</td>
</tr>
<tr>
<td>Figure 4. Solubility Question about the Dilution of Sugar Water</td>
<td>70</td>
</tr>
<tr>
<td>Figure 5. Phase Change Question about the Composition of Bubbles in</td>
<td>73</td>
</tr>
<tr>
<td>Boiling Water</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

Educators agree that the prior conceptions held by students are critical to their learning (Bodner, 1986). A large body of literature reveals a known set of alternative conceptions in the sciences. Databases of students’ alternative conceptions are available for many subject areas, including biology, chemistry, and physics. Many alternative conceptions have been found to be universal; that is, the same alternative conceptions occur consistently across diverse populations regardless of age, ability, or nationality of students. Furthermore, these alternative conceptions are remarkably resistant to change using conventional teaching methods (Wandersee et al, 1994).

Multiple and varied sources of alternative conceptions held by students have been identified. Such sources include parallels from history, use of intuitive rules, prior experience, use of language, and even instruction (Osborne & Wittrock, 1985; Stavy et al, 2002; Wandersee et al, 1994).

Since effective teaching requires that students’ alternative conceptions be directly addressed, it is important to identify the alternative conceptions held by one’s students. In addition to using the databases in the literature, several other methods have been used in this effort, including multiple choice assessment tests, questionnaires, interviews, and concept mapping. Once a teacher is aware of the alternative conceptions held by his students, he can use teaching strategies that encourage conceptual change (Tobin et al, 1994).
Students at all levels have been found to hold alternative conceptions about almost all areas of chemistry. These alternative conceptions persist after instruction. Even graduate students in chemistry have been found to retain alternative conceptions.

While it may not be surprising that students have difficulty with complex concepts such as moles, stoichiometry, and thermodynamics, it might be somewhat surprising that alternative conceptions about such basic concepts as density, solubility, phase changes, and states of matter also abound. Many alternative conceptions in chemistry may be related to a fundamental lack of understanding of the nature of matter (Gabel & Bunce, 1994).

The concept of density poses a problem for students even at the college level. Most students view density as simply the mathematical operation of \( d = \frac{m}{V} \), thus making it an abstract concept. This concept of density requires no understanding of the denseness with which particles are packed (Hawkes, 2004).

Several common misconceptions about phase changes have been noted in the literature. Concepts such as evaporation and condensation are very difficult for students to understand. Often, phase changes are viewed as chemical changes, as when students identify the bubbles in boiling water as \( \text{H}_2 \) and \( \text{O}_2 \). This misconception was identified even in chemistry students at the graduate level (Bodner, 1991). Students also attribute changes in matter to the particles themselves rather than attributing the change to particle motion and arrangement (Kikas, 1996).

Student’s conceptions about solubility are prevalent at the college level also. The terminology used by students to describe what happens when a substance dissolves reveals the confusion. The substance might be described as “melting away” or “disappearing” (Lee et
Some students view dissolving as a chemical change, as they suggest that a new substance is formed (Nieswandt, 2001). Few students are able to describe the process of dissolving at the molecular level (Lee et al, 1993).

_Laboratory Instruction in Chemistry_

In the sciences, laboratory activities have been proposed as a teaching strategy that will help students to undergo conceptual change. Labs can be used to expose alternative conceptions held by students (Sheiland, 1999). However, there is inconsistent data on whether traditional lab activities aid in promoting conceptual change. Traditional labs have been criticized for not promoting or developing higher order thinking (Hilosky et al, 1998). Most traditional lab activities are “cookbook” experiments for which students do not understand a clear purpose. Students do not grasp the relationship between the design of the experiment and its purpose, not do they have time to reflect on the main ideas, as they are consumed with the details and technical aspects of the activity (Hofstein & Lunetta, 2004; Johnstone, 1991). Despite the criticisms, a meta-analysis comparison of traditional and non-traditional lab activities in chemistry showed no difference in cognitive learning for the two methods. An additional study showed no significant difference between instructional styles in the lab in terms of student achievement on post-tests (Domin, 1999).

_The Research Question_

The present study seeks 1) to determine what alternative conceptions about density, solubility, and phase changes are held by community college chemistry students and 2) to examine whether traditional laboratory activities aid in promoting change in students’ conceptual understanding of these topics.
A pre-test with ten multiple-choice items and ten terms to be defined by the students was administered at the first meeting of the lab class. After completing three weeks of traditional lab activities focusing on physical properties and processes, including density, solubility, and phase changes, a post-test was administered. The post-test was identical to the pre-test except for the order of the questions and the multiple-choice responses. The pre- and post-tests were analyzed to determine if there was any change in the students’ conceptions and some students were identified to be interviewed for further clarification about how they were thinking about the concepts. The interviews were transcribed and analyzed to identify common alternative conceptions in each concept area, and to determine if any general ideas emerged about how students think about the concepts.
Chapter 2

**REVIEW OF THE LITERATURE**

*Knowledge Acquisition*

For centuries, philosophers have been interested in the nature of knowledge. Traditional learning theories were based in an epistemology of empiricism, which holds that all knowledge comes from experience. Further, experience provides evidence for and is linked to beliefs by a set of logical rules. It is seen as a matter of accumulating experiences and making generalizations from them. Learning is viewed as an additive process (Strike & Posner, 1985).

The more recent epistemology of conceptual change views learning as a transformative process. New ideas aren’t simply added to old ones; rather, the new and old interact and an adjustment occurs. Thus, knowledge is acquired from interactions between experience and current conceptions when a discrepancy occurs—when the learner’s current conception is inadequate to solve a problem (Strike & Posner, 1982).

The important difference between these two epistemologies is in how the learner’s current conceptions are viewed. Empiricism places no importance on current conceptions, while the conceptual change theory sees current conceptions as a critical factor in one’s learning (Strike & Posner, 1982).

*Cognitive Development*

Many theories of cognitive development can be viewed as being epistemological rather than psychological. These theories address the question of how knowledge is acquired rather than being concerned primarily with central organizing processes. The more notable of
the cognitive development theories recognize the learner’s prior conceptions as part of the basis for acquiring new knowledge (Bodner, 1986).

Jean Piaget’s theory of cognitive development is well known. The theory recognizes four stages of human development: the sensor-motor stage, the preoperational stage, the concrete-operational stage, and the formal-operational stage. Piaget further suggested that learners construct knowledge by organizing their experiences in terms of existing mental structures and within the constraints of the learner’s developmental stage (Bodner, 1986). Piaget proposed that learning is accomplished by two processes that he called assimilation and accommodation. Assimilation occurs by using a pre-existing structure to interpret sensory data. Accommodation occurs when those existing structures are modified to fit newly assimilated data (Bodner, 1986).

David Ausabel’s theory of meaningful learning states that learning occurs when the learner’s existing knowledge interacts with new knowledge. In order for learning to be meaningful, the learner has to make sense of new information (Taber, 2001). If there is no prior concept with which to connect the new information, new concept structures must be built. Otherwise, any learning that occurs is simply rote and has no meaning (Tsarpalis, 1997). Simply stated, Ausabel’s theory is that “The single most important factor influencing learning is what the learner already knows” (Bodner, 1986).

Lev Vygotsky explored the relationship of culture and language to learning. Vygotsky pointed out that learning has both internal and external aspects. Learning requires negotiation of meaning and is dependent on the learner’s external environment (or culture) as well as internal processing of information (Barba, 1995). Knowledge and understanding are constructed when individuals engage socially in talk and activity about shared problems or
tasks (Driver, et al, 1994). Thus, social processes allow for the learning of language and language makes thought possible.

Donald Norman’s works are typical of cognitive psychologists who subscribe to an information processing model of knowledge acquisition. This model draws an analogy between learning and memory and the workings of a computer. Accretion is the addition of new knowledge to existing conceptual frameworks. This occurs via experiential or sensory processes. Structuring involves the building of new conceptual frameworks (Barba, 1995). It occurs when new information that has entered into the working memory via accretion is processed into the long-term memory (Tsarpalis, 1997). Structuring or learning cannot occur without an existing conceptual framework on which to build.

Human Constructivism, a theory put forth by Joseph Novak, encompasses both a theory of learning and an epistemology of knowledge building. Novak’s work is based on that of Ausabel and on cognitive development theories similar to those of Piaget (Mintzes & Wandersee, 1997; Wandersee, 1986). Constructivists hold that individuals construct meanings by forming connections between new concepts and those that are part of an existing framework of prior knowledge. Further, constructivists assert that scientists and students come to know things in much the same way; that there is no qualitative difference in the way that people learn. However, no two people will construct precisely the same meaning when presented with the same objects or events, since their prior knowledge affects their perception (Mintzes & Wandersee, 1997).

The recognition that prior conceptions are significant in the learning process has important implications for teachers. No student comes to class as a blank slate; all students come instead with their own sets of prior conceptions.
Students’ conceptions are often inconsistent with the science conceptions they are expected to learn. Various terms have been proposed for these inconsistent prior conceptions that students bring to class: alternative frameworks (Driver & Easley, 1978), misconceptions (Helm, 1980, cited in Gilbert & Watts, 1983), preconceptions (Novak, 1977), children’s science (Gilbert, et al, 1982, cited in Glibert and Watts, 1983), everyday conceptions (Nieswandt, 2001), and alternative conceptions (Hewson, 1981; Driver & Easley, 1983), among others. Researchers have expended some effort in determining which of these terms is most appropriate. For example, “misconceptions” is seen as having a negative connotation. Use of this term suggests a view that students’ prior conceptions are barriers to learning (Abimbola, 1988; Clements, 1993). Furthermore, Dykstra, et al (cited in Klaasen & Lijnse, 1996) note that “These alternative conceptions manifest themselves as useful commonsense beliefs about the world.” Thijs & Van Den Berg (1995) make a case for “alternative conceptions” over “frameworks,” noting that “alternative frameworks,” are defined as being consistently used across a variety of contexts. Alternative conceptions, particularly for secondary or younger students, are not used in a manner that is consistent enough to justify the term “alternative frameworks.” Thijs & Van Den Berg (1995) also differentiate between preconceptions and alternative conceptions. Preconceptions are those conceptions that the learner holds before instruction, while alternative conceptions are those that are inconsistent with accepted scientific conceptions even after instruction (Thijs & Van Den Berg, 1995). Abimbola (1988) also prefers “alternative conceptions,” contrasting it with “mistakes” and preferring it to “alternative frameworks.” He argues that a mistake, unlike an alternative conception, is easily corrected through instruction. Defining “framework” as a
basic structure of ideas—more the organization of the ideas than the ideas themselves—he suggests that

‘frameworks’ has limited application as a descriptor for student conceptions. The term is useful when it is possible to group student conceptions under, say “Aristotelian physics” or “Lamarckian evolution.” What happens when the topic is human respiration? Unlike the physical sciences, in biology, it is usually not easy to group student conceptions under a system of laws and theories. (Abimbola, 1988, p. 181).

The term of preference for many researchers seems to be “alternative conception,” as noted above and by Wandersee et al (1994, p. 178):

Not only does it [the term “alternative conception”] refer to experience-based explanations constructed by a learner to make a range of natural phenomena and objects intelligible, but it also confers intellectual respect on the learner who holds these ideas—because it implies that alternative conceptions are contextually valid and rational and can lead to even more fruitful conceptions (eg. science conceptions).

*Universality of Alternative Conceptions*

Education research literature has revealed a number of alternative conceptions held by science students. Many of these alternative conceptions are universal; they occur with “remarkable consistency across diverse populations, irrespective of age, ability, or nationality” (Champagne, Gunstone, Klopfer, 1983, p. 173 In Wandersee, et al, 1994).

Alternative conceptions within specific domains such as biology, chemistry, and physics follow “conceptual trajectories” that are common across different cultures and educational systems (Garnett et al, 1995). Most researchers believe that the set of common alternative conceptions within a given science domain is relatively small (Wandersee, et al, 1994).
Resistance to Change

Students’ alternative conceptions are “tenacious” and often resistant to change, especially via conventional teaching methods (Nussbaum & Novick, 1982; Wandersee et al, 1994). In fact, the resistance is such that high school and even college students are consistently found to hold the same alternative conceptions as children (Gabel & Bunce, 1994).

Why are they resistant to change? Using Piaget’s terms, a student might assimilate new information into his existing, *alternative*, framework. If the new knowledge “fits” into this existing framework, no cognitive dissonance will occur, and thus accommodation will not be necessary for this student (Taber, 2001). Using an Ausabelian argument brings one to the same conclusion. Ausabel’s theory says that in order for meaningful learning to take place, the student must place new information into an existing cognitive structure and make connections. If new information is not viewed as being relevant to any existing knowledge, no learning will occur. Further, if the prior knowledge held by the student is inaccurate, new knowledge may simply be anchored to an alternative framework. In either case, no learning occurs (Taber, 2001). Even when students reach acceptable understanding of a concept within the context of the classroom, they have great difficulty extending their knowledge into the real world (Bodner, 1991). In fact, school science tends to be isolated from real-life experience (Wu, 2003). The result is several different and distinct sets of science knowledge, used as applicable in different settings (Osborne & Witrock, 1985). Often, after instruction, students will adopt the scientific concept without abandoning their alternative conception. For example, high school students in a study were identified as attributing bulk properties to atoms and molecules. Thus, rather than viewing the arrangement and motion of atoms and
molecules as determining the properties and behavior of a substance, the students attributed the behavior and properties of a substance to the atoms and molecules. An atom of copper, for example, would be viewed as being malleable and reddish-brown in color (Ben-Zvi, et al 1986). They simply added the conception of the particulate nature of matter to their concept of matter as continuous instead of replacing the continuous model with the particulate model (Nakhleh, 1992). As Bodner (1986) asserts, “Knowledge is not the same as understanding.”

Sources of Alternative Conceptions

Where do students’ conceptions originate? If, after instruction, a student retains or develops an alternative conception, how does that occur? A number of sources have been proposed.

Intuitive Rules.

Stavy et al (2002) have observed that students intuitively react in similar ways to a variety of scientific tasks in mathematics, physics, chemistry, and biology. Students’ responses to three types of tasks were determined to be governed by “Intuitive Rules.” These rules are (a) More A- More B, (b) Same A- Same B, and (c) Everything can be Divided Endlessly. The first two rules deal with comparison tasks, while the third relates to repeated division tasks. Data collected on western students as well as Taiwanese, Aboriginal Australians, and Israeli students suggest that students across cultures are affected by these rules, which are activated by external task features. The students were given a variety of tasks that differed in regard to the content area and type of reasoning required but which shared common features. For example, to test the More A- More B rule, students might be asked, “Is the size of a muscle cell of a mouse larger then/equal to/smaller than/ the muscle cell of an elephant?” Most students will incorrectly argue that the mouse muscle cell is
smaller than the elephant’s since mice are smaller than elephants. Or, if students were told
that Tom saves 15% of his salary and Mary saves 20% of hers, they might claim that Mary
saves more money than Tom since 20% is larger than 15%.

The Same A-Same B rule was tested in a like manner. Students were told that John
and Donna each save 10% of his/her salary. Students will argue that John and Donna save
equal amounts of money. When asked if differently-shaped bacterial cells with the same
volume have different resistance to dryness, students tend to respond that the cells are
equally resistant to dryness since their volumes are equal.

Finally, to test the Endless Divisibility rule, students were asked if a line segment
could be divided endlessly. They were asked the same question about a piece of copper wire.
Most students aged 15 and up incorrectly agreed that both a line segment and a piece of wire
were infinitely divisible.

Stavy et al (2002) propose that these three rules are universal and therefore affect all
science students’ conceptions.

Experience.

A learner’s first science conceptions stem from experience and how that experience is
interpreted. Out of accumulated experiences, simple explanations or generalized models to
explain natural phenomena are constructed (Harrison & Treagust, 1996). In other words,
learners generate meaning from experience (Osborne & Wittrock, 1983). Students have
“invented ideas” about science based on their sensory impressions, and these ideas influence
how the student responds to and understands scientific concepts when presented in the
classroom (Driver & Erickson, 1983). This is true across a wide variety of domains in
biology, chemistry, physics, and mathematics, (Chinn & Brewer, 1993; Driver & Erickson,
A well-documented example has to do with the relationship of force and motion. Everyday observations suggest that an object will continue to move only if a force is continuously applied. This conflicts with the orthodox physics view that an object at motion will continue to move with the same velocity until a force acts upon it to stop it. The orthodox view is well–established, yet students of all ages from grade school through graduate school, and even some teachers cling to their experiential concept (Taber, 2001). Osborne & Wittrock (1985) refer to the intuitive ideas generated by learners as “Gut Science,” and note that children in particular, because of their self-centeredness, their human-centered point of view, everyday use of language, and their limited experience, are likely to develop ideas that are very different from those of scientists. For instance, even after instruction in which they are told that the world is round, children will cling to their preinstructional, experiential belief that the earth is flat. They simply see the earth as disc-shaped (Chinn & Brewer, 1993).

**Historical Parallels.**

A number of authors, including Piaget in 1962, have noted the similarity of students’ conceptions at different levels of education with historical scientific conceptions (Thijs & Van Den Berg, 1995). Piaget based further work on this premise, arguing that

The fundamental hypothesis of genetic epistemology is that there is a parallelism between progress made in the logical and rational organization of knowledge and the corresponding psychological processes (Wandersee, et al., 1994, p. 186). Such parallels have been noted especially in physics, particularly in the areas of force and motion, where the rules of the belief system used by college students can be seen to align with those of Aristotle. Fewer studies have examined the historical parallels in biology and
even fewer in chemistry. Nevertheless, biology students’ views about living organisms and the changes they undergo are similar to those of Lamarckian evolutionists, while chemistry students are known to hold conceptions of the nature of gases that are consistent with those held by Aristotle (Bunce & Gabel, 1994; Wandersee, et al 1994).

Conceptual change theorists suggest that an understanding of conceptual change within the science community might thus provide a guide for the study of conceptual change in science students (Abimbola, 1988). For instance, in a statement that illustrates how a student learning physics might parallel the discoveries of the great physicists, Strike and Posner suggest that

the history and philosophy of science has light to shed on learning. Not every student in a Newton or an Einstein, but every serious student, like every great scientist, is faced with reorganizing old beliefs in the light of new ideas (Strike & Posner, 1992, p. 232).

This statement highlights the belief that, for all learners, new ideas or discoveries must interact with and affect the content and organization of existing concepts. The learner isn’t “simply adding or subtracting inventory pieces in his conceptual warehouse” (Strike & Posner, 1992).

Language.

How language is used and the use of science terms in everyday language affects every learner’s conceptions. If, as the constructivists assert, the goal of education is shared meaning (Mintzes & Wandersee, 1997), then it is important to note that students and teachers/scientists do not use language in the same way. “The issue of language is difficult and complex. Students use language which is meaningful to students; teachers use language
which is meaningful to teachers” (Klaassen & Lijnse, 1996, p. 121). Language creates different mental pictures for different people, so educators must be careful to use words and expressions that are precise and unambiguous (Garnett, et al 1995). To quote Francis Bacon, “the ill and unfit choice of words wonderfully obstructs the understanding” (Wandersee, et al, 1994, p. 178). Before formal instruction has occurred, students develop conceptions for many words used in science (Watts & Gilbert, 1983). These conceptions are often in conflict with accepted scientific conceptions. For example, students base their notion of force on intuitive rules such as (a) If a body is not moving, there is no force acting on it; (b) If a body is moving, there is a force acting on it in the direction of its motion; and (c) Static objects do not exert force. These alternative conceptions pose a distinct difficulty when a teacher introduces the Newtonian concept of force. Clearly, the term “force” has a very different meaning for the student and the teacher. The teacher’s concept is contradictory to the students’ prior experience. This presents an obstacle to the students’ acceptance of the scientific explanation (Klaassen & Lijnse, 1996). Further, because the “energy” is connected to “force” in everyday language, students often use the terms synonymously (Kikas, 2004; Watts & Gilbert, 1983).

Students across three different cultures and language groups were found to have a conception of matter that is inconsistent with the scientific idea (Solomonidou & Stavridou, 2000). Chemical substances were qualified in terms of what they are used for in everyday life rather than in terms of what the substances were. Materials were viewed as objects instead of as substances (Solomonidou & Stavridou, 2000). Another related example is the term “particle.” In everyday language, a particle is a very small solid piece of matter. The
scientific use of the term for atoms and molecules is quite different (Kikas, 2004). These everyday conceptions impact students’ ideas about the property and transformation of matter.

The use of metaphors and analogies to explain scientific ideas can also be problematic. A metaphor is a statement that two things are the same when in fact they are not; an analogy is a statement that two things bear the same relationship to each other (Beall, 1999). Both can be effective in transferring information from a known domain into a new domain (Kikas, 2004). However, a metaphor can be taken too literally, and an analogy taken too far, leading to confusion and misconceptions (Beall, 1999; Kikas, 2004).

Examples of commonly used metaphors include the idea of electron “clouds,” which provides a mental image of literal clouds of electrons; radioactive “decay,” which implies that the nucleus was once alive and is now dead; and the statement in the Kinetic Molecular Theory that gas molecules bounce off of one another and the walls of the container, which implies that gas molecules are round balls (Beall, 1999).

A common analogy used by students and teachers explains the reason for seasonal changes by suggesting that temperature differences in summer and winter are caused by the difference in distance between the earth and the sun at different times of the year. This analogy derives from everyday experience with heat sources (Kikas, 2004).

Clearly, in order to learn science, “students must appropriate their use of language and reconstruct meanings for terms that are commonly used in cultural and linguistic practices outside of school” (Wu, 2003, p. 872). Students’ use of scientific language is not a guarantee of understanding. Their use of such language may simply mask alternative conceptions. Students often adopt terms and use scientific language as a “veneer” without
substantially changing their conceptions (Lee et al, 1993). Being able to give a name for a phenomenon substitutes for deeper understanding (Taber, 1996).

**Instruction: Teachers and textbooks.**

Aspects of classroom instruction have been implicated in the development of students’ alternative conceptions. Nearly 90% of teachers use a textbook 90% of the time (Abimbola & Baba, 1996). Both teachers and the textbooks they use can introduce alternative conceptions (Muthukrishna et al, 1993; Wandersee, et al, 1994). American high school biology teachers rely heavily on textbooks, yet the three biology texts used most often in American high schools have been identified as potential sources of alternative conceptions in genetics. Problems were identified in areas of content sequencing, establishment of conceptual relationships, use of terminology, and introduction of mathematical elements. Fifteen alternative conceptions frequently held by biology students are often perpetuated by teachers or textbooks (Wandersee, et al, 1994).

American textbooks in general overload students with a vast array of unrelated, poorly communicated concepts. They have been described as “encyclopedic,” or as “compendiums of topics,” none of which are covered in any depth (Muthukrishna, 1993). Furthermore, the way in which the material is presented may lead to confusion. Diagrams and models may not be drawn to scale and may over-simplify the concepts they are intended to clarify. If not properly constructed, such tools may give rise to alternative conceptions. For example, many texts use a diagram showing the earth’s orbit as elliptical and stretched out to demonstrate the angle of the earth’s axis toward the orbit. This diagram is often misinterpreted (Kikas, 2004). Sources of conceptual confusion due to diagrams and models have been noted in chemistry texts as well (Wandersee, et al, 1994).
It is probable that teachers inadvertently pass on alternative conceptions to their students. This is particularly true for concepts that students could not have derived experientially. An example of this is how atoms interact. There is nothing in a student’s experience to suggest anything about the movement or behavior of atoms. Therefore, it is likely that alternative conceptions originate in instruction (Taber, 2001). Primary and even secondary school teachers have fragmentary knowledge about the subjects they teach (Kikas, 2004). Teachers’ alternative conceptions may persist because of poorly written college textbooks or poorly taught college courses. Studies on teachers’ conceptions have highlighted alternative conceptions in areas such as conservation of matter, Newtonian mechanics, light and optical phenomena, and electrical circuits, among others (Wandersee, et al, 1994). Improper interpretation of terminology may contribute to teachers’ alternative conceptions. Teachers, like students, may confuse scientific and everyday meanings for terms such as “particle,” and “force,” for instance (Kikas, 2004). Further, terms that were once meaningful in the context of accepted theory at the time they were proposed are still used although the theory is no longer accepted. Examples of this are “heat capacity” and “heat flow.” Often, complex ideas are simplified by teachers to help students learn a concept for the first time. Students remember the simplification instead of the more explicit and correct concept (Bodner, 1991).

Identification of Alternative Conceptions

It has been asserted that prior or alternative conceptions influence how and what students learn. There is abundant evidence that instruction will do little to alter student conceptions unless they are directly addressed (Minstrell & Smith, 1983; Taber, 1996; Tobin et al, 1994). It is therefore important to identify the alternative conceptions that students
bring with them. If a teacher determines which alternative conceptions are present among his students, he can choose an instructional sequence designed to develop a more acceptable understanding (Wandersee, 1986). Several methods have been used to reveal students’ conceptions. As a first step, teachers might search the literature. A large database of alternative conceptions exists, and there may be an assessment tool readily available (Libarkin, 2001).

A carefully designed multiple-choice test can be used to catalog students’ alternative conceptions. Choices should include options that coincide with commonly-held alternative conceptions. Requiring students to supply reasons for their choices can help to indicate the strength of the student’s belief in their conception. Free response questions can be used to supplement and clarify responses to the multiple choice questions (Wandersee, 1986; Birk & Kurtz, 1999; Libarkin, 2001).

Kikas (2004) used a questionnaire to elicit student and teacher conceptions about velocity and force, seasons, and freezing. Respondents were presented with statements and asked to rate the correlation to accepted scientific theory on a Likert-type scale. Targeted questionnaires can be developed for most concepts (Libarkin, 2001). Interviews have been successfully used; indeed, Piaget, who some view as the originator of the conceptual change movement, is also credited with designing the clinical interview (Posner & Gertzog, 1982). Others have revised or refined the technique to reveal their students’ alternative conceptions (Gilbert & Watts, 1985; Posner & Gertzog, 1982; Renstrom, et al, 1990; Sanger, 2000). If properly conducted, an interview can help toascertain the nature and extent of one’s knowledge about a concept. Interviews help to identify conceptions and perceived relationships between concepts (Posner & Gertzog, 1982).
Concept maps have also been used to aid instructors in gaining insight into the way their students view a scientific concept. They are especially useful for showing how students organize knowledge into a conceptual framework (Libarkin, 2001).

**Addressing Alternative Conceptions**

Once the students’ alternative conceptions are identified, the teacher must determine the best method for changing those conceptions to match accepted scientific ideas. By what process does conceptual change occur? Posner et al (1982) recognize two types of conceptual change: The use of existing ideas to deal with new phenomena is called assimilation, while the replacement or reorganization of central concepts is called accommodation. Accommodation is a more radical change and is thus more difficult to effect. Several conditions must be met before accommodation takes place. First, there must be dissatisfaction with existing concepts. The learner’s existing conceptions must be inadequate to solve new problems or address anomalies that the learner has encountered. The new conception must also be intelligible; that is, the learner must be able to see how experience can be structured by the new concept. Plausibility of the new concept is also important. The learner must see that the new concept has the ability to solve problems that were not solvable using the prior concept. The concept must be consistent with other knowledge and theories. Finally, a new concept must suggest opportunities for further inquiry (Hewson & Hewson, 1983; Posner et al, 1982; Tobin et al, 1994).

What teaching strategies are likely to encourage conceptual change? Several general ideas have emerged.

Lessons that create cognitive conflict have been found to promote conceptual change in students. This type of lesson might include lectures, demonstrations, problems, or lab
exercises. The key is to design lessons that will help students to experience anomalies or observe discrepant events (Posner et al, 1982; Wu, 2003; Klaassen & Lijnse, 1996).

Teachers may choose to make students aware of the alternative conceptions they hold. This can be done by exposing the students’ alternative conceptions and comparing them with accepted scientific conceptions (Gonzalez-Espada, 2003). A study in which instruction for an experimental group focused on students’ alternative conceptions showed a significant gain in scientific conceptions of density, mass, and volume. The gain in scientific conceptions was accompanied by a significant reduction in alternative conceptions. The control group in this study exhibited neither gains in scientific conceptions nor reduction in alternative conceptions. Instructional strategies for the experimental group and the control group incorporated classroom discussion and experimentation (Hewson & Hewson, 1983).

Because it can generate in-depth descriptions, classroom discussion can also help to air alternative interpretations. Student-initiated discourse reveals alternative conceptions and provides a context on which to build meanings. Science is made meaningful by linking it to real-world situations (Wu, 2003).

Wandersee (1986) suggests sharing alternative conceptions of early scientists with students. This is particularly effective if the early scientists’ conceptions match those of the students.

Use of a bridging analogy, an intermediate example that helps to bridge the gaps between an idea for which students hold an alternative conception and one for which they have an accepted scientific conception. For example, physics students have difficulty accepting that the force of a hand on a spring and that of a book on a table are similar. Resting a book on a flexible board serves as a bridging analogy. It may be easier for students
to make the connection from case A (hand on spring) to case B (book on flexible board) to case C (book on table) than to go directly from case A to case C (Clement, 1993).

It may be beneficial to help students see why they should alter their definitions of scientific terms that are used differently in everyday life. Inducing in students a need to have terms available that have precise scientific meaning can aid students in changing their conceptions. An example of this is the force concept referenced above. If the student’s definition of force does not apply to the book on the table example, it is necessary for the student to acquire a new definition of the term “force” before conceptual change can be completely effected (Klaassen & Lijnse, 1996).

The bottom line is that teachers must view learning in terms of understanding. To that end, teaching strategies that enhance a view of science concepts as useful and connected must be employed (Tobin et al, 1994).

Alternative Conceptions in Chemistry

Literature reveals a variety of alternative conceptions held by students from elementary school through the beginning of graduate school. Chemistry students at the college level retain naïve conceptions about a multitude of chemistry concepts. The list of areas for which alternative conceptions appear in students seems exhaustive (Birk & Kurtz, 1999; Garnett et al, 1995; Nakhleh, 1992; Nicoll, 2003; Taber, 1996; Wandersee et al, 1994). It includes, perhaps not surprisingly, complex concepts such as moles, (Gable & Bunce, 1994; Wandersee et al, 1994); balancing equations, chemical and net ionic reactions, stoichiometry (Bodner, 1991; Gable & Bunce, 1994; Garnett et al, 1995; Johnstone, 1980), acids and bases (Gable & Bunce, 1994; Garnett et al, 1995; Wandersee et al, 1994), chemical equilibrium (Hewson, 1986; Johnstone, 1980; Nakhleh, 1992; Wandersee et al, 1994) thermodynamics
(Bodner, 1991; Garnett, et al, 1995; Johnstone, 1980; Lee et al, 1993; Mulford & Robinson, 2002), and bonding, including polarity of bonds and molecules, intermolecular forces, molecular shapes, organic structures and the octet rule (Birk & Kurtz, 1999; Johnstone, 1980; Nakhleh, 1992; Nicoll, 2003). However, significant numbers of students also harbor alternative conceptions about more basic chemistry concepts such as mass, weight, volume, density, states of matter and phase changes (Arons, 1997; Bodner, 1991; Gable & Bunce, 1994; Hawkes, 2004; Hewson, 1986; Lee et al, 1993), conservation of matter (Bodner, 1991; Lee et al 1993), volume displacement, solutions, gas laws, and the nature of matter (Gabel & Bunce, 1994; Gable et al, 1987; Nieswandt, 2001; Taber, 1996; Wandersee, et al, 1994).

**The Particulate Nature of Matter**

It is the last concept that might be at the root of alternative conceptions for many of the other topics. Findings consistently report that students have great difficulty explaining the nature of substances and observable changes to them (Lee et al, 1993). Literature suggests that students who have an understanding of the particulate nature of matter have better understanding of chemistry concepts (Gabel, 1993). Indeed, most of the alternative conceptions held by student from grade school through graduate school can be linked to a weak understanding of the nature of matter (Nakhleh, 1992). Many properties of matter, including chemical and physical changes can be explained in terms of the arrangement and motion of particles (Lee et al, 1993; Nakhleh, 1992). Yet in several studies, students failed to use the particle concept to explain physical or chemical changes. Students persist in using general, macroscopic explanations even when cued to use particle behavior (Gabel & Bunce, 1994). For example, upon observing the heating of copper metal and the formation of black copper (II) oxide, students are apt to say, “The copper has turned black,” suggesting that
properties of substances can change without any real change to the substance (Nieswandt, 2001).

Most students do not have an accurate interpretation of matter or even of the term “particle.” In everyday use, the term “particle” refers to something solid, whereas in chemistry, the term is used to denote atoms and molecules. It is logical then, that many students think of atoms and molecules as tiny solids. Even after completing a chemistry course, students do not have an acceptable notion of matter as particulate and dynamic. In one study, over 60% of students beyond junior high school did not picture empty space between the particles of a gas (Novick & Nussbaum, 1981). Students view matter as continuous and static (Nakhleh, 1992). Students often think of molecules being in substances rather than viewing substances as being composed of molecules. Often, atoms or molecules are viewed as being embedded in a substance. For example, air is seen as having air between air molecules; water is seen as having water between water molecules (Lee et al, 1993; Nieswandt, 2001; Resstrorn et al, 1990). Even students who have completed instruction about gases and who accept that gases are made up of particles reject the notion that there is empty space between the particles or that the particles are in motion (Lee et al, 1993; Nakhleh, 1992; Novick & Nussbaum, 1981). Students also have great difficulty conceptualizing the size of molecules. They are described as being similar in size to dust particles or germs (Lee et al, 1993; Nakhleh, 1992).

A poor conception of the particulate nature of matter leads to difficulties in understanding such complex concepts as balancing equations, as students do not see that a balanced chemical equation represents a rearrangement of atoms (de Vos et al, 1994; Nakhleh, 1992). This problem follows through to other concepts: net ionic equations,
stoichiometry, equilibrium, molarity and solutions, among others (Gabel & Bunce, 1994; Johnstone, 1980).

However, an understanding of even the most basic concepts in chemistry, such as states of matter, density, solubility, and phase changes, require an understanding of the particulate nature of matter. Multiple studies in education research literature show that students at all levels experience difficulty understanding even these fundamental concepts.

*States of matter.*

Students’ explanations of the different states of matter display almost exclusively macroscopic interpretations. Rarely are substances described at the molecular level. The majority of high school students do not exhibit a thorough understanding of the different phases of matter. No mention is made of particles nor are terms from kinetic theory used to describe the differences between different states of matter (Stavy, et al, 1985). Solids are described as hard and heavy; liquids as wet and runny; and gases as invisible and light. A number of students view gases as having no weight (Lee et al, 1993; Nahkleh, 1992). When asked on a post-test about the change in mass when a sealed tube of iodine is heated to vaporization, 24% of freshman chemistry students indicated that the weight of the gas would be less. Most of them reasoned that a gas weighs less than a solid (Mulford & Robinson, 2002). Observable, macroscopic properties are attributed to the molecules of a substance (Ben-Zvi et al, 1986; Lee at al, 1993). Lee at al (1993) provide some student quotes to illustrate:

“Molecules are frozen in ice, because they are solid together.”

“The ice is cold…the ice molecules would be colder that the ones in water.”

(p. 261).
Other macroscopic properties attributed to atoms and molecules are color, odor, and conductivity, among others. Students might claim that one atom of a gas is compressible. Some students attribute different states of matter to differences in the particles that make up substances. An atom of the gas phase of a given substance is thought to be larger than an atom of the solid phase of the same substance (Ben-Zvi et al, 1986). In addition to thinking that particle sizes change with state, most students have incorrect ideas about the relative spacing of particles in different states (Gabel & Bunce, 1994; Nieswandt, 2001).

Density.

Several studies have highlighted the alternative conceptions about mass, volume, and density held by high school students. Many students lack a scientific conception of volume. Thus, relatively few students can articulate a scientific definition of density (Arons, 1997; Hawkes, 2004; Hewson, 1986; Hewson & Hewson, 1983). Hawkes (2004) notes that density is a formal concept, yet only half of students are formal reasoners. They cannot intuitively see the relationship of mass to volume. The lack of understanding of mass, volume, and density is also linked to a weak understanding of the particulate nature of matter (Gabel & Bunce, 1994).

Arons (1997) reports that even students at the engineering physics level do not have an acceptable understanding of the concept of volume; many have no operational definition of the term and confuse it with “area”, using both to mean “size.” Some students do not differentiate between mass and volume. Others do not differentiate between mass and density (Hewson & Hewson, 1983). These difficulties, combined with the inability to use ratio reasoning and algebraic reasoning, clearly contribute to alternative conceptions about density. A belief that density is simply the result of dividing mass by volume makes the
concept an abstraction; it requires no understanding of the *denseness* with which mass is packed. Simply requiring students to do problems using the formula \( d = \frac{m}{V} \) does not help students make meaning of the concept. Numerical values for the density of substance do not have meaning for many students, although these same students may be able to solve problems using the formula. Students who view density as simply an arithmetic operation are not using a particulate conception of matter. They miss such key ideas as (a) the more closely packed atoms are, the higher the density will be; (b) density does not depend on size or shape; (c) density increases upon compression (Hawkes, 2004). Indeed, most students offer macroscopic explanations of compression, suggesting that gases can be compressed because they are light. Liquids cannot be compressed because they are harder or heavier than air. They [liquids] take up more room than gases because there is more “stuff” in a liquid (Lee et al, 1993). Further, students do not apply the idea of particle motion to describe the distribution of particles when a gas is compressed. Indeed, many students do not recognize that particles are uniformly distributed (Novick & Nussbaum, 1981).

*Phase Changes.*

Students’ conceptions about matter extend to phase changes. Many freshman level chemistry students incorrectly believe that water dissociates to hydrogen and oxygen upon evaporation. Similar responses were found when students were asked to identify the source of the bubbles in boiling water. Fewer than half correctly identified the bubbles as water vapor. The most common response was that the bubbles were made of hydrogen and oxygen gas. This belief—that water decomposes into hydrogen and oxygen upon boiling— is consistent with the alternative conception that hydrogen and oxygen from the air combine to form water during condensation. Another viewpoint commonly expressed is that the bubbles
observed in boiling water are air (Bodner, 1991; Mulford & Robinson, 2002; Osborne & Cosgrove, 1993).

Students use scientific terms such as evaporation and condensation without any real understanding of those processes (Nakhleh, 1992; Osborne & Cosgrove, 1983). Students are often unable to explain where water from condensation originates. Many suggest that water that condenses on the exterior of a glass has somehow come through the glass. The idea of water vapor in the air seems difficult to grasp, perhaps because it is invisible (Lee et al, 1993; Mulford & Robinson, 2002; Osborne & Cosgrove, 1983). There is a lack of understanding of conservation of matter upon phase changes. Students describe evaporation of water by saying “It disappeared.” Or, they might exhibit the belief that a chemical change has occurred: the water “turns into air” (Lee et al, 1993).

Another pervasive misconception among students is that particles (molecules) melt when a solid melts or that particles expand when a substance is heated (Kikas, 2004; Taber, 1996). Thermal expansion is explained as a result of molecules getting bigger (Ben-Ziv et al, 1986; Nahkleh, 1992). Interestingly, when students do discuss particle motion, they more often attribute a change in particle motion to heating than they do to cooling (Novick & Nussbaum, 1981).

**Solubility.**

Students’ conceptions about solubility can also be inaccurate. Students do not grasp the conservation of matter upon dissolving. Again, they tend to use terms such as “disappears.” They also use terms such as “melted away,” which displays a confusion of the types of physical changes that matter can undergo (Lee et al, 1993). In a study of undergraduate chemistry students, fewer than one-third indicated that the concentration of a
saturated solution stays the same as the water evaporates. Many students believed that there would be the same amount of salt, albeit in less water. Oddly, a question asked about adding water to a solution of sugar in water yielded a correct response rate of 78%. Similarly, only 75% of students knew that the mass of the solution formed by adding one pound of salt to twenty pounds of water would be twenty-one pounds (Mulford & Robinson, 2002). An additional alternative conception is the view that dissolving is a chemical change. Students often think of a solution as a new substance (Nieswandt, 2001). Lee et al (1993) found that almost no students in their study were able to give a molecular explanation of dissolving.

**Addressing Alternative Conceptions in Chemistry**

As previously discussed, a general strategy for instruction is to have students evaluate new ideas by comparing them with ideas the students already hold to be true. New concepts must fit the learner’s conceptual framework; they must make sense to the learner and they must solve problems or answer questions that the old ideas did not. New concepts must allow for further investigation. Simply stated, new conceptions must be intelligible, plausible, and fruitful. (Hewson & Hewson, 1983; Mintzes & Wandersee, 1997; Rickey & Stacy, 2000; Tobin et al, 1994). To induce conceptual change, it is necessary to expose the students’ alternative conceptions. One way to do this is to use an “exposing event” followed by a teacher-guided discussion. An exposing event is a phenomenon that is carefully selected for its ability to evoke a student’s preconceptions about a scientific idea. Once the students are aware of their alternative conceptions, the instructor can induce conceptual conflict, or disequilibrium, by using a “discrepant event,” an event that creates disharmony between the exposed preconception and an observed phenomenon which the student cannot explain using the prior conception. Finally, instructors must encourage conceptual change. As students
begin to accommodate the new conception, they should be encouraged to articulate and elaborate their new ideas (Nussbaum & Novick, 1982; Taber, 1996; Tobin et al, 1994).

A specific strategy for chemistry is to make connections between macroscopic observations and molecular explanations (Rickey & Stacy, 2000). A discussion of three commonly suggested instructional strategies to be used by chemistry teachers follows.

*Problem-Solving.*

One focus of chemistry instruction has been to teach students how to be successful problem solvers (Gabel, 1999). While this is a valid goal of instruction, too often teachers rely on algorithmic methods of problem solving. The lack of focus on conceptual understanding creates barriers to student learning (Duchovic, 1998).

Many students are able to solve problems algorithmically without having an acceptable understanding of these concepts (Arons, 1997; Mason et al, 1997; Nahkleh & Mitchell, 1993; Sanger, 2000; Sawrey, 1990). This is particularly true for novice chemistry students who are usually much more successful at solving algorithmic problems than problems that are conceptually based. Conversely, it is the rare student who lacks the ability to solve algorithmic problems while possessing conceptual understanding (Mason, et al. 1997). Further, teaching students to solve problems algorithmically does not ensure conceptual understanding. Students can be trained to manipulate complex formulas to work problems without displaying any understanding of the fundamental principles involved in the problems (Niaz & Robinson, 1992; Rickey & Stacy, 2000). Many chemistry concepts are very abstract; learning new concepts requires a link in the long-term memory to which the new concept can be related (Gabel, 1999). Algorithmic problem solving methods do not provide the links needed to enhance understanding of new concepts. Nahkleh (1992) found
that college freshman were unable to move from algebraic knowledge of gas laws to a particulate model of gases. In the same study, 68% of the students could successfully solve stoichiometry problems, while only 11% could answer conceptual questions on the topic. Hawkes (2004) has noted that most students can solve density problems using \( d = \frac{m}{V} \), but few have a good understanding of the concept of density.

Students who rely on algorithmic methods to solve problems are often using a method that is no more sophisticated than trial and error. While it is true that perhaps most of the problems presented to introductory chemistry students can be solved algorithmically, students rely on algorithmic methods when they are not needed or even appropriate. Furthermore, algorithmic methods often take longer than conceptual methods, since students simply begin “plugging in” to algorithmic methods when presented with problems, then discover that the algorithm is unnecessary. Even students who are high conceptual learners tend to rely on algorithmic methods; it is possible that they do not trust their conceptual understanding of chemistry or that their understanding is incomplete (Nakhleh & Mitchell, 1993). These findings highlight the need for chemistry instructors to teach conceptually.

If students are taught to solve problems only by using algorithms, they will not be forced to recognize their own alternative conceptions. They will not experience cognitive conflict and will thus not experience the need for conceptual change (Nussbaum & Novick, 1982).

*Teaching the Particulate Nature of Matter.*

As previously, discussed, the particulate nature of matter is associated with many concepts in chemistry. Indeed, four of the seven fundamental physical variables (space, time,
mass, and electrical charge) are described using particle behavior (de Vos & ver Donk, 1996). However, nothing about the properties of particles is self-evident. Students have no mental models for particulate phenomena since it cannot be observed (Gabel & Samuels, 1987; Nicoll, 2003). Furthermore, in most chemistry courses, instruction about the particulate nature of matter is insufficient to help students achieve a high level of understanding of such fundamental chemistry concepts as solids, liquids, gases, elements, compounds, and mixtures (Gabel & Samuels, 1987).

Increased instructional emphasis on the particulate nature of matter might bring about better problem-solving ability and make chemistry more understandable by providing a framework for the discipline. Concepts must be adequately understood in order for students to solve problems correctly (Gabel & Samuels, 1987).

Several studies suggest that chemistry instruction should begin with an introduction of atoms and molecules as the basic structural units—without introducing electrons, valence shells, the periodic table, bonding, etc. Educators must help students begin to understand the differences in these fundamental particles (Gabel, 1993; Nakhleh, 1992; Sanger, 2000; Tsarpalis, 1997) and that the molecule is “the smallest bit of matter that retains certain (but not all) properties of a pure substance” (Tsarpalis, 1997, p.923). Students’ failure to distinguish between the macroscopic and molecular world causes confusion about very basic terms in chemistry such as atoms, elements, compounds, and molecules. This confusion is evident in quotes included in a study by Taber (1996). These quotes are from students who have completed a full year of chemistry.

“One carbon atom breaks down due to heat” (p. 43). 

“When sugar is placed in hot water, the sugar molecules break down or melt” (p.43).

“Metallic molecules are shiny’ (p.45).

Since particles cannot be observed, emphasizing the particulate level requires instructional emphasis of either the symbolic or the macroscopic mode at the same time. Stressing the particulate nature of matter therefore helps to integrate chemical knowledge at all three levels in which chemistry in taught and understood (Gabel, 1993). Sanger’s (2000) study that demonstrated that students are better able to answer conceptual questions if they are taught with an emphasis on the particulate nature of matter and using particulate drawings to illustrate concepts.

Without an understanding of the behavior of particles, chemical interactions are not viewed as dynamic, and students try to learn concepts by rote. Nakhleh (1992) perhaps says it most succinctly: “If you can’t explain it in molecular terms, you don’t really understand it.” (p.195).

Laboratory Instruction.

Laboratory activities have been touted as a way to help students actively construct knowledge through experience. If labs are well-designed, students will be engaged directly with materials and phenomena from which they can make observations and draw conclusions. Working in the lab allows students the opportunity to work cooperatively as they investigate scientific phenomena and relationships. Cooperative learning has been linked to student achievement, and the social aspect of labs allows for “reflexive discourse.” Students can learn together how to solve problems and develop understanding of scientific
principles (Hofstein & Lunetta, 2004). Labs can be used to expose alternative conceptions and to make subject matter relevant (Sheiland, 1999).

However, there is insufficient research to determine which type of laboratory instruction or activities might promote conceptual understanding in chemistry students (Gabel, 1999). Four types of labs have been identified by Domin (1999). The terms “Discovery” and “Inquiry” are often used as synonyms. However, the two differ with respect to the procedure and the outcome of instruction. Labs in which students generate questions and are then guided by a teacher to a desired outcome are Discovery labs. Inquiry labs have an undetermined outcome and require students to come up with a procedure. Both types are inductive. The other two types of labs are deductive. Problem-based labs center around a problem designed by the instructor. Expository lab instruction is the traditional and also the most criticized type of lab activity in United States schools. These types of labs are often called “verification” or “cookbook” labs. The instructor defines the topic to be investigated and directs the students. The outcome is known and results are compared to expected results. Students are not involved in planning the investigation, nor is there generally an emphasis on interpretation of results.

For nonbiological sciences such as chemistry, physics, and geology, one meta-analysis comparison between traditional and nontraditional lab methods showed significant improvement in cognitive learning when nontraditional methods were used. However, when chemistry was examined by itself, no difference in cognitive learning was discerned. In two other studies that were not part of the meta-analysis, there was no significant difference between instructional styles in terms of student achievement on post-tests (Domin, 1999).
Traditional labs have been criticized for the lack of emphasis on thinking and for not promoting conceptual change (Domin, 1999). These labs are not designed to promote or develop higher order thinking (Hilosky et al, 1998). To be effective, labs must increase cognitive demand on students. A number of strategies have been proposed to increase the learning potential of labs for chemistry students. Having students predict results and explain their predictions before completing a lab exercise can help to expose the students’ alternative conceptions. The social component of lab work—group discussions, explanations, forming hypotheses together—can be used to promote reflection (Sheiland, 1999). Asking students to suggest some applications for an experiment can help to make the material relevant. Students can be challenged to higher order thinking by having them analyze and interpret their results in a broader context (Duchovic, 1998; Sheiland, 1999).

The effectiveness of labs is decreased by several factors inherent in the way experiments are generally run. Because most traditional labs are of the “cookbook” variety, students do not have clear idea about the purpose of the experiments. The perception held by many students is that the purpose is following instructions or getting the correct answer. The detail and quantity of information in most lab books distracts from the main goals. Further, since students have very little, if any, experience designing experiments, they do not see the relationship between the design of the experiment and its purpose. They fail to note discrepancies between their work and others, including results expected from the scientific perspective. Students working in the lab usually do not have time to reflect on central ideas in science because they are too involved in the technical aspect of the activity. Students are easily overwhelmed by too many instructions and observations. New skills must be learned while the experiment is being conducted (Hofstein & Lunetta, 2004; Johnstone, 1991). The
lab becomes about “manipulating equipment but not manipulating ideas” (Hofstein & Lunetta, 2004).

To help students connect the purpose of the experiment to the procedure, Sheiland (1999) recommends having the students identify relevant variables before proceeding with an experiment. In lieu of designing their own experiment, asking students to summarize a prepared experiment will help them to determine the main ideas. To get them to think critically about the experiment design, instructors might have students design their own data tables, suggest possible sources of error, and propose modifications to the experiment. These kind of pre-lab activities help to organize student thinking. (Johnstone & Letter, 1991; Sheiland, 1999). Follow up discussions with teachers are needed to help students negotiate and interpret meaning (Hofstein & Lunetta, 2004).

Labs may be an effective instructional strategy if they are well-designed. Cognitive conflict can be induced by lab activities and teachers can help students toward accommodation of accepted scientific conceptions (Hofstein & Lunetta, 2004). The teachers’ role is important, as the move from a student’s alternative conceptions to the complex understandings of the scientific community is difficult. Chemistry students are, after all, expected to make molecular interpretations from macroscopic observations (Gabel, 1999).

Summary

The conceptions held by students prior to instruction have an influence on how and what they learn. Students’ prior conceptions are often inconsistent with accepted scientific conceptions, and are thus termed “alternative conceptions.” These alternative conceptions have been found to be universal and to be resistant to change via traditional teaching methods. Multiple sources have been suggested for the alternative conceptions held by
students. Among the sources are intuitive rules, past experiences, parallels to historical
theories, use of language, and even prior instruction.

It is important for teachers to identify the alternative conceptions held by their
students, because effective teaching requires directly addressing the alternative conceptions.
A number of methods for identifying them have been documented in education literature
including using carefully designed multiple-choice tests, questionnaires, interviews, and
concept mapping.

Instructional strategies that promote conceptual change are those that introduce
cognitive conflict. Classroom discussion, use of bridging analogies, and encouraging students
to see the need to use precise scientific language have been used successfully.

Chemistry students, like students in other disciplines, hold a variety of alternative
conceptions, many of which appear to be linked to a lack of understanding of the particulate
nature of matter. Even the term “particle” is problematic for chemistry students. Students
have misconceptions about very basic concepts in chemistry such as states of matter, density,
phase changes, and solubility. One method that has been suggested to help chemistry
students change their alternative conceptions about these and other topics is the use of
laboratory activities.

This study was done to determine which alternative conceptions about density,
solubility and phase changes are held by community college chemistry students and to
determine if traditional laboratory activities aid in changing those alternative conceptions to
accepted scientific conceptions.
Chapter 3

METHODOLOGY

Purpose

The purpose of this study was to 1) determine the alternative conceptions held by community college students regarding density, solubility, and phase changes; and 2) to see if standard introductory chemistry laboratory activities aid in changing the alternative conceptions to those of accepted scientific ideas. To accomplish this, an assessment instrument was constructed from previously published assessments and from new items generated by the researcher. The assessment instrument was pilot tested with a group of community college students to determine if modifications were needed. In the next semester, another group of students were chosen for the investigation using the modified instrument. These students were pre-tested at the beginning of the semester and were post-tested after completing laboratory experiments that focused on physical properties, including density, solubility, and phase changes. The pre- and post-test results were evaluated, and students who consistently had difficulty with the concepts were selected for interviews. The interviews were conducted to gain better understanding of the students’ ideas about the concepts.

The Setting

The setting for the study was a large community college in North Carolina. This college has an annual enrollment of 58,000 full-time and part-time students. The college has many program areas, including vocation and technical, continuing education, and curriculum education. This study was conducted using curriculum education students. Curriculum Education is divided into several divisions: Health Sciences (two-year programs in Nursing,
Radiography, Dental Hygiene, etc); Engineering Technology (two-year programs in Pharmaceutical Technology, Environmental Technology, etc.); Computer Information Systems (two-year degrees in Computer Information Technologies); Academic Support (a division that serves students who are planning to enter curriculum programs but who do not have the necessary math and language skills); Arts, Humanities, and Social Sciences (Associate in Arts degree); and Mathematics and Sciences (Associate in Science degree). For the 2003-2004 academic year, the enrollment for curriculum education programs was approximately 11,000 students. The college subscribes to an open-door policy, which means that no one is denied entrance, and there is no cost for admission. Tuition for classes is very low compared to public universities in the state. Each student that is admitted takes placement tests in math, reading, and writing to determine proper placement in classes. Students who need remediation with math and language skills must complete a series of precurriculum courses before enrolling in their program courses. Of the students who enter the college with the intent to pursue the Associate in Arts (A.A.) or Associate in Science (A.S.) degree, approximately 50% require math remediation, while 33% require English remediation. Students who are pursuing either of these two degrees are considered to be in the College/University Transfer Program. These students typically complete all or most of the requirements for the two-year degree and then transfer to a four-year college or university to obtain a Bachelor’s degree. The courses that they take to satisfy the A.A. or A.S. degrees are transferable to most four-year schools; therefore, in most cases, the students can enter the four-year schools as juniors. The college transfer program had an enrollment of 4,637 students for the Spring of 2004. Those students were 50.1% male and 49.9% female with an average age of 24 years. The ethnic distribution as indicated on applications for
admission was 68.8% White, 18.4% Black, 0.5% American Indian, 3.7% Hispanic, 5.4% Asian, and 3.2% Other/Unknown/Multi-racial. Sixty-two percent of the college transfer students were part-time students in the Spring of 2004.

The campus is a non-residential campus, and perhaps the most significant difference between these students and students at most four year institutions is the number of students who hold down full-time jobs and/or are married with children. The majority of the students work at least part-time.

The Population

The majority of the students who take General Chemistry are A.A. or A.S. degree seeking students. The chemistry course is the academic equivalent of a university-level general chemistry course and is transferable for university credit at most four-year universities or colleges in the United States. The prerequisites for the chemistry course are high school chemistry, eligibility for college level English, and completion of one semester of college level math, either College Algebra (for A. A. students) or Precalculus Algebra (for A. S. students). Therefore, these students either did not need or have already completed any remedial courses needed in English or math. EFL (English as a Foreign Language) students must also have passed sufficient EFL courses to make them eligible for college-level English. Students who take the chemistry course fall mostly into three categories: 35% A.S. students who plan to transfer to the engineering school of a nearby university; 33% A.S. students who plan to obtain science or medical degrees, and 13% A.A. students who plan to get four year Nursing degrees. The remainder of the students fall into various other categories, including those pursuing Education degrees.
Pilot Study--Subjects

The pilot study was conducted in the spring of 2004. One hundred twelve students from seven first semester General Chemistry lab sections taught by three different instructors participated. Each lab section had a maximum of 16 students. The age range of the students was 18-48 years, with the average age of 23 years. The students were 63% male and 37% female. The ethnic breakdown of the students as indicated on their application for admission was 65% White, 14% Black, 12% Asian, 5% Hispanic, and 4% Other/Unknown/Multi-racial. The population was made up of 64% A.S. students, 26% A.A. students, and 10% students from other programs, mostly Health Sciences.

The Pilot Study--Instrument

The pilot test instrument was designed to assess students’ conceptions of physical properties and processes; specifically density, solubility, and phase changes. Using research from chemistry education literature, a number of common alternative conceptions in these three areas were identified. A pilot test made up of 17 questions, 15 open-ended and two multiple choice, was created. Three questions on the pilot instrument were selected from the alternative conceptions literature, while the rest were generated by the researcher. The two multiple choice questions (Numbers six and 12) came from The Journal of Chemical Education’s online Conceptual questions and Challenge Problems Chemical Concepts Inventory (2001). Question number 13 appeared in a number of sources, but was first published in Osborne & Cosgrove (1983). The remainder of the questions were created by the researchers and were designed to determine how students were thinking about physical properties. All but five of the questions asked for particle behavior descriptions to explain
macroscopic behavior. The number of questions related to the density concept was eight; for the solubility concept, four; and for the phase change concept, five. (See Appendix A.)

The pilot test was administered by the students’ lab instructors on the first week of lab following a mandatory safety orientation. Students were informed that this study was being done to see how they were thinking about certain concepts before they began instruction. They were further told that their participation was voluntary. All students had ample time to complete the test and all who were present chose to do so.

*The Instrument for the Study: Pre-test*

Results of the pilot test were compiled and used to design the test instruments for the final study. An item analysis was done for each question to determine which alternative conceptions were present. It was found that the students were inconsistent, that they had difficulty with many of the open-ended questions, and it was, in many cases, hard to tell if the difficulty was with the concept area or in expressing their conceptions in the way they had been asked to do so on the test. The difficulty of analyzing the data from the pilot test prompted the researcher to choose a multiple-choice format for the study instrument. Using student responses to pilot test questions on the density concept, the most prevalent alternative conceptions for this group of students were identified. The most common alternative conceptions were used as multiple-choice responses on the study test. Questions about solubility and phase changes were treated similarly. In addition, students were asked to provide definitions for 10 terms that are related to the concepts. The final product had approximately equal numbers of questions for each concept area. In addition, six of the multiple-choice questions related to the particulate nature of matter. For density, there were seven multiple-choice questions and one definition; for solubility, there were three multiple-
choice questions and four definitions; and for phase changes, there were two multiple-choice questions and five definitions. Two multiple-choice questions were each classified in two categories: one question related to both density and solubility; the other question related to both phase change and solubility. The post-test was composed of the same questions as the pre-test, although the order of some questions and some multiple-choice responses was changed. (See Appendix B.) After analyzing the results of the pre- and post-tests, students were identified to be interviewed for further clarification of their thinking about the concepts in the study.

The Subjects for the Study

The study was conducted in the fall of 2004. Students in three lab sections of first semester General Chemistry were chosen to be the subjects. These students were selected because all three sections were taught by the same instructor. In addition, the three sections all met at the same time of day on different days. Initially, each section had a maximum of 16 students. They were 59% male and 41% female, with an age range of 18-44 years and an average age of 22 years. The ethnicity of the group was 63% White, 15% Black, 13% Asian, 4% Hispanic, 2% American Indian, and 3% Other/Unknown/Multi-racial, as indicated on their applications for admission. Students voluntarily agreed to participate in the study. They were told that the purpose of the study was to assess conceptual understanding of some fundamental chemistry topics. As an incentive to participation, all students who completed a pre- and post-test and who agreed to be interviewed if selected would receive compensation in the form of their lowest lab quiz grade being dropped. (Other students could receive this reward only by having perfect attendance in the lab portion of the course). The students were assured that the tests and interview tapes would not be seen by
their instructor or by anyone other than the researchers and that they would not be identified in any way. The students were coded using two-digit numbers to identify corresponding pre-tests, post-tests, definitions tests, and interviews.

The researcher administered the pre-test during the first meeting of the labs following a mandatory Safety Orientation. Students signed voluntary consent forms before completing the pre-test. All 38 students present elected to take the pre-test. During the following three weeks, the students completed one laboratory activity per week.

The Laboratory Activities

The first lab exercise was an experiment dealing with density, titled Density of Solids and Liquids: Measurement and Significant Figures (Pellow, et al, 2004). For this experiment, the students calculated the density of a regular geometric solid (a block of wood) by determining its mass and measuring the dimensions to calculated volume. Next, they determined the mass of an irregular solid, determined its volume by displacement in water, and calculated the density. They then calibrated a 25-ml graduated cylinder to determine the precise volume of liquid contained in the cylinder when filled to the 25-ml mark. This was accomplished by filling the cylinder to the 25-ml mark with distilled water of a known temperature. Using the density of water at the given temperature and the mass of the water determined by subtraction, the volume of water in the cylinder was calculated. This exercise was repeated twice and the mean volume, the standard deviation from the mean, and the average deviation from the mean volume were calculated. Using the calibrated cylinder, the density of an unknown salt solution was calculated by reading the volume of solution in the graduated cylinder and determining mass by subtraction. Again, students repeated the
exercise twice and calculated the mean density and the standard deviation from the mean density. For the complete experiment, see Appendix C.

The second experiment was titled, “Identification of Substances by Physical Properties” (Pellow, et al, 2004). The purpose of this experiment was to measure or observe physical properties of two unknown substances, one a solid and the other a liquid, and to use those properties to identify the substances. Students were given a list of possible identities and physical property data for the identified substances. To begin the experiment, students examined the solubility of the two unknowns in three solvents: water, ethyl alcohol, and cyclohexane. Then the density of each of the unknown substances was determined. The density of the unknown liquid was calculated in the same manner as the unknown salt solution in the first experiment. The density of the unknown solid was calculated like that of the irregular solid in the first experiment. However, in this case, by using their solubility data, the students first had to select the solvent in which the unknown was insoluble in order to determine the volume by displacement. Finally, the melting point of the unknown solid and the boiling point of the unknown liquid were determined. Using the physical property data collected for each substance, students selected the most likely identity of each from the list of possible substances with which they were provided. For the complete experiment, see Appendix D.

The third experiment allowed students to use the physical properties of the substances in a mixture to separate the mixture. The title of this experiment was “Separation of a Mixture” (Pellow, et al, 2004). Students were given a mixture containing sand (SiO₂), salt (NaCl), and ammonium chloride (NH₄Cl). They determined the mass of the mixture and of the container. The mixture was heated to drive off the NH₄Cl by sublimation. After cooling,
the remaining mixture was reweighed and the mass of the ammonium chloride determined by subtraction. After cooling the remainder, distilled water was added to the mixture to extract the NaCl. The liquid was decanted into another preweighed container and then heated to boil and evaporate the water. The mass of the salt was determined by subtraction. Meanwhile, the original container was left with wet SiO₂, which was heated gently to dry it. When it was completely dry, the mass of the sand was determined. The students calculated the mass of each substance in the mixture, the percent composition of each substance by mass, and the percent recovery. For the complete experiment, see Appendix E.

The Post-test

The post-test was administered in week six, two weeks after completion of the third lab activity. Following a short problem session on stoichiometry that was done during the lab period, the post-test was administered by the researcher. All students present who had also completed the pre-test completed the post-test. Twenty-eight students of the original 38 took the post-test, giving an attrition rate for the study of 26%. The typical attrition rate for this course is between 25 and 30 percent. Therefore, the attrition for the study group was what would be expected.

Analysis of the pre-and post-tests

The multiple-choice items on the pre-and post-tests were compared for overall differences in achievement using paired t-tests. Again using paired t-tests, the tests were analyzed to see if students’ improved in their understanding in any of the three concept areas (density, solubility, phase changes). Item analyses were independently conducted by two researchers to identify specific difficulties with the multiple-choice questions. The definitions were reviewed to identify patterns in the responses, to locate inconsistencies with related
multiple-choice items, and to provide a clearer picture of how students understood the concepts.

The Interviews

To more completely depict students’ understandings of the concepts, six interviews were conducted for each of the three concept areas. Two researchers independently identified students to be interviewed. Those students identified by both were chosen for interviews. The only determining factor in choosing interview candidates was performance on the pre- and post-tests. Students were selected because 1) based on the multiple-choice items, they consistently displayed a lack of understanding of the concept, or 2) there was inconsistency between their responses to the multiple-choice items and the definitions they provided, which suggested an alternative understanding of the concept.

Twelve students were initially identified for interviews. Some were identified in more than one concept area, which reduced the number of necessary interviews from 18 to 12. No students were interviewed for all three concept areas. Two of the originally identified students were unavailable for interviews; one dropped the class and the other did not return several phone calls. One of the two was replaced by a candidate originally identified in one concept area and identified as an alternate in a second area. The other candidate was replaced by a student identified as an alternate for the concept area needed. The total number of interviews thus conducted was 11, with six per concept area. An interview for a given concept area took between 10 and 15 minutes, so no student was involved in interviews for longer than 30 minutes. Each interview was videotaped.

In addition to identifying problem areas from the multiple-choice tests, the researchers noted that the definitions provided by the students were almost exclusively
macroscopic in nature. The responses displayed almost no awareness or explanation of the behavior of particles. Therefore, the interview questions focused on the areas of conceptual difficulty with an emphasis on determining if the students had an understanding of how the behavior of particles influences how matter behaves and thus what is observed. A set of interview questions to use as a guide was generated for each concept area (See Appendix F). Because the students’ ideas about particles were in question, each interview was to begin by asking the student for his or her definition of the word “particle.” For all three concept areas, questions were generated that would attempt to elucidate whether or not students understood how particle behavior explains the behavior of matter.

In order to give the questions context, it was decided that each interview would be premised on an observation of an event that the students could be asked to explain. For example, interviews about the density concept began by giving the student a syringe and having them pull the plunger back to a specific volume mark, thus filling the syringe with air. After ascertaining that the student knew that there was air in the syringe and asking some questions about the make-up of air, the student was asked to put his/her finger over the hole at the end of the syringe barrel and push the plunger. This, of course, compressed the air in the syringe, and a series of questions was designed to determine if the student understood what happens to the particles when air is compressed, as well as how compression affects the density. (The researcher avoided using the word “compressed” unless it was first used by the student.)

Interviews on the solubility concept began with the student dissolving a small quantity of table sugar in a beaker of distilled water. After the sugar was dissolved the student was asked where it was or why it could no longer be seen. The questions for the
remainder of the interview focused on determining if the student understood what is happening at the particulate level when one substance is dissolved in another.

The phase change interviews began by having the student watch a video of a beaker of water being heated until it began to boil and until it reached a full, rolling boil. The student was then asked to identify the bubbles and how they got there. Questions for the interviews on this topic were designed to see if students understood that the motion of particles and changes to their arrangement governs the phase change process.

Analysis of the Interviews

The videotapes of the interviews were transcribed and analyzed by the researcher. For each interview subject in each concept area, specific alternative conceptions were noted. The individual alternative conceptions were compared and those common to all or most of the subjects in a concept area were identified. Each alternative conception was given a name; for example, if the subjects for the density interviews could not say what was between particles or gave an incorrect response to that question, that misconception was called “Lack of Understanding of Space between Particles.” This process was completed for each of the subject areas and also for the particle definition that each interviewee gave at the beginning of his/her interview. The alternative conceptions for all of the interview subjects and concept areas were further analyzed to find commonalities between concept areas.
Chapter 4

RESULTS

This study was conducted to identify the misunderstandings that community college students have regarding density, solubility, and phase changes as well as to see if standard introductory laboratory activities aid in changing those conceptions to those of normally accepted scientific understandings.

The Study Subjects

The study group consisted of 28 students from three chemistry lab classes taught by the same instructor. The students were pre-tested; they completed three weeks of lab activities; then they were post-tested; and, finally, some individuals were selected to be interviewed. The original pre-test group consisted of the 38 students who were present for lab on the first day that labs met for the semester. Twenty-eight of those 38 students took the post-test. Analyses were conducted using data only from those students who completed both the pre-and post-tests. An illustration of the number of students in the study is presented in Table 1.

The Pre- and Post-tests

The pre-test was composed of 10 multiple-choice questions and 10 definitions relating to three concept areas: density, solubility, and phase changes. The post-test was identical to the pre-test except for the order of the questions and the order of the multiple-choice responses. Six of the ten multiple-choice test items were related to the density concept, while only one multiple-choice item related to each of the other concepts. There were two items that could be categorized in more than one of the concept areas. One item
related to both density and solubility and one item dealt with both solubility and phase changes. Figure 1 depicts the breakdown of the multiple-choice items by category.

Table 1

Number of Lab and Testing Participants

<table>
<thead>
<tr>
<th>Gender</th>
<th>Lab</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Pre and Post-test*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>19</td>
<td>15</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Males</td>
<td>27</td>
<td>23</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Totals</td>
<td>46</td>
<td>38</td>
<td>28</td>
<td>28</td>
</tr>
</tbody>
</table>

*Only those present on the first day of lab completed the pre-test. Only those who completed the pre-test were asked to complete the post-test.

The definitions that the students were asked to provide on the pre- and post-tests were largely focused on solubility and phase changes. There were four definitions for words that related to the solubility concept, five for words that related to the phase change concept, and one definition that related to the density concept. Overall, taking into account both multiple-choice items and definitions, there were approximately equal numbers of questions for each concept. (See Table 2).
Table 2

Breakdown of the Written Test Items by Topic and Response Type

<table>
<thead>
<tr>
<th>Response</th>
<th>Density</th>
<th>Solutions</th>
<th>Phase Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Choice</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Definition</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Total Items</td>
<td>8</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Figure 1. Classification of multiple-choice test items.
Analysis of the Multiple-choice Pre-and Post-test Items

Using a one-tailed t-test, overall pre- and post-test scores were analyzed. The scores for the post-test were found to have a mean that was significantly lower than that for the pre-test. (See Table 3).

Table 3

Means and Standard Deviations of Pre and Post-Test Scores for the Ten Multiple-Choice Items

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-Test</th>
<th>Post-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-Choice Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>7.2</td>
<td>6.4 *</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

* Significant at the alpha = 0.05 level (p< 0.008)

Next, the multiple-choice items were analyzed by looking at the three different concept areas. Again, one-tailed t-tests were used to determine if the mean scores on the tests were significantly different. Mean scores for the phase change and solubility concepts pre- and post-tests were not significantly different. The density concept means were significantly lower on the post-test. Again, it is somewhat difficult to explain why this occurred, especially
since an entire lab exercise was devoted to the density concept. See Table 4 for the breakdown of means and standard deviations of the multiple-choice items by concept area.

Finally, each item was analyzed using the one-tailed t-test. (See Appendix K for a description and details for each item). There was a significant difference in the pre- and post-test means for only one item, the Transfer Liquid item. There are two misconceptions involved in the most common incorrect response to this item. The first is that transferring a liquid to another container changes the density of the liquid. The second is that increasing the volume increases the density. It is possible that the students were thinking of putting the liquid in a smaller beaker as a type of compression and that they just looked at the picture and picked the response that indicated the density would be increased. It is also possible that some of the students simply guessed correctly on the pre-test but incorrectly on the post-test.

Figure 2 shows a comparison of pre- and post-test responses for each item and depicts the trend of fewer correct responses for the post-test. Table 5 and Figure 2 also show that for all questions except the Bubbles in Water Item, greater than 50% of students were able to choose the correct response. The Bubbles in Water Item will be discussed in more detail later in this chapter.
<table>
<thead>
<tr>
<th>Topic</th>
<th>Pre-Test</th>
<th>Post-Test</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>5.4</td>
<td>4.7</td>
<td>0.016 *</td>
</tr>
<tr>
<td>(7 items)</td>
<td>1.1</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Solutions</td>
<td>2.2</td>
<td>2.0</td>
<td>0.085</td>
</tr>
<tr>
<td>(3 items)</td>
<td>0.99</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>1.1</td>
<td>1.1</td>
<td>0.24</td>
</tr>
<tr>
<td>(2 items)</td>
<td>0.66</td>
<td>0.54</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at alpha = 0.05
<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-Test Correct</th>
<th>Pre-Test Percent</th>
<th>Post-Test Correct</th>
<th>Post-Test Percent</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular Solid</td>
<td>21</td>
<td>75%</td>
<td>18</td>
<td>64%</td>
<td>0.16</td>
</tr>
<tr>
<td>Compressed Air</td>
<td>14</td>
<td>50%</td>
<td>15</td>
<td>54%</td>
<td>0.37</td>
</tr>
<tr>
<td>Make More Dense</td>
<td>22</td>
<td>79%</td>
<td>18</td>
<td>64%</td>
<td>0.081</td>
</tr>
<tr>
<td>Sinking Block</td>
<td>24</td>
<td>86%</td>
<td>22</td>
<td>79%</td>
<td>0.21</td>
</tr>
<tr>
<td>Transfer Liquid</td>
<td>23</td>
<td>82%</td>
<td>18</td>
<td>64%</td>
<td>0.048*</td>
</tr>
<tr>
<td>Displace Water</td>
<td>25</td>
<td>89%</td>
<td>22</td>
<td>79%</td>
<td>0.092</td>
</tr>
<tr>
<td>Dissolve Salt</td>
<td>22</td>
<td>79%</td>
<td>19</td>
<td>68%</td>
<td>0.13</td>
</tr>
<tr>
<td>Dot Concentration</td>
<td>20</td>
<td>71%</td>
<td>19</td>
<td>68%</td>
<td>0.29</td>
</tr>
<tr>
<td>Salt Water Freezing</td>
<td>20</td>
<td>71%</td>
<td>19</td>
<td>68%</td>
<td>0.33</td>
</tr>
<tr>
<td>Bubbles in Water</td>
<td>10</td>
<td>36%</td>
<td>9</td>
<td>32%</td>
<td>0.29</td>
</tr>
</tbody>
</table>

* Significant at alpha = 0.05
Figure 2. Comparison of pre and post-test scores by individual items on the multiple-choice test. Twenty-eight students took both the pre and post-tests.

The post-test data was tested for internal consistency reliability using the KR-20 analysis. As indicated in Table 6, the KR-20 for this 10 item post-test was 0.67. Many test developers consider a score above 0.70 acceptable. However, a score of 0.67 is reasonable for a test of only ten items. Table 6 also displays Item Difficulty and Item Discrimination scores for each item. (Refer to Appendix B to see the pre-test and Appendix K for details about the individual items.)

Item difficulty is the proportion of students who correctly answered an item. Although item difficulty is the accepted term, the resulting score can be more accurately
described as “item ease,” where the higher score means more people responded with the correct answer. Except for the “Bubbles in Water Item”, all items had Item Difficulty scores of greater than 50%. Further discussion of this item will follow later in the chapter.

The “Rectangular Solid Item” had an Item Discrimination score of 0.29, while all other items had scores of over 0.35. A positive Item Discrimination score indicates that more students who scored in the upper quartile on the test chose the correct response for a particular question than did students who scored in the lower quartile. A score of over 0.25 is considered “good,” while a score of over 0.35 is considered “excellent.” Therefore, the test can be considered to be one that discriminates well.

It is worth noting that the “Transfer Liquid Item,” the one item for which there was significant decline in scores on the post-test, has an Item Discrimination score equal to that of three other items (0.57). This suggests that those students who were most knowledgeable about the topics on the test answered it correctly and that those who changed their answer to an incorrect answer did poorly on the overall post-test. Those who chose the incorrect response for this item on the post-test may have simply guessed correctly on the pre-test.

**Analysis of the Definitions**

After analysis of the pre- and post-test multiple choice items, the definitions provided by the students were reviewed and analyzed. (See Appendix B for the list of terms at the end of the pre-test.) Responses to each term were cataloged to find similarities in the definitions as well as to identify common alternative conceptions. Overall, the definitions provided by the students were overwhelmingly based on macroscopic interpretations of the concept. Only seven of 280 definitions provided on the post-test made references to particle behavior. Three of those references demonstrated misconceptions. It should be noted that the students were
not specifically asked to include particle behavior in their definitions; they were simply asked
to define the terms to the best of their ability. Table 7 shows the most common correct post-
test definition provided for each term as well as the percentage of students who provided that
response. Few students altered their definitions from pre-test to post-test.

Table 6

Item Analysis of the Multiple-Choice Post-Test (KR-20 = 0.67)

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Difficulty</th>
<th>Item Discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular Solid</td>
<td>0.64</td>
<td>0.29</td>
</tr>
<tr>
<td>Compressed Air</td>
<td>0.54</td>
<td>0.71</td>
</tr>
<tr>
<td>Make More Dense</td>
<td>0.64</td>
<td>0.71</td>
</tr>
<tr>
<td>Sinking Block</td>
<td>0.79</td>
<td>0.57</td>
</tr>
<tr>
<td>Transfer Liquid</td>
<td>0.64</td>
<td>0.57</td>
</tr>
<tr>
<td>Displace Water</td>
<td>0.79</td>
<td>0.57</td>
</tr>
<tr>
<td>Dissolve Salt</td>
<td>0.68</td>
<td>0.71</td>
</tr>
<tr>
<td>Dot Concentration</td>
<td>0.68</td>
<td>0.57</td>
</tr>
<tr>
<td>Salt Water Freezing</td>
<td>0.68</td>
<td>0.43</td>
</tr>
<tr>
<td>Bubbles in Water</td>
<td>0.32</td>
<td>0.71</td>
</tr>
</tbody>
</table>
Table 7

Breakdown of Most Common Responses for Terms to be Defined

<table>
<thead>
<tr>
<th>Term</th>
<th>Most Common Correct Response</th>
<th>Percentage of Students with a Correct Definition</th>
<th>Concept Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compress</td>
<td>to decrease the volume</td>
<td>54 %</td>
<td>Density</td>
</tr>
<tr>
<td>Soluble</td>
<td>able to be dissolved</td>
<td>61 %</td>
<td>Solubility</td>
</tr>
<tr>
<td>Saturate</td>
<td>when no more solid can be dissolved</td>
<td>21 %</td>
<td>Solubility</td>
</tr>
<tr>
<td>Mixing</td>
<td>combining two or more substances</td>
<td>61 %</td>
<td>Solubility</td>
</tr>
<tr>
<td>Dissolve</td>
<td>form a solution</td>
<td>39 %</td>
<td>Solubility</td>
</tr>
<tr>
<td>Boil</td>
<td>liquid to gas</td>
<td>64 %</td>
<td>Phase</td>
</tr>
<tr>
<td>Evaporate</td>
<td>liquid to gas</td>
<td>75 %</td>
<td>Phase</td>
</tr>
<tr>
<td>Melt</td>
<td>solid to liquid</td>
<td>82 %</td>
<td>Phase</td>
</tr>
<tr>
<td>Freeze</td>
<td>liquid to solid</td>
<td>71 %</td>
<td>Phase</td>
</tr>
<tr>
<td>Condense</td>
<td>gas to liquid</td>
<td>21 %</td>
<td>Phase</td>
</tr>
</tbody>
</table>

The term “compress” was the only definition that related to the density concept. Most students correctly defined the word “compress” as a decrease in volume. However, few
students indicated how this would occur. Only one student referenced particle behavior with regard to this term. That student’s definition was “for particles to come together and become more dense.” Even this definition is not completely clear. Are the individual particles becoming more dense or is the substance becoming more dense? Four other students on the post-test also indicated that in addition to the volume decreasing, the density of the substance would increase upon compression. Other alternative conceptions were presented as well. Just over half of the students were able to correctly define “compress,” even at the macroscopic level.

There were four terms to be defined that related to the solubility concept. In this concept area, only one reference to particle behavior is found—in the definition for “dissolve.” One student defined this word as “evenly spread particles throughout a solvent.” The majority of students who defined this term correctly said that to dissolve is “to form a solution.” However, fewer than half of the students were able to provide an adequate definition for this term. Alternative conceptions presented included, in almost equal numbers, “breaks down,” the meaning of which is unclear, (14 %); “disappears,” (14 %); and “loss of composition,” (11 %).

The terms “mixing” and “soluble” were a little less difficult for the students to define. Sixty-one percent of the students were able to provide a correct macroscopic definition for these two terms. “Mixing” was most commonly defined as “combining two or more substances,” which is technically correct. However, the researcher was left to wonder what was meant by the word “combining.” The most common alternative conception presented for “mixing” was to define the term as “to make one.” This definition is even more ambiguous than the previous one, and it seems to imply that there is chemical change taking place. A
couple of students expressly stated that “mixing” is “to make one new substance.” The students also provided a very generic, although correct, definition of “soluble.” The definition provided by most students was “able to be dissolved.” However, 21% of the students defined this term with a specific reference to water, as in “able to be dissolved in water.” This is probably not surprising, since their experiences are largely with water. However, these students did perform a lab activity in which they tested the solubility of various solids and liquids in three different solvents, only one of which was water.

The term “saturate” was defined correctly by only 21% of students. The definition provided by these students was “when no more solid can be dissolved.” There were equal numbers of students (21%) who defined the term as either “completely wetting a solid,” or as “being full.” Most of the students seemed unfamiliar with this term as it is used in chemistry and solutions.

For the phase change category, the first thing that stood out to the researcher was a lack of differentiation between definitions for “boil” and “evaporate.” The most common correct response for both of these terms was “liquid to gas,” which was the definition provided by 75% of the students for “evaporate,” but only 64% of the students for “boil.” The term “boil” was defined by 21% of students as “heating until evaporation, “and by 43% of them as “liquid to gas.” One student referred to particle behavior in this area, defining boiling as “molecules of that liquid start to leave the surface because of excess kinetic energy.” The number of students who were able to provide a macroscopic definition of the term “boil” might suggest that they understand this term. Only two students referred to “heating until air bubbles are given off,” or “heating until O₂ is released.” However, the Bubbles in Water Item on the multiple-choice part of the test was the most incorrectly scored
item overall. Only 32% of students identified the bubbles in boiling water as water vapor, while 29% identified the bubbles as H₂ and O₂. There is clearly some confusion with this term or this process.

For the term “freeze,” 71% of the students gave a correct macroscopic definition, “liquid to solid.” This was the term for which particle behavior was most often referenced (three references) and it was referenced incorrectly in all cases. Three students defined “freeze” as “the point when the molecules stop moving” or “when the kinetic energy of the molecules goes to zero.” Interestingly, only eight of the 20 students who gave the correct definition specifically noted that the change occurred due to lowering of the temperature. Besides the alternative conception regarding molecular motion, several students defined freezing as simply “lowering the temperature,” with no mention of a change of state.

The term “condense” presented the most difficulty for the students. Only 21% of the students gave an acceptable macroscopic definition of this term, defining it as “gas to liquid”, or in one case, “opposite of evaporation.” More students incorrectly equated this term with the term “compress” than defined it correctly. Thirty-six percent of the students defined “condense” as “decreasing the volume” or “make smaller” or “same as compress.” One student referred to the particle behavior as if the term were “compress,” stating that “the particles move closer together.” This is also the only term for which more than one student did not provide a definition —five students did not attempt to define this term.

Analysis of the Interviews

After reviewing the results of the multiple-choice items and the definitions, two researchers identified students to be interviewed. It was determined that six interviews per subject area would be conducted, for a total of 18 interviews. Interview candidates were
identified based on their responses to the multiple-choice items and the definitions. Students who exhibited a lack of understanding of a concept or whose responses were inconsistent were independently identified by two researchers. Several students were identified in more than one subject area. Those students were interviewed for two concept areas. No student was interviewed for all three concepts. The interviews were designed to focus on students’ understandings of how particles behave and how that behavior affects macroscopic behavior. Each interview was to begin by asking the candidate to define the word “particle”.

Once the interview candidates were selected, the researchers generated a set of interview questions for each concept. The decision was made to have each interviewee observe a phenomenon and to use that event to launch the interview. The multiple-choice item in each concept area for which students had the lowest scores was used as the starting point for the interviews for that concept. Other questions were generated as a guide for the interviewer. To look at the sample interview questions, see Appendix F. The interviews were conducted by the researcher and videotaped so that they could be transcribed. Students were assured that neither their instructor nor anyone else would see the tapes.

*Density Interviews*

The lowest scored multiple-choice item for the density concept was the Compress Air Item. (See Figure 3.) In this question, students were asked how the density of air changes if the air in a tube is compressed, although the term “compressed” was not used in the question. The majority of the students who answered this item incorrectly chose a response that indicated a lack of understanding of the relationship between density and pressure, a concept that is related to the particle nature of matter. The multiple-choice response chosen by these students stated that the density would not change with the pressure. Students who chose this
response do not understand that increasing the pressure decreases the space between the particles and therefore increases the density.

The definitions provided by the students for the term “compress” fail to provide insight about their notions of particle behavior. Most students defined this term as a “decrease in volume,” with no reference to the effect on density.

The focus of these interviews was to determine if students understood what happens to gas particles when a gas is compressed; to see if the student could explain, using the behavior of particles, why the volume of a gas can be decreased with pressure and how that increases the density of the substance. To begin the interview for this topic, the interview candidate was given a syringe and asked to pull the plunger back to a certain point (the 15-mL mark) on the barrel. The student was asked what was in the syringe, and if “air” was the answer, then asked if air was composed of particles. (If “air” was not the answer, the researcher did try to get the student to that point. All of the students were able to correctly state that the “empty” cylinder contained air.) The student was then asked to put his/her thumb over the opening on the end of the syringe barrel and push the plunger as far as possible without taking the thumb away. They were then asked to read the new volume. Questions were asked to elicit student understanding of space between particles, particle motion, how gases behave differently from solids and liquids, and why, and whether air has mass or density.
“A glass cylinder contains compressed air as illustrated in tube A. If the plunger is pushed down as in tube B, will the density of the air change?”

a. The density of the air sample will not change; only the pressure will change. (9)
b. The density of the air sample will not change, the density of air, like that of any given substance, is a constant. (1)
c. The density of the air sample will increase because the volume of the sample will decrease. (15)
d. The density of the air sample will decrease because the volume of the sample will decrease. (3)
e. None of the above is correct. (0)

Figure 3. Density question about compressed air. The numbers in parentheses after the answers represent the number of students who chose that answer on the post-test. Fifty-four percent of the students correctly answered this item (option c).

Three common misconceptions surfaced during the interviews. Table 8 shows the misconceptions for the density concept. Transcripts from the density interviews can be found in Appendix H.

Five of the six students did not have an understanding of the concept of space between particles. Excerpts from the interviews demonstrate this problem.

I: What is between the particles?
S: Uh…Well, is a particle an atom?
I: Well, we agreed that air is made up of particles, right?
S: So a particle of water is one molecule of H₂O? Is that right?
I: Okay, let’s go with that definition.
Later in the interview:

I: What is between the particles? Why can you push them together?
S: Well, it’s because it’s a gas. Like they’re…I guess the difference between gas particles and solid particles…gas particles are further apart. I guess that each particle has an electron shell around it. It’s a nucleus and an electron shell around it and when you increase the pressure you lower the area and the volume…ah, I don’t know.

Another student’s interpretation:

I: What’s between the particles?
S: Good question. It’s empty space…more air.
I: Empty space or more air?
S: I’d say more air.
I: Well, how does that happen? You have air particles and you’re pushing them together.
S: I don’t know.

Four of the six indicated that solids are compressible, although most suggested that some sort of force or “heavy machinery” would be required. One student differentiated between “hard” solids and “soft” solids:

I: Could you compress a solid?
S: It depends on the solid. Hard solid or soft solid? Some solids are composed that the particles can be pressed closer together.
I: Do you think there is a difference in how the particles are arranged in those solids that can be compressed?
S: Yes.
I: What’s the difference?
S: Some of them are spaced out more than others. In a hard solid, it’s tight.

Only three of the six students were directly asked if air has mass, and all three of them, at least initially, said “no.” Two of the students answered “no” when asked if air had mass, but re-thought their answer when asked if air had density. (The third acknowledged that “It’s a possibility” that air has mass, given that it has volume and density.) A portion of the transcripts from the former two students:
I: Does air have mass?
S: No.
I: Does it have density?
S: Yes, so I guess it would have to have mass…I know it has density…

And,

I: Does air have mass?
S: I would say no.
I: Does it have density?
S: I would also have to say no, but I’m not sure.
I: Well, does it have volume?
S: [Student looks at syringe.] Well, I guess it depends on the composition of the air. Where it’s in this area, it’s obviously got it.
I: So it has volume?
S: Yeah.
I: And when we pushed the syringe up you said you compressed it?
S: Yeah.
I: But it doesn’t have mass or density?
S: Well, obviously it has to if it has volume.

Some information about the motion of particles was obtained from the density interviews as well. This will be discussed later in the chapter.

Table 8

Alternative Conceptions about the Density concept elicited from Interviews

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Number of students with this conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of understanding of space between particles</td>
<td>5/6</td>
</tr>
<tr>
<td>Air does not have mass</td>
<td>3/3*</td>
</tr>
<tr>
<td>Solids are compressible</td>
<td>4/6</td>
</tr>
</tbody>
</table>

*Only three students were directly asked this question. All three responded that air does not have mass.
Solubility Interviews

The solubility interviews began by giving the student a beaker containing distilled water and having the student add sugar to the beaker and stir until all of the sugar was dissolved. This phenomenon was chosen because the Dot Concentration Item was the item for the solubility concept that was answered incorrectly most often. Thirty two percent of students answered this question incorrectly on the post-test. Five of the eight who answered it incorrectly chose a response that indicated that particles in solution “disappear” with addition of solvent. (See Figure 4.) It is worthy of note that this question was altered from the pilot test question that it derived from. (See Appendix A.) On the pilot test, there was an additional response choice that showed fewer particles in solution with addition of solvent, but that did not show a mathematical relationship between the number of particles and the volume of solvent. The correct choice shows six particles in solution, while the deleted choice showed seven. The most common response on the pilot test was the correct choice, but an almost equal number of students chose the deleted response on the pilot test. The researcher decided to eliminate that response to see if students could select the correct response from fewer choices. Thus, the choice on the study instrument was between “disappearing particles,” “fewer particles”—in a mathematically correct proportion, “the same number of particles,” or “twice as many particles.” In fact, 68 % of the students did choose the correct response on the multiple-choice test.

The definitions provided by student for the terms that relate to the solubility concept did little to illuminate their thinking about particle behavior in solutions. Even at the macroscopic level, only 39 % of the students gave an acceptable definition for “dissolve.” Furthermore, the definitions for “soluble” and “mixing” were either completely macroscopic
or ambiguous. It was hoped that the interviews could shed some light on student understanding of solutions.

Sugar was chosen for the interviews specifically instead of salt, as the researcher did not want the ionization of the solid to confuse the issue. Once the sugar was dissolved, the interviewee was asked where it went; why it could no longer be seen. Further questions were generated to determine how the student understood the behavior of particles in solution. Four misconceptions surfaced in the solubility interviews. All six of the students were unable to define what it means for a solid to dissolve. None of them had a concept of solubility equilibrium. In addition, all of these students stated that all solutions must have at least one liquid component. Three of the four interviewees who were asked about how the addition of the sugar affected the density of the final solution did not know. Table 9 displays the alternative conceptions that came up in the solubility interviews.

“Figure 1 represents 1.0 L of water with sugar dissolved in it. Which of the following best represents how it will look upon the addition of 1.0 L of water?”

![Figure 1](image1.png)

Figure 4. Solution question about the dilution of sugar water. The numbers in parentheses after the answers represent the number of students who chose that answer on the post-test. Sixty-eight percent of the students correctly answered the item
Excerpts from the interviews may illuminate some of the misconceptions held by the students. The following examples illustrate the difficulty the students had in describing what happens when something dissolves:

I: So, where did it [the sugar] go?
S: It melted into the water. Well, I don’t know if I’d use the word “melt.” It dissolves it. It made it into a liquid.
I: Okay. It made the sugar into a liquid?
S: Yeah.

And a second student:

I: Okay, now that it is dissolved, we can’t see it anymore. So where did it go?
S: It’s soluble in water, so it became a compound.
I: It became a compound…I’m not sure what you mean by that.
S: Okay, well, it broke down into small particles, I guess you could say.

Later, same interview

I: So when we mixed the sugar in there, how do you think the sugar was distributed in the beaker?
S: You know, ummm…
I: It’s still in there, right?
S: Yeah.
I: So where do you think the sugar molecules are?
S: I think they’re attached to…sucrose is made of what? C\textsubscript{22}H\textsubscript{12}O\textsubscript{11}?
I: I’m not sure of the formula, but it is a compound made up of carbon, hydrogen, and oxygen, yes.
S: I don’t know where they’re at.

The concept of solubility equilibrium was equally difficult for the students to describe. Even those whose responses suggested that particles move in and out of solution could not say why that occurs. Not one student referred to the motion of particles in this portion of the interview. Some examples:

I: Do you think the dissolved and undissolved particles could trade places?
S: Yeah, I think.
I: You think they can trade places?
S: Yeah, I do.
I: Why do you think they might trade places?
S: [Shakes his head and laughs] I don’t know. It’s just like that. Just because.

And another student:

I: What do you think determines which particles of sugar are going to dissolve and which ones won’t dissolve?
S: The ones with the greater amount of particles—it will depend on the volume of the water.
I: Okay. Suppose we have some [sugar] sitting in the bottom [of the beaker] that is undissolved and we also have some [that is] dissolved. Do you think that an undissolved particle and a dissolved particle might ever trade places?
S: Yes, but you’re going to have to have a force to make that take place, which is going to be more stirring.

And one more:

I: Do you think the dissolved and undissolved particles could ever trade places?
S: No, I don’t think so.
I: Are the sugar particles moving?
S: Yes.
I: Are the water particles moving?
S: Yes.

These students display a lack of understanding about how the motion of the particles determines the process of solubility. Transcripts for the solubility interviews can be found in Appendix I.

Table 9

Alternative Conceptions about the Solubility concept elicited from Interviews

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Number of students with this conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacks definition for “Dissolve”</td>
<td>6/6</td>
</tr>
<tr>
<td>Lacks concept of Solubility Equilibria</td>
<td>6/6</td>
</tr>
<tr>
<td>Solutions require liquid</td>
<td>6/6</td>
</tr>
<tr>
<td>Addition of solute changes density</td>
<td>3/4*</td>
</tr>
</tbody>
</table>

*Four students were directly asked this question. Three did not know how the addition of a solute would affect the density
The phase change interviews

For the phase change concept, the item most often answered incorrectly was the Bubbles in Water Item. In fact, this was the item that students had the most difficulty with on the entire multiple-choice portion of the test. Only 32% of the students chose the correct response to this item, while 29% chose the second most common, incorrect response. The incorrect response most favored by the students shows a misconception that the phase change from liquid to vapor caused by boiling results in chemical decomposition of the substance. (See Figure 5). The second most common incorrect response, chosen by 21% of the students indicates that the boiling water produces bubbles composed of air. Fourteen percent of the students chose a response that said that the bubbles produced by boiling water are composed of CO₂. There is definitely some confusion with regard to the concept of phase changes.

“Suppose you observe water that has been boiling for 20 minutes. What are the bubbles you see composed of?”

a. H₂O (9)
b. H₂ and O₂ (8)
c. Air (6)
d. H₂O, H₂, O₂, and air (1)
e. CO₂ (4)

Figure 5. Phase change question about the composition of bubbles in boiling water. The numbers in parentheses after the answers represent the number of students who chose that answer on the post-test. Thirty-two percent of the students correctly answered this item (option a).
This confusion was not displayed as clearly in the students’ responses to the definitions, as only two students on the post-test indicated that boiling produces a gas other than water vapor (i.e. air or O\textsubscript{2}). However, recall that the student responses to the definitions were very basic—most students defined boiling as “liquid to gas.” Furthermore, the students tended to equate evaporation with boiling. Therefore, the interviews for the phase change concept began by having the students observe, via videotape, a beaker of water as it was heated and began to boil and until the water in the beaker was boiling vigorously. The student was then asked what the bubbles were, how they formed, etc. The interview progressed to asking whether all substances can boil/what substances cannot boil and then to questions about evaporation, condensation, and freezing. The questions were focused on determining how students understand what is happening when a substance undergoes a phase change. Table 10 shows the list of alternative conceptions that came to light in this set of interviews.
Table 10

Alternative Conceptions about the Phase Change concept elicited from Interviews

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Number of students with this conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacks understanding of “Evaporation”</td>
<td>3/4*</td>
</tr>
<tr>
<td>Lacks understanding of “Condensation”</td>
<td>5/6</td>
</tr>
<tr>
<td>Equates boiling with decomposition</td>
<td>5/6**</td>
</tr>
<tr>
<td>Heat/Energy required for Evaporation</td>
<td>4/6</td>
</tr>
<tr>
<td>Did not know the composition of Steam</td>
<td>4/4***</td>
</tr>
</tbody>
</table>

*Only four students were directly asked this question. Three could not articulate a definition for “Evaporate.” The term was either equated with boiling or the students did not have an idea of how to explain evaporation.

**The sixth student stated that the composition of the bubbles in boiling water was air.

***After this came up in one of the interviews, the researcher asked all subsequent interviewees if they knew what the composition of steam was. All four students asked gave incorrect responses or did not know.

The interviews for the phase change concept highlighted the students’ confusion about what is happening when a phase change occurs. There was very little reference to particle motion in the students’ attempts to explain the phenomena with the exception of freezing. Almost all of the students used the concept of molecular motion to discuss freezing, although a couple of them mistakenly believed that molecules stop moving completely when a substance freezes.

Excerpts from the interviews help to illustrate the misconceptions about boiling and evaporation.

After watching the video of the beaker of boiling water:

   I: “…what were those bubbles made of?”
   S: Something was evaporating.
   I: Okay, what was evaporating?
   S: Either hydrogen or oxygen.
I: So do you think that the bubbles were hydrogen or oxygen?
S: I’m not sure. Do you want me to guess?
I: Yeah…go ahead. Just tell me what you think is in there.

After some discussion…

S: Well, it’s a physical change. Yeah…everything is going to get evaporated, so it is hydrogen and oxygen.
I: So when water boils, it changes into hydrogen and oxygen?
S: No…well, yeah. It starts out being hydrogen and oxygen. Each water is made up of two molecules of hydrogen and one molecule of oxygen.
I: Okay, so are the bubbles hydrogen and oxygen then?
S: No, maybe it’s H2O gas. No. wait maybe one of them is burned away…one of them evaporates and the bubbles are hydrogen or oxygen. I’m not sure.

Another student:

I: What are those bubbles that we saw?
S: Those bubbles are…gas. Gas escaping. Hydrogen gas escaping from the water.
I: Okay. So the bubbles are hydrogen gas escaping from the water? Coming from the water molecules?
S: Yes.

Later, same interview:

I: What kind of substances can you boil?
S: Hmmm. Not all substances. I guess they’d have to have specific heat. I guess I’d say that only liquids can boil.
I: Well, suppose I had a piece of copper. Could I boil that?
S: Well, you could put it in water and boil the water. But as far as the copper itself…I guess you could break it down to a liquid and then boil it.
I: Could you boil steam?
S: I don’t think so, because steam is being let off from a boiling substance.
I: So all boiling substances let off steam?
S: Ummmm. Yeah.
I: What is steam?
S: Steam is the evaporating…I guess it would be anything that evaporated from a boiling substance.

When asked about the difference between evaporation and boiling, the students were confused:

I: Is evaporation different from boiling?
S: I think so. Evaporation…well, you have to boil to evaporate so it all gets gone, but I think…wow…

Another student attempts the same question:

I: What is the difference between evaporation and boiling?
S: Boiling is the speeded up process of evaporation.

And a third:

I: What’s the difference between evaporation and boiling?
S: Maybe specific heat temperature? When you boil you take it to a different temperature degree. Because of the heat, it causes the evaporation of water to increase while…I guess the difference would be specific heat and temperature.

The concept of condensation posed a problem for almost all of the students interviewed. This was also the term that the least number of students were able to define on the post-test. Although all of the students were familiar with the phenomenon, they had great difficulty in explaining what was occurring. In the interviews, the interviewer set up the question:

I: Suppose I had a glass of iced tea and I set it on the table and left it there for a bit. When I come back, there will be a clear liquid on the outside of the glass. Have you ever seen that? (All students agreed that they had seen this before.)

A couple of student responses will highlight how students perceive this concept:

I: What is that liquid?
S: Condensation.
I: Where does it come from?
S: I guess the temperature. Since the glass has ice in it, the container is cooler than the temperature of the surroundings, it causes the cold to expand…to try to expand around the room and try to get the room temperature to drop a few degrees, so I guess the condensation comes from the colder temperature and the warmer surroundings.
I: Do you know what the condensation is made of?
S: Ummmm.
I: Do you know what that substance is?
S: No.
Another student seems to have a better understanding, but still cannot explain what is occurring:

I: Do you know what that liquid is?
S: It’s water particles.
I: How did it get there?
S: [Laughs] I have no idea.
I: Did it come from inside the glass?
S: No, it did not. It comes from the atmosphere and the outside of the glass.
I: Okay, so it’s due to…?
S: Temperature change.

And, finally, a student who has a fairly resilient alternative conception for what is occurring when water condenses on the outside of a glass:

I: What is that liquid?
S: You mean, like….condensation?

After some discussion:

S: What’s on the outside of the glass is because of the temperature change. ‘Cause it’s warmer outside, so it’s been heated from the outside, so it evaporates…well, it doesn’t evaporate, but it collects on the outside, but it’s the same water that was inside.
I: The same water that was inside the glass? So it comes from inside the glass?
S: [Looks puzzled] Well, I think it comes from inside. It can’t come from inside because there is no opening.
I: Well, if it doesn’t come from the inside, where might it come from?
S: Well, if it’s cold inside and warm outside, maybe something is collecting on the glass. But I know that over time there is less water inside—less tea inside. Like, when you leave it for awhile, there will be less inside because what is outside used to be inside, kind of? Is that right?
I: Well, I agree with you that over time, some will be missing. How is it missing?
S: It evaporates.
I: Okay, it evaporates. So is that the same liquid that’s on the outside [of the glass]?
S: Well, where else would it come from? You start with water in the glass and the only water there is in the glass, so the water on the outside must come from the inside from the temperature change.
These interviews show that students do not understand the behavior of particles with respect to phase changes. Transcripts for the phase change interviews can be found in Appendix J.

**Particle definition Interviews**

Before beginning the concept area interviews with each student, the student was asked to define the word particle. Eleven students were interviewed; some for more than one concept area. All eleven were asked to define “particle.” The transcripts for their responses are in Appendix G. Seven of the 11 students defined a particle as “a small piece,” or “a part” of something. Only two students referenced atoms or molecules in their definition, and no students referred to ions or subatomic particles. One student could not/would not provide a definition. Most of the students suggested that a given particle could have a phase associated with it. Only two students referred to the arrangement of particles as determining the phase of a substance, and one of those students stated that all particles are themselves solid. In addition, the researcher searched all of the interview transcripts for all of the concepts to determine how students were thinking of particle motion. Eight of the 11 students were specifically asked about particle motion or addressed it on their own. Of those eight, five indicated that the particles in a solid are not moving at all. Table 11 shows the alternative conceptions displayed by the students about particles.
Table 11

Alternative Conceptions about particles elicited from Interviews

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Number of students with this conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defines “particle” as small piece or part of something</td>
<td>7/11</td>
</tr>
<tr>
<td>Associates a phase with the particle</td>
<td>7/8*</td>
</tr>
<tr>
<td>Solid</td>
<td>3/8</td>
</tr>
<tr>
<td>Solid, Liquid and Gas</td>
<td>4/8</td>
</tr>
<tr>
<td>Does not know that solid particles are in motion</td>
<td>5/8**</td>
</tr>
</tbody>
</table>

*Only eight students were specifically asked if particles had a phase associated with them. One student could not define the term and was thus not asked. The interviewer failed to asked this question to two additional students.

**Only eight of the 11 students specifically addressed particle motion. This data was compiled from all of the interviews rather than just the particle transcripts.

Again, the interview transcripts are enlightening.

I: What is a particle?
S: A part, like a small piece.
I: Of?
S: Just a small piece.
I: A small piece of anything?
S: Yeah.
I: Okay. Does it have a phase associated with it, like solid, liquid or gas?
S: I think it could be solid, liquid, or gas.

Another student’s ideas:

I: Can you define the word particle for me?
S: A very small piece of matter. Like an atom or a molecule.
I: Does it have a phase associated with it: solid, liquid, or gas?
S: Well, I’d think they’re solid, but there are different phases of matter.
I: How do you think that works?
S: I guess the way the pieces are put together.
I: So do you think the particles themselves are solid?
S: Yeah, I think so.
These students, in general, are not thinking of particles in the sense that the term is used in chemistry. Much of their understanding and the way that they define the term is, like that of the other concepts, macroscopic.

Summary

The study reveals a number of common misconceptions held by community college chemistry students about physical properties and processes, and specifically about density, solubility, and phase changes. The use of three different methods (multiple-choice testing, asking the students to provide definitions, and, finally, interviewing selected students) helped the researcher to gain insight into how the students were thinking about these concepts and how the students understand particle behavior as related to the concepts. Fifteen specific alternative conceptions were held by at least half of all students who were interviewed and specifically asked about each concept. Of those 15 alternative conceptions, 13 are directly linked to a lack of understanding of particle behavior. Table 12 summarizes these findings.

There was little change in students’ conceptions on the pre-and post-tests. No significant improvement in students’ understanding of the concepts was noted. Indeed, in most cases, the students’ test scores indicated a slight decline in understanding. For one concept area, that of density, the post-test scores were significantly lower than the pre-test scores. It remains unclear why there was a decline in scores, however slight.
Table 12

Summary of Alternative Conceptions

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>Linked to Particulate Nature of Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defines “particle” as small piece or part of something</td>
<td>Yes</td>
</tr>
<tr>
<td>Associates a phase with the particle</td>
<td>Yes</td>
</tr>
<tr>
<td>Does not know that solid particles are in motion</td>
<td>Yes</td>
</tr>
<tr>
<td>Lacks understanding of “Evaporation”</td>
<td>Yes</td>
</tr>
<tr>
<td>Lacks understanding of “Condensation”</td>
<td>Yes</td>
</tr>
<tr>
<td>Equates boiling with decomposition</td>
<td>Yes</td>
</tr>
<tr>
<td>Heat/Energy required for Evaporation</td>
<td>Yes</td>
</tr>
<tr>
<td>Did not know the composition of Steam</td>
<td>No</td>
</tr>
<tr>
<td>Lack of understanding of space between particles</td>
<td>Yes</td>
</tr>
<tr>
<td>Air does not have mass</td>
<td>Yes</td>
</tr>
<tr>
<td>Solids are compressible</td>
<td>Yes</td>
</tr>
<tr>
<td>Lacks definition for “Dissolve”</td>
<td>Yes</td>
</tr>
<tr>
<td>Lacks concept of Solubility Equilibria</td>
<td>Yes</td>
</tr>
<tr>
<td>Solutions require liquid</td>
<td>No</td>
</tr>
<tr>
<td>Addition of solute changes density</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Chapter 5

CONCLUSIONS

This study was done to identify the alternative conceptions about density, solubility, and phase changes held by community college chemistry students. An additional objective of the study was to determine if traditional lab activities aid in changing these alternative conceptions to accepted scientific conceptions.

Three different methods were used to identify the students’ alternative conceptions. A ten item multiple-choice test was used to determine which alternative conceptions the students held at the beginning of the semester. At that same time, students were asked to provide definitions for ten terms related to the concept areas. After completing three lab activities, focusing on these physical properties and processes, the students were post-tested using the same format. After analysis of the multiple-choice items and the definitions on the pre- and post-tests, students who exhibited difficulty in each concept area were selected to be interviewed for further clarification of how they were thinking about the concept.

The Alternative Conceptions

The students in this study were found to harbor alternative conceptions about density that are similar to those cited in literature. Although more than half of the students correctly answered each of the multiple-choice items on the tests and 54% of them defined the word “compress” correctly, some common misconceptions surfaced. For example, many of these students lack an understanding of the concept of space between particles. Density appears to be viewed as merely a mathematical operation, a phenomenon noted also by Hawkes (2004). This is further illustrated by the comments in the interviews: “Well, if it [air] has density and volume then it must [have mass.]” The students who were interviewed agreed that liquids
cannot be compressed, but their reasoning, like that of the students in the 1993 study by Lee et al, highlights their lack of awareness of particle behavior. An interesting alternative conception held by the students who were interviewed in the present study was that solids are compressible. The literature did not reveal this misconception in other groups of students. It is unclear if this misconception is specific to this group of students.

The alternative conceptions about solubility also resemble those found in literature. Like Lee et al (1993), this researcher was unable to find any student who was able to give a molecular explanation of dissolving. Rather, terms such as “melted,” “became liquid,” or “disappeared” were used by the students when they tried to explain the phenomenon. In addition, these students did not have an understanding of solubility equilibria. Based on the multiple-choice items, at least one-third of the students did not know that the addition of solute to a solvent will create a solution with a density higher than that of the solvent. Those who were interviewed showed confusion about this topic as well, as three of the four students who were directly asked how the addition of sugar to water would affect the density could not answer correctly. Definitions provided by the students in the solubility concept area were completely macroscopic and gave no insight into their understanding of particle behavior. In addition, the students interviewed in this study unanimously indicated that all solutions must have at least one liquid component. This misconception did not appear in the literature. It may be one that is easily corrected, as it seems to be semantic in nature. However, additional data would be needed to determine if this is a widely held misconception.

Nakhleh (1992) and Osborne & Cosgrove (1983) noted that students use scientific terms such as “evaporate” and “condensation” without having any real understanding of the processes. The students in this study were similar. They knew, for example, that the liquid
that forms on the outside of a glass of iced tea was called condensation. However, even if they knew condensation is water, they were unable to explain how it got on the outside surface of the glass. Some suggested that it came from inside the glass. These findings are similar to those of Lee et al (1993), Mulford & Robinson (2002), and Osborne & Cosgrove (1993). Also similar to findings in the other studies, fewer than half of the students in the present study correctly identified the bubbles in boiling water as water vapor. The most common alternative conception identified by the multiple-choice tests was that the bubbles are composed of H₂ and O₂. This idea suggests that boiling is equivalent to decomposition. Another common misconception is that the bubbles are air bubbles. The definitions provided by the students for the terms in this concept area were almost exclusively macroscopic and did not provide the same insight into the students’ thinking. The interviews, however, did show agreement with the multiple-choice test results. An interesting discovery from the interviews was that several of the students were unaware that steam is water vapor (as opposed to being just a generic term for any vapor.) This was not found in the literature, and more research would be needed to determine if this misconception is pervasive or if it is unique to this group.

The Effectiveness of the Lab Activities

The traditional lab activities used in this chemistry course did not aid in changing the students’ alternative conceptions about density, solubility, and phase changes to those of accepted scientific conceptions. In fact, the multiple-choice tests show a decline in understanding in each of the three concept areas. For the density concept, the scores on the post-test are significantly lower than those on the pre-test. The definitions provided by the students showed very little change from pre- to post-test. In addition, the definitions were so
macroscopic in nature that they provided little insight into the students’ thinking about the processes. The interviews verified the results from the multiple-choice tests, helped to clarify some of the students’ thinking with regard to the definition terms, and uncovered additional alternative conceptions not highlighted by the tests.

**Link to the Particulate Nature of Matter**

Most of the alternative conceptions expressed by these students can be linked to a lack of understanding of the particulate nature of matter. The definitions provided by the students show that the students think macroscopically about the processes being studied, as they included almost no references to particles or particle behavior. On the multiple-choice test, the most incorrectly answered item in each concept area is directly linked to particle behavior. Furthermore, the interview responses show that students are not thinking at the particulate level when they attempt to explain the behavior of matter with regard to density, solubility, and phase changes.

**Use of Language**

Inappropriate use of scientific language by the students was noted in their definitions and in the interviews. This problem is well-documented in the literature; teachers and students commonly use scientific terms in ways that do not fit accepted scientific conceptions. The students in this study are no exception. For example, to describe “dissolving,” students in interviews used such terms as “it melted into the water,” or “it became liquid,” or “it was broken down—it became a compound,” or even, “it disappears.” Many of the definitions used similar terminology.

While reviewing the interview transcripts and definitions for some of the terms that seemed to cause the most difficulty for the students, the researcher became curious about the
use of such terminology. A quick check of “Dictionary.com” revealed that incorrect
definitions are pervasive for scientific terms that are used in everyday language. An example
is the word “dissolve.” All or most of the incorrect definitions provided by the students were
present as definitions for this term in each of eight standard English dictionaries. “Dissolve”
is defined in the following ways in the American Heritage Dictionary of the English
Language, 4th edition:

1. To cause to pass into solution
2. To reduce solid to liquid form; to melt
3. To cause to disappear or vanish
4. To break into component parts; disintegrate

Similar definitions appeared in each source from Dictionary.com. One source (Word Net 2.0,
Princeton University, 2003) even uses an example sentence to further “clarify” use of the
term: “The giant iceberg dissolved over the years during the global warming phase.” Similar
findings were noted for terms such as “evaporate” and “condense.”

A review of the use of language leaves one wondering if the alternative conceptions
about particle behavior are resulting in imprecise language, or if the use of imprecise
language is simply so pervasive that it goes unnoticed so that students are completely
unaware that they are using terms that indicate different behaviors to mean the same thing, as
in the case of “melt” and “dissolve.” The results from this study suggest that there are
alternative conceptions about particle behavior independent of language issues, but the two
issues do appear to be connected.
Ideas for Additional Research

Because most of the alternative conceptions expressed by the students are linked to a lack of understanding of particle behavior, further research about teaching strategies that emphasize the particulate nature of matter would be beneficial. The development of a chemistry course that introduces each topic with particle behavior and retains the focus on particle behavior might be especially fruitful. In addition to specifically drawing attention to the concept of particle behavior, a constant focus throughout the course would provide the repetition necessary for most students’ to accept a new scientific concept (Nieswandt, 2001). It is most likely a mistake to introduce and discuss particles at the beginning of the course and then to assume that students will relate properties of matter to particle behavior without being guided to do so.

Furthermore, since particle behavior cannot be demonstrated, additional research is needed to determine how best to help students develop mental models of particle behavior and to determine how early in their science education this should occur.

Summary

The community college chemistry students in this study exhibited alternative conceptions about the concepts of density, solubility, and phase changes similar to those found in the literature for high school and college students. The traditional lab activities they participated in did not aid in converting their alternative conceptions to acceptable scientific conceptions. The results of this study point to the need to teach even basic chemistry concepts with a focus on the particulate nature of matter. Finally, chemistry teachers must strive to use precise language and to teach their students to do so as well.
References


Chemistry Conceptions

1. Imagine a very dense object. Draw a close-up view of the object illustrating the atoms. Now imagine a less dense object. Draw a close-up view of that object illustrating the atoms. Label your drawings for clarity.

2. What is “dissolving?” Draw a series of pictures to illustrate your answer.

3. Assume that the structure of a solid looks like picture “A.” In the space provided for picture “B,” draw how the structure would change as the substance begins to melt.

4. Describe the motion of sugar molecules as a sugar cube sits in water. (You may draw a picture if necessary.)

5. Suppose you freeze some salt water from the ocean. What is the composition of the ice?
6. The circle below shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after some of the water evaporates?

7. Which of the following substances has the lower density? Why?

8. A glass cylinder contains compressed air as illustrated in tube “A.” If the plunger is pushed down as in tube “B,” will the density of the air change? Why?

9. Draw a picture of the gas molecules in tube “A” of question #8. Then draw a picture of the gas molecules in tube “B.”
10. Suppose you had the power to do anything. How could you make an object more dense?

11. Why does table salt readily dissolve in water while flour does not?

12. Figure 1 represents 1.0 L of water with sugar dissolved in it. Which of the following best represents how it will look upon addition of 1.0 L of water?

Figure 1

13. Suppose you observe water that has been boiling for 20 minutes. What are the bubbles that you see composed of?

14. Consider the two rectangular solids below. Both have a mass of 25.0 grams. Which would you expect to displace a greater volume of water? Why?
15. A block of an unknown substance is placed in beaker “A,” which contains distilled water. The block sinks. It is then placed in beaker “B,” which also contains distilled water. Will the block float in beaker “B?”

![Image of beakers A and B](image)

16. An airtight glass tube contains a gas. Draw the gas molecules in the tube at room temperature in the first box provided and at a temperature low enough to change the vapor to liquid in the second box provided.

![Drawing of gas molecules](image)

17. An unknown liquid is contained in beaker “A.” Will the density of the liquid change if it is transferred to beaker “B?” If so, how will it change?

![Image of beakers A and B](image)
Conceptions

1. Which if the following substances has the lower density? (Both are rectangular solids drawn to scale.)

![Diagram of two rectangular solids labeled A and B with masses 10 grams each.]

a. Substance A has the lower density because it has a larger volume.
b. Substance B has the lower density because it has a smaller volume.
c. Substances A and B have the same density because their masses are equal.
d. There is not enough information to answer the question.

2. A glass cylinder contains compressed air as illustrated in tube A. If the plunger is pushed down as in tube B, will the density of the air change?

![Diagram of two tubes labeled A and B with different air levels.]

a. The density of the air sample will not change; only the pressure will change.
b. The density of the air sample will not change; the density of air, like that of any given substance, is a constant.
c. The density of the air sample will increase because the volume of the sample will decrease.
d. The density of the air sample will decrease because the volume of the sample will decrease.
e. None of the above is correct.
3. Suppose you have the power to do anything. How could you make an object more dense?
   a. Decrease the volume by compressing the object.
   b. Remove some of the mass.
   c. Put it in a smaller container.
   d. None of the above.

4. A block of an unknown substance is placed in beaker A, which is filled with distilled water. The block sinks. The same block is then placed in beaker B, which is also filled with distilled water. Will the block float in beaker B?

   a. The block will not float in beaker B. The new volume of the water does not affect the density.
   b. The block will float in beaker B. The volume of the water has changed, so the density of the water has changed.
   c. The block will float in beaker B. The volume of water relative to the size of the block has increased.
   d. There is not enough information to answer this question.

5. An unknown liquid is contained in beaker A. Will the density of the liquid change if it is transferred to beaker B?

   a. The density of the liquid will decrease because its volume will increase.
   b. The density of the liquid will increase because its volume will increase.
   c. The density of the liquid will remain the same.
   d. There is not enough information to answer the question.
6. Consider the two rectangular solids below. If both have a mass of 25.0 grams and both sink in water, which would you expect to displace a greater volume of water?

a. A will displace more water because it is more dense.
b. B will displace more water because it is more dense.
c. A will displace more water because it has a smaller volume.
d. B will displace more water because it has a larger volume.
e. Both will displace the same amount of water because they have the same mass.

7. Figure 1 represents 1.0 L of water with sugar dissolved in it. Which of the following best represents how it will look upon addition of 1.0 L of water?

Figure 1

(a) (b) (c) (d)
8. Suppose you freeze some salt water from the ocean. What is the composition of the resulting solid?
   a. Salt
   b. $\text{H}_2\text{O}$
   c. Salt and $\text{H}_2\text{O}$
   d. Salt water cannot be frozen

9. Suppose you observe water that has been boiling for 20 minutes. What are the bubbles you see composed of?
   a. $\text{H}_2\text{O}$
   b. $\text{H}_2$ and $\text{O}_2$
   c. Air
   d. $\text{H}_2\text{O}$, $\text{H}_2$, $\text{O}_2$, and air
   e. $\text{CO}_2$

10. If you dissolve 1 pound of salt in 20 pounds of water, which of the following statements will be true?
     a. The density of the resulting solution will be the same as that of the water.
     b. The density of the resulting solution will be less than that of the water because the volume of the solution will be greater than that of water.
     c. The density of the resulting solution will be greater than that of the water because the mass of the solution will be greater than that of the water.
     d. There is not enough information to answer the question.
To the best of your ability, define the following terms:

a. dissolve

b. evaporate

c. melt

d. soluble

e. boil

f. freeze

g. condense

h. compress

i. mixing

j. saturate
Density of Solids and Liquids
Measurement and Significant Figures

OBJECTIVE: This experiment involves the determination of the density of liquids and solids. Precision measurements and significant figures are stressed.

Upon completing this experiment, the student should be able to:

- Understand the mathematical relationship between mass, volume and density.
- Weigh materials accurately to two (2) decimal places.
- Determine the density of regular and irregular solids.
- Determine the precise volume of a container.
- Determine the density of an unknown liquid.
- Calculate average and standard deviation for a set of measurements.

EQUIPMENT AND MATERIALS:

Wooden blocks of regular shape
Metal cylinders
Metric ruler
100 mL graduated cylinder
25 mL graduated cylinder
disposable pipets and bulbs
liquids of unknown densities
top-loading balance

INTRODUCTION:

A fundamental physical property of any substance is its density. Density is defined as the mass of a substance per unit volume. By that we mean that a particular volume is selected (e.g. one milliliter), and we determine the mass of one milliliter of a substance. Since volume changes with temperature, due to expansion or contraction, the density of any material is always given for a particular temperature. For example, at exactly 4 degrees Celsius, the density of water is exactly 1 g/mL. At the end of this introduction is a table that provides the density of water at different temperatures.

Density can be very useful property to know. It can be used in the "non-destructive testing" of objects. The classic example of such a test was allegedly performed by the Greek scientist Archimedes, who was asked to determine if a gold crown was really an alloy containing other metals. He determined the density of the crown,
finding that it did not match that of pure gold. A chemical test for purity requires the removal of a sample from the object, or at least a chemical attack on a portion of the object's surface. A more modern example is the testing of jade art objects. Not only are there two kinds of jade, but in the case of Central American art objects, it appears that the Native Americans used a variety of green stones, even mixing them in mosaics. True jadeite is denser than its look-alikes, and thus can be separated from them.

In order to calculate the density of an object, it is necessary to know both the volume of the object and its mass. Density is then a simple calculation as follows:

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]

In this experiment, you will find the density of a solid object by calculating its volume from direct measurements, and also by using Archimedes' method. You will also find the density of an unknown solution.

This experiment also requires that you follow the rules for significant figures when making measurements, and when using these measurements in calculations. The precision of a measurement depends on how many digits can be included in that measurement. For example, in this experiment you will weigh objects to two decimal places. The precision of the balance limits the weights of objects over 31 grams to two decimal places.

When performing calculations, the number of significant digits cannot exceed the actual precision of the measurements used in the calculation. When adding or subtracting measurements, only the fewest decimal places are allowed in the result. When multiplying or dividing, only the fewest significant figures are allowed.

In Part Three of this experiment, a graduated cylinder will be calibrated, and the calibration procedure will be performed three times. The average deviation and standard deviation of the three calculated volumes for the graduated cylinder will be determined. The calculations are as follows:

\[
\text{Average Deviation} = \frac{\sum |x_i - \bar{x}|}{n}
\]

\[
\text{Standard Deviation} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}
\]

Where \(x_i\) stands for each calculated volume, \(\bar{x}\) stands for the average of these values, and \(n\) is the number of values.
TABLE I - DENSITY OF WATER IN GRAMS PER MILLILITER

<table>
<thead>
<tr>
<th>Temperature (Celsius)</th>
<th>Density</th>
<th>Temperature (Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>0.9986</td>
<td>25</td>
</tr>
<tr>
<td>19</td>
<td>0.9984</td>
<td>26</td>
</tr>
<tr>
<td>20</td>
<td>0.9982</td>
<td>27</td>
</tr>
<tr>
<td>21</td>
<td>0.9980</td>
<td>28</td>
</tr>
<tr>
<td>22</td>
<td>0.9978</td>
<td>29</td>
</tr>
<tr>
<td>23</td>
<td>0.9976</td>
<td>30</td>
</tr>
<tr>
<td>24</td>
<td>0.9973</td>
<td></td>
</tr>
</tbody>
</table>

EXPERIMENTAL PROCEDURE:

PART ONE – DENSITY OF A REGULARLY SHAPED OBJECT

a. Obtain a wooden block and metric ruler from the supply table. Record its code number in your notebook.

b. Measure the dimensions of the block as precisely as the ruler will allow. Record these values.

c. Weigh the block to two decimal places on the top-loading balance. Record its mass.

PART TWO – MEASUREMENT OF DENSITY USING ARCHIMEDES' PRINCIPLE

a. Obtain a metal cylinder from the supply table. Write the identification number of the cylinder in your notebook. Check that the cylinder is dry. Weigh the cylinder on the top-loading balance, recording its mass to a precision of two decimal places. Record this mass in your notebook.

b. Fill the 100 mL graduated cylinder part way with water. (How much water depends on the size of your metal cylinder. Estimate how much space the metal object will occupy when it is placed inside the graduated cylinder, and then add enough water to insure that the metal will be completely covered.) Read the volume of water as precisely as the graduations allow. Record this value.

c. Holding the graduated cylinder at an angle, slide the metal cylinder into the graduated cylinder, completely submerging it (be careful not to splash out any water). Read the new volume precisely and record it. The difference
between the volume of water with and without the cylinder is the cylinder’s volume. Calculate this value and write it in your notebook.

d. Dry the metal cylinder carefully with a paper towel and return it to the supply table.

PART THREE - DENSITY OF A LIQUID

I. Determining the Precise Volume of the 25 mL Graduated Cylinder

a. Clean and dry the 25 mL graduated cylinder as follows: Rinse the graduated cylinder with tap water followed by a single rinse with distilled water. Then rinse the graduated cylinder once with approximately 5 mL of acetone. Carefully pour this material directly into a sink drain, and rinse it away with cold water. Then place the graduated cylinder upside down in a beaker containing a folded paper towel, and allow it to drain for at least five minutes. After draining is complete, examine the graduated cylinder for visible droplets of liquid on the inside wall. If such droplets are visible, again rinse the graduated cylinder with acetone and allow it to drain. If your graduated cylinder has a plastic base, remove the base and check for water trapped between the glass tube and plastic socket. Dry as necessary.

b. Weigh the graduated cylinder two decimal places. Record the mass of the cylinder.

c. Fill the graduated cylinder with distilled water up the 25 mL calibration line etched on the cylinder. Use a disposable pipet and bulb to help you add small volumes of liquid. Be sure that the lowest level of the meniscus is even with the calibration line. If there are any droplets clinging to the inside of the neck of the graduated cylinder, they must be removed. Roll a paper towel into a small cylinder and insert it into the graduated cylinder neck to remove droplets. If you overfill the graduated cylinder slightly, touching the towel to the surface of the liquid will cause a small amount to be absorbed, lowering the liquid level.

d. Wipe the outside of the graduated cylinder with a paper towel. Weigh the graduated cylinder on the balance, recording the total mass. Calculate the mass of water.

e. Measure the temperature of the water in the graduated cylinder. Use the table listing density of water vs. temperature in order to determine the density of water in this experiment.
g. Now repeat this entire procedure twice more from the beginning, again drying the graduated cylinder with acetone, weighing it dry, filling it with water, and weighing it again.

II. Determining the Density of the Unknown Liquid

a. Using a clean, dry beaker, obtain about 50 mL of a salt solution whose density is unknown. Record the code for this material.

b. Empty the water from the 25 mL graduated cylinder. Rinse the graduated cylinder three times with unknown liquid, using about 5 mL each time. This will remove the water from the inside walls of the graduated cylinder, and replace it with the unknown liquid. It is not necessary to dry the graduated cylinder. (Note that the graduated cylinder has not again been dried and weighed empty. The average of the empty, dry weight from the calibration of the cylinder will be used instead of reweighing.)

c. Fill the graduated cylinder to the calibration line with unknown liquid. Again use a disposable pipet to add small amounts of liquid when filling the cylinder carefully to the 25 mL calibration line. Use the same techniques that you used before to remove any droplets from the inside of the neck of the graduated cylinder, and to dry the outside of the graduated cylinder. Weigh the graduated cylinder on the balance. Record the mass.

d. As a test of how precisely you can fill the graduated cylinder to the calibration line, empty about 5 mL from the graduated cylinder, and refill to the calibration line. Again clean the graduated cylinder and weigh it. Repeat this operation. This will give you three sets of data.
INTERPRETAION OF DATA

Part One – Density of a Regularly Shaped Object

Calculate the volume of the wooden block and its density, using the proper number of significant figures. The number of significant figures is controlled by the precision to which you measured the dimensions and mass of the block.

Note: If your block is actually a triangle or a cylinder, be careful to use the correct formula for calculating volume.

Part Two – Density Using Archimedes Principle

Calculate the density of the metal cylinder from the measured mass and volume of water displaced. Use the proper number of significant figures. Since you used a 100 mL graduated cylinder, which is calibrated in 1 mL increments, you should estimated between the calibration lines and read the volume to the nearest 0.1 mL.

Part Three

Calibration of the Graduated Cylinder:

The precise volume of the graduated cylinder can now be calculated by rearranging the formula for density. Do not assume that the graduated cylinder is precisely 25.0 mL. Be sure to use the proper number of significant figures. You will have measured the mass of water to four significant figures, and we will use four significant figures for the density of water given in the table.

Calculate the volume of the graduated cylinder twice more, and obtain an average of the three values. Calculate the average and standard deviations using the formulas given in the Introduction.

Density of the Unknown Liquid:

You now have the necessary data to calculate the density of the unknown liquid, in triplicate, using the proper number of significant figures. Be sure to use the average calculated volume of the graduated cylinder, not 25 mL. Average the three values. Calculate the standard deviation.
LABORATORY REPORT FORM: Density of Solids and Liquids

PART ONE – Density of a Regular Solid

Identification code for wooden block  ____  Shape of block

Dimensions of block (as appropriate)  
length ____ cm  width ____ cm  
height ____ cm

Mass of wooden block  _______ g  
Calculated volume of block  _______ cm³  
Density of block  _______ g/cm³

PART TWO - Archimedes Principle

Identification code for Metal  

mass of metal cylinder  _______ g  
volume of water in graduated cylinder  _______ mL  
volume with addition of metal cylinder  _______ mL  
volume of metal cylinder  _______ mL  

density of metal cylinder  _______ g/mL
PART THREE  Density of a Solution

I.  Determination of Graduated cylinder Volume

mass of empty graduated cylinder  ________g ________g
mass of graduated cylinder + water  ________g ________g
mass of water  ________g ________g
temperature of water  ________ oC ________ oC
density of water (from table)  _______g/mL _______g/mL

calculated volume of graduated cylinder  ________mL ________mL ________mL

average calculated graduated cylinder volume  __________
mL

average deviation  __________
mL

standard deviation  __________
mL

II.  Density of unknown liquid

Unknown Code____

mass of graduated cylinder + unknown liquid  ______g _____g _____g
average mass of empty cylinder (from before)  ______g _____g _____g
mass of liquid  ______g _____g _____g
calculated density of liquid in g/mL  _______ _______ _______

average density  __________ g/mL
standard deviation  __________ g/mL
average deviation  __________ g/mL

CALCULATIONS
Identification of Substances by Physical Properties

OBJECTIVE: To identify two unknown compounds by experimentally determining several of their physical properties.

EQUIPMENT AND MATERIALS

Apparatus

- assorted beakers and flasks
- small test tubes
- test tube rack
- eye dropper
- 10 ml graduated cylinder
- spatula
- capillary tube
- small rubber band
- watch glass
- long glass tube
- 10 ml pipet
- pipet bulb or pump
- 2 hole rubber stopper
- boiling stones
- ring stand
- utility clamp
- hot plate
- thermometer

Chemicals

- Ethanol
- Cyclohexane
- Acetone
- Naphthalene
- Two Unknowns (1 solid and 1 liquid)

INTRODUCTION

Physical properties are those characteristics of a pure substance that can be measured without altering the chemical composition of the material. Such properties include color, odor, taste, melting point, boiling point, solubility, density, surface tension, viscosity, refractive index, etc. By measuring a sufficient number of physical properties of an unknown pure substance, the identity of the substance may be determined. Several notable reference books exist that contain large compilations of such physical properties. These include the Chemical Rubber Company's Handbook of Chemistry and Physics and N. A. Lange's Handbook of Chemistry. A very abbreviated table is provided in Table 1.

In this experiment, you will use the properties of solubility, density, melting point and boiling point to identify one solid and one liquid unknown.

The solubility of a substance in a particular solvent is the maximum amount of the substance that will dissolve in a given volume of solvent (for example, grams/liter) at a given temperature. In this experiment, you will qualitatively determine the solubility of a few solutes in several solvents. The solubility will be designated as soluble (s), partially soluble (p), or insoluble (i).
The density, \( d \), of a substance is defined as the ratio of its mass, \( m \), to its volume, \( v \) and measures the compactness of the atoms or molecules making up a substance.

\[
d = \frac{m}{v}
\]

As a general rule, the solid form of a substance is denser than its liquid form which, in turn, is denser than the gaseous form.
The melting point of a solid is the temperature at which the solid and liquid phases are in equilibrium. Since the melting points of many inorganic (ionic) salts are quite high, the determination of melting points as a means of identification is not that practical; sodium chloride, for example, melts at 801 °C. Organic compounds typically have lower melting points and may be identified with the help of their melting points.

The normal boiling point of a liquid is the temperature at which the vapor pressure of the liquid equals 760 torr and is a constant for a particular liquid. The liquid and gaseous phases are in equilibrium at this temperature and bubbles of vapor can be seen to form within the liquid. For precise work, one must take into account that normal atmospheric pressure is not exactly 760 torr and the observed boiling point will vary depending upon the exact atmospheric pressure. We will not concern ourselves with this small correction.

**PROCEDURE**

**A. Solubility**

You will qualitatively determine the solubility of two knowns (naphthalene and acetone) and two unknowns (one solid and one liquid) in each of three solvents (water, cyclohexane and ethanol). In order to draw any valid conclusions, it is important to use approximately equal amounts of solute and solvent in all cases.

Place a few crystals of naphthalene in each of three small clean test tubes. Add approximately 2 ml of water to the first test tube, 2 ml of cyclohexane to the second test tube, and 2 ml of ethanol to the third test tube. Cover each test tube with parafilm or use a stopper and mix well. You can also use a glass stirring rod to mix the contents of each test tube. If the naphthalene does not dissolve immediately, wait a minute and mix again. Even soluble compounds require time to completely dissolve. Record the solubility as “s” (soluble), “i” (insoluble), or “p” (partially soluble).

Repeat the above procedure for acetone and your solid and liquid unknowns. Be consistent with the amounts of solute and solvent. Note: any cloudiness or the appearance of a second layer indicates insolubility. Compare the results for your two knowns with the solubility provided in Table 1; they should agree.

Dispose of the naphthalene, cyclohexane and your unknowns as directed by your instructor.

**B. Density**

In order to determine the density of your solid unknown, weigh about 1.5 g of the solid accurate to three decimal places. Be sure the balance reads three decimal places. Half fill a clean dry 10 ml graduated cylinder with a solvent in which your unknown solid was insoluble. Be careful to keep the walls of the cylinder dry. Record the volume of solvent in the cylinder to two decimal places. Carefully transfer the weighed solid unknown to the graduated cylinder. Using a spatula or a stirring rod, make sure the solid sinks to the bottom of the cylinder. If any of the solid floats or adheres to the walls of the graduated cylinder, you will not get an accurate volume. Record the final volume to two decimal places. The difference between the final and initial volumes yields the volume of your solid unknown.
Using the measured mass and computed volume for your solid unknown, calculate its density. Repeat if time permits.

In order to determine the density of your liquid unknown, weigh a small clean dry beaker to three decimal places. Obtain about 15 ml of the unknown liquid in a test tube. Carefully pipet 10.0 ml of the unknown liquid into the weighed beaker. Using a pipet bulb or pump, draw the liquid up to the calibration mark; the bottom of the meniscus should be even with the calibration line. Do not blow out the last bit of liquid from the pipet; it is calibrated to deliver the proper volume under the influence of gravity. Record the mass of the beaker with liquid and compute the density of the liquid unknown. Repeat if time permits.

C. Melting Point

In order to determine the melting point of your solid unknown, tap the open end of a capillary tube into a sample of the finely pulverized solid. If the solid is not already finely pulverized, you may need to use a mortar and pestle. You need a sample of unknown that is only about 5 mm in length. A small sample helps to insure temperature homogeneity during the melting point determination; do not use too much sample. Drop the capillary tube, open end up, down a long glass tube in order to pack the sample in the bottom of the capillary tube.

Attach the capillary tube to a thermometer using a small rubber band or piece of rubber tubing. The sample should be centered next to the thermometer bulb. Clamp the thermometer in a beaker of water on a hotplate so that the thermometer bulb and sample are completely submerged under water. The thermometer should not touch the sides or bottom of the beaker. Very gradually heat the water and note the temperature at which the sample begins to melt. At this point the crystals may appear shiny and begin to coalesce. Also, note the temperature at which the sample has completely liquefied. The true melting point can be taken as the average of these two temperatures. It is imperative that the heating is done very slowly otherwise you will not get good results. Be patient. Repeat if time permits.

D. Boiling Point

The normal boiling point of your liquid unknown will be done as a demonstration by your instructor.

E. Identification of Unknowns

Using the physical properties of your solid and liquid unknowns determined above, identify them from Table 1. Find the two pure substances that best fit all of your data. In a neat table, compare your measured results with the theoretical (correct) values from Table 1. Write the properties of the solid unknown in the table followed in the row below with the identity for the unknown and the corresponding table properties. Repeat for the liquid unknown.
<table>
<thead>
<tr>
<th>Substance</th>
<th>Density (g/ml)</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Solubility¹ in Water</th>
<th>Solubility in Cyclohexane</th>
<th>Solubility in Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetanilide</td>
<td>1.22</td>
<td>114</td>
<td>304</td>
<td>p</td>
<td>p</td>
<td>s</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.79</td>
<td>-95</td>
<td>56</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Benzophenone</td>
<td>1.15</td>
<td>48</td>
<td>306</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Bromoform</td>
<td>2.89</td>
<td>8</td>
<td>150</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>2,3-Butanedione</td>
<td>0.98</td>
<td>-2.4</td>
<td>88</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>t-Butyl Alcohol</td>
<td>0.79</td>
<td>25</td>
<td>83</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.49</td>
<td>-63.5</td>
<td>61</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>0.78</td>
<td>6.5</td>
<td>81.4</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>p-Dibromobenzene</td>
<td>1.83</td>
<td>86.9</td>
<td>219</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>p-Dichlorobenzene</td>
<td>1.46</td>
<td>53</td>
<td>174</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>m-Dinitrobenzene</td>
<td>1.58</td>
<td>90</td>
<td>291</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Diphenyl</td>
<td>0.99</td>
<td>70</td>
<td>255</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Diphenylamine</td>
<td>1.16</td>
<td>53</td>
<td>302</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Diphenylmethane</td>
<td>1.00</td>
<td>27</td>
<td>265</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Ethyl Propyl Ether</td>
<td>1.37</td>
<td>-79</td>
<td>64</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.66</td>
<td>-94</td>
<td>69</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>0.79</td>
<td>-98</td>
<td>83</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Lauric Acid</td>
<td>0.88</td>
<td>43</td>
<td>225</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Methyl Alcohol</td>
<td>0.79</td>
<td>-98</td>
<td>65</td>
<td>s</td>
<td>p</td>
<td>s</td>
</tr>
<tr>
<td>Methylene Chloride</td>
<td>1.34</td>
<td>-97</td>
<td>40.1</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>1.15</td>
<td>80</td>
<td>218</td>
<td>i</td>
<td>s</td>
<td>p</td>
</tr>
<tr>
<td>α-Naphthol</td>
<td>1.10</td>
<td>94</td>
<td>288</td>
<td>i</td>
<td>i</td>
<td>s</td>
</tr>
<tr>
<td>Phenylbenzoate</td>
<td>1.23</td>
<td>71</td>
<td>314</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Propionaldehyde</td>
<td>0.81</td>
<td>-81</td>
<td>48.8</td>
<td>s</td>
<td>i</td>
<td>s</td>
</tr>
<tr>
<td>Stearic Acid</td>
<td>0.85</td>
<td>70</td>
<td>291</td>
<td>i</td>
<td>s</td>
<td>p</td>
</tr>
<tr>
<td>Thymol</td>
<td>0.97</td>
<td>52</td>
<td>232</td>
<td>p</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.87</td>
<td>-95</td>
<td>111</td>
<td>i</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>p-Toluidine</td>
<td>0.97</td>
<td>45</td>
<td>200</td>
<td>p</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Zinc Chloride</td>
<td>2.91</td>
<td>283</td>
<td>732</td>
<td>s</td>
<td>i</td>
<td>s</td>
</tr>
</tbody>
</table>

¹ s = soluble  i = insoluble  p = partially soluble
Report Form: Identification of Substances by Physical Properties

A. Solubility

<table>
<thead>
<tr>
<th>Substance</th>
<th>Water</th>
<th>Cyclohexane</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphthalene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Unknown</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Unknown</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Density of Unknowns

<table>
<thead>
<tr>
<th>Unknown Type</th>
<th>Final Volume of Liquid</th>
<th>Volume of Liquid</th>
<th>Initial Volume of Liquid</th>
<th>Mass of Beaker plus Liquid</th>
<th>Volume of Solid</th>
<th>Mass of Empty Beaker</th>
<th>Mass of Solid</th>
<th>Density of Solid</th>
<th>Density of Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Unknown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Unknown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C. Melting Point of Solid Unknown

<table>
<thead>
<tr>
<th>Initial Temperature</th>
<th>Final melting Temperature</th>
<th>Melting Point of Solid (avg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D. Boiling Point of Liquid Unknown (Demonstration)

<table>
<thead>
<tr>
<th>Boiling Point of Liquid Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

E. Identification of Unknowns

<table>
<thead>
<tr>
<th>Substance</th>
<th>Density</th>
<th>Melting Pt.</th>
<th>Boiling Pt.</th>
<th>Water</th>
<th>Cyclohexane</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid #</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid #</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Separation of the Components of a Mixture

OBJECTIVE: The purpose of this experiment is to determine the percent composition of a mixture of substances using physical processes to separate the mixture into its constituent parts.

Upon completing this experiment, the student should be able to:

• Weigh objects to three decimal places using an electronic balance.
• Perform a sublimation in a fume hood.
• Perform and extraction and decantation.
• Evaporate a salt solution to dryness
• Calculate percent composition of a mixture

EQUIPMENT AND MATERIALS:

Top-loading balance
Ring stand with iron ring
Watch glass
Small evaporating dish
Clay triangle
Hot plate
Casserole dish
Bunsen burner
Wire screen
25 mL graduated cylinder
Crucible tongs
Mixture of NH₄Cl, NaCl,
SiO₂

INTRODUCTION:

In this experiment a mixture of sand (SiO₂), salt (NaCl) and ammonium chloride (NH₄Cl) will be separated by physical means and the percentages of each in the mixture determined.

The physical processes to be employed are sublimation, extraction, and decantation. Sublimation occurs when a solid evaporates directly, without passing through the liquid state. The classic example of a compound that sublimes is “dry ice”, which is solid carbon dioxide. Solid carbon dioxide vaporizes easily at room temperature. Extraction is a process where a substance is dissolved in a liquid that can then be separated from any remaining material. In this experiment the salt is extracted using water, and the resulting solution is then separated from the sand via the third process, called decantation. Decantation simply means pouring off a liquid leaving behind other material in the container.
PROCEDURE:

1. Weigh a clean, dry evaporating dish to the nearest 0.01 g using the top-loading balance. Record this weight in your notebook.

2. Add about 2 grams of the mixture to the evaporating dish, and weigh it again. Don’t forget to record this second weight.

3. In the hood there will be a ring stand, iron ring, and clay triangle set up with a Bunsen burner. Place the evaporating dish on the clay triangle and begin heating. Heat carefully so that no material spatters from the dish. White fumes will appear. When the white fumes stop, heat strongly for about 5 minutes. The material remaining in the evaporating dish must not have a yellowish coloration. A yellow color indicates that not all the Ammonium Chloride has sublimed.

4. Using the crucible tongs, remove the evaporating dish and place it on a wire screen at your bench. While the dish is cooling heat about 40 mL of deionized water on a hot plate. Do not allow this water to boil. After the evaporating dish has cooled, weigh the dish and record the value.

5. Next weigh a clean, dry casserole dish and watch glass together. Record this combined mass.

6. Now add about 15 mL of warm deionized water to the sand-NaCl mixture in the evaporating dish. Stir gently for about 10 minutes. Then allow any suspended sand to settle and decant the salt solution into the casserole, leaving the sand behind. You will not be able to pour out all of the liquid. It is acceptable to leave a small amount in the dish.

7. Add an additional 10 mL of warm deionized water to the evaporating dish and mix with the sand for about 5 minutes more. Again decant the solution into the casserole, leaving the sand behind. Repeat this step with another 10 mL portion of water. You will now have about 35 mL of salt solution in the casserole, and the sand remaining in the evaporating dish will be wet, but should be free of NaCl.

8. Place the casserole, covered with the watch glass, on a hot plate. Place the evaporating dish containing the sand on the same hot plate, but in one corner. Heat the solution in the casserole so that it boils very gently. Adjust the watch glass so that steam can escape from the spout of the casserole. Avoid loss of solution through spattering or boil-over.
9. The sand will dry first. When it is dry remove the evaporating dish from the hot plate. Allow it to cool, and then weigh it. Don't forget to record the value in your notebook.

10. When the water in the casserole has evaporated there may still be droplets clinging to the underside of the watch glass. Pick it up with the crucible tongs and drain the droplets into the dish. Replace the watch glass and heat until the underside is completely dry.

11. Allow the casserole and watch glass to cool, and weigh them together. Record this final mass.

12. Dispose of the sand in the trash. Wash all glassware and evaporating dishes to remove salt and any other residual materials.
INTERPRETATION OF DATA:

Calculate the percent of each component (Ammonium Chloride, Sodium Chloride, Silicon Dioxide) in the sample.

\[
\text{\% component} = \frac{\text{mass component in grams}}{\text{mass of sample in grams}} \times 100
\]

Calculate the total mass of the three components, and using the original mass of the sample find the percent recovery of material.

Prepare a report that includes all experimental data as well as the calculated results. All data should be presented in a table. Discuss any errors that occurred in your experimental work.
Density Interview Questions

Students will be given a syringe. Student will be asked to pull back the plunger to a certain mark, then asked “What is in the syringe?”

If student responds that “Air” is in the syringe, ask “What is air made of?”

Students may respond with names of compounds comprising the make-up of air. Question then might be “What are those elements/compounds made of?” Lead to “Is air made up of particles?”

Ask student to read the volume of air in the syringe.

Ask if air has mass. Density?

Have student put thumb over end of syringe and attempt to compress the air as much as possible

Have student read new volume.

Ask “Where did the air go/what happened to it/ what change was there to the particles?”

Ask what is between the particles?

Ask “When it is compressed, does the density of the air change? Why/why not?”

Ask if liquids can be compressed? (Student can try this with water if they want to) Why or why not?

Ask if solids can be compressed? If student says “yes,” ask for an example for clarity.

Phase Change Interview Questions

Students will be presented (on video) with a beaker of boiling water.

Ask what the bubbles are.

If the student says “air,” ask where the air comes from. If they say “Water vapor,” ask why/how it forms. If student says H₂/O₂, ask how it forms.

Can all substances freeze? Can gases freeze? Do molecules stop moving at the freezing point?

Ask the student what would happen if a drop of methanol was placed on the table top. (They have used methanol in the lab; they should know it evaporates.)

What’s the difference between evaporation and boiling? Do you have to heat water to evaporate it?

Suppose I place a glass of iced tea on the table top and after a time clear liquid droplets form on the outside of the glass. What is that liquid? Where does it come from/how does it get there?

**Solubility Interview Questions**

Give the student a sample of sugar and ask him/her to describe it. Have him/her dissolve a small quantity of sugar in water.

Ask where did the sugar go?

Where in the beaker would you find the sugar? (How is it distributed?)

If we let this sit for an hour, where would a particle that is in the middle now be at the end of the hour? At the end of two hours? Three hours? Why?

Is this a mixture? A solution? A homogeneous mixture?

Is the density of this solution different from the density of the water? Why?

If we stuck this in the freezer and it froze, how would the sugar be distributed in the frozen material?

Suppose we put so much sugar in that it will not all dissolve. What determines which particles dissolve? Do dissolved and undissolved particles ever exchange?

Can there be a solution that is not made up of a solid and a liquid?
Definition of particle

I: What is a particle?
S: Like a molecule?
I: Okay, is that what a particle is?
S: Well, gases are made of particles, so I guess it could be an atom or a molecule, which is two atoms.
I: Are liquids made of particles?
S: Ummm. Why don’t you define particle?
I: [Laughs] Nice try.
S: Well, that’s just a word in the English language. It could mean anything.
I: Do we have a specific meaning for it in chemistry?
S: Well, in chemistry it means ...a small piece?
I: Okay, and so are liquids made up of particles?
S: Yeah.
I: Are solids?
S: Yeah.

Definition of Particle

I: What is a particle?
S: A part, like a small piece.
I: Of?
S: Just a small piece.
I: A small piece of anything?
S: Yeah.
I: Okay. Does it have a state associated with it?
S: (Long Pause)
I: A phase. Like a solid, liquid or gas?
S: I think it could be solid, liquid, or gas.
I: Okay.

Definition of Particle

I: What is your definition of the word particle?
S: Hmmm, let’s see. If I have like a CO₂ molecule, one carbon and two oxygens, I guess that would be a particle...I think that’s about the best I can do.
I: Okay, what if you had a particle of copper? What would that be?
S: I guess just one copper?
I: One copper what?
S: Well, copper is an element, so I guess just one copper...element?
87 Definition of Particle

I: What is your definition of the word particle?
S: If I thought about particle, I would think it has to do with an object or an item.
I: Is there a phase associated with it? Like solid, liquid, or gas?
S: I think the phase would be solid.

14 Definition of particle

I: Can you tell me what your definition of the word particle is?
S: Particle? Hmm. I’d go so far as to say it’s something…like if you have an object and something breaks away. A part of that object.
I: Okay. Do particles have a phase associated with them?
S: (Long Pause)
I: Like solid, liquid, or gas…
S: No. Well, I’d have to say solid. Well, no because then that’s broken down. I guess they’d have all three. That’s a good question. Yeah, I guess they’d have all three.
I: Okay.

49 Definition of Particle

I: What is your definition of the word particle? If you were asked to define that word, how would you define it?
S: Okay, that’s tough. Umm. It’s a…piece of something, like a clump of sand…just the smallest little grain.
I: Okay. Does it have a phase associated with it? Like is it a solid a liquid or a gas?
S: I would say that it could be any of those. When I think of particle, I automatically go to solid, but I think it could be any.

39 Definition of Particle

I: Can you define for me the word particle?
S: A particle is any leftover or any remains of a substance.
I: Remains after what?
S: Remains after precipitation. That’s what I’d say a particle is.

08 Definition of Particle

I: The first thing I’m going to ask you is what is your definition of the word particle?
S: The word particle…I’m not sure about that.
I: You don’t have a definition?
S: No.
I: Can you use it in a sentence?
S: Ummmm. Particle….no, not really.
I: Okay, we’ll move on.

83 Definition of Particle

I: What is your definition of the word particle?
S: A piece of something that’s whole.
I: Okay. Do particles have a phase associated with them, like solid, liquid, or gas?
S: Can be either. It’s a matter of what makes up a solid. liquid, or gas. In a solid the particles are very close together but in a gas they are free-flowing and in a liquid they just do whatever.

16 Definition of Particle

I: Can you define the word particle for me?
S: A particle is a very small amount of something.
I: Does it have a phase associated with it, solid, liquid, or gas?
S: Dust particles, so I assume they would be solid.
I: Okay, so are all particles solid?
S: Probably not, but I’m not aware of others.

02 Definition of Particle

I: How do you define the word particle?
S: A very small piece of matter. Like an atom or molecule.
I: Okay, does a particle have a phase associated with it?
S: Well, I’d think they’re solid, but there are different phases of matter.
I: How do you think that works?
S: I guess the way the pieces are put together.
I: So you think the particles themselves are solid?
S: Yeah, I think so.
Student is given syringe and asked to pull back the plunger to a certain mark on the barrel.

I: Is there anything in the syringe?
S: Umm. O₂. A mixture of O₂ and other gases.
I: Okay, is there a name for that mixture of gases?
S: Air?
I: Okay..is that what is in there?
S: Yes.
I: What would you say air is made of?
S: Hydrogen, oxygen, just gases.
I: Is air made of particles?
S: Yeah.
I: Okay.
I: So how much air is in there right now? Just approximately?
S: Fifteen mls?

Student is now asked to place his/her thumb over the end of the syringe barrel hole and push the plunger as far as possible without releasing the thumb.

I: Now how much air is in there?
S: Same amount?
I: Read the volume.
S: Seven mls---of compressed air.
I: Okay, so you compressed the air?
S: Yeah, because of the pressure. Is that right?
I: Well, what happened to the particles when you pushed on the cylinder?
S: They got compressed. Wait, compression is different from pressure, isn’t it? I forgot.
I: Well, what do you think happened to them? Just tell me what you think.
S: The gases have no definite volume, and they take the shape of whatever they’re in, so now it’s in here, and because there is particles in here, it’s not nothing, when you compressed it, it just kept the amount of gas the same, so the same amount of gas in a smaller area, and a lower pressure….wait….how do I explain?
I: Well, you used the word “compress.” So when you compressed it, what happened to the particles that allowed them to take up less space?
S: They got closer together.
I: Okay, what’s between the particles?
S: Uh…well, is a particle an atom?
I: Well, we agreed that air is made up of particles, right?
S: So a particle of water is one molecule of H₂O? Is that a particle?
I: Okay, let’s go with that definition.
S: Okay, so if air is O₂….is air O₂?
I: Well, you said earlier that air was made up of O₂ and some other things.
S: Yeah, but if you were to write “air,” how would you write it?
I: Well, I think it’s a mixture, is that right?
S: Yeah.
I: Okay. Is it a mixture made up of particles?
S: Yeah.
I: So, my question to you is when you pushed the plunger up—you used the word compress, and I think that’s a valid word—when you compressed it, you said that the particles got closer together? Is that right?
S: [Nods]
I: What is between the particles? Why can you push them closer together?
S: Well, because it’s a gas. Like they’re… I guess the difference between gas particles and solid particles… gas particles are further apart. I guess that each particle has an electron shell around it. It’s a nucleus and an electro shell around it and when you increase the pressure you lower the area and the volume….Ah, I don’t know.
I: That’s okay. Let’s move on.
Could you compress a liquid?
S: I don’t think so.
I: Why not?
S: Because a liquid… well it’s like in a gas, the molecules are about his far apart [gestures with hands], and in a liquid this far apart [demonstrates molecules are closer together] and a solid this far apart [very close together]
I: So, could we compress a solid then?
S: Well, you could, but it would take an awful lot of force. No, you can’t actually. You can’t.

80 Density

Student is given syringe and asked to draw the plunger back to a certain mark on the barrel.

I: What is in the syringe?
S: Air. [laughs]
I: Okay. What is air made of?
S: Well, it has water vapor in it, and there’s all kinds of gases. There’s carbon dioxide, and there’s water in the air, and there’s oxygen, and I know there’s other stuff…
I: That’s okay. So it’s gases?
S: Yeah.
I: So what are those gases made up of?
S: Elements.
I: Are they… what’s the smallest part of one of them?
S: Atoms.
I: Are they all elemental gases?
S: I think… I don’t know…
I: Would you say that air is made of particles?
S: Yes?
Student is now asked to place his/her thumb over the end of the syringe barrel and push the plunger as far as possible without releasing the thumb.

I: What is the new volume?
S: About 10 ml.
I: Okay, so what happened? If air has particles, and before you pushed the plunger, the volume was 15 ml of air and now it’s 10, what happened to the particles that allowed you to do that?
S: They got smooshed together…I decreased the volume and there was nowhere else for them to go.
I: Did anything happen to the individual particles?
S: Maybe, but I don’t know.
I: Do you know what’s between the particles?
S: (Long pause) I would say other particles…They’re all just floating around in space.
I: So do you think there is anything between the particles?
S: Space. I mean, when I had it like this [pulls plunger back to original position], there was more space, and they may have been bouncing around more. Then when it was all smooshed together, there was less space in between.
I: Does air have mass?
S: No.
I: Does it have density?
S: Yes, so I guess it would have to have mass…I know it has density….
I: Well, does it have volume?
S: Yeah, it can. Well, I just did it [gestures to syringe], so it must.
I: What happened to the density then, when you pushed the cylinder up?
S: Ummm. Well, when it was back here, it was …oh, I increased it.
I: Okay, and why did it increase?
S: I changed the volume.
I: Did you do anything to the mass?
S: No. Mass stayed the same.
I: Could you compress a liquid the way you did the air?
S: No.
I: Why not?
S: ‘Cause if I had a liquid in here, it would just go out.
I: What’s different about a liquid and a gas that allows you to compress the gas but not the liquid?
S: Oh, there’s less space in the…when I had the air in here, there was obviously enough space between to let me squeeze out 5 ml. In a liquid, there’s less space.
I: Could you compress a solid?
S: [Laughs] Only if I had heavy machinery.

87 Density

Student is given syringe and asked to pull back the plunger to a certain mark on the barrel.
I: Is there anything in the syringe?
S: What’s in it? There’s like…Oh, air!
I: Okay, air. Now, if you were going to read the volume of air, what’s the approximate volume of air in the syringe?
S: Umm, about 15 ml.
I: Okay. So we have a known volume of air. What is air made of, do you know?
S: I don’t know what air is made of.
I: Well, do you know what kind of matter air is made of—is it solid, liquid, or gas?
S: It’s a solid.
I: A solid.
S: Hmmm. Yes.

Student is now asked to place his/her thumb over the end of the syringe barrel hole and push the plunger as far as possible without releasing the thumb.

I: Did anything happen to the volume of air?
S: It tightened.
I: It tightened. Did it get bigger or smaller?
S: It got smaller.
I: What would you call what we just did? Do you have a word for that?
S: Hmmm
I: Did the density of the air change?
S: Yes. We added more to the end…more pressure.
I: Okay, would you call that compression?
S: Yes.
I: Okay, when we compressed it, what changed?
S: The volume and the density.
I: How did the density change?
S: It got smaller.
I: So the volume got smaller and the density got smaller?
S: No—oops--the density got bigger.
I: Did we change the mass?
S: No.
I: Is air made of particles?
S: Yes.
I: Okay. When we compressed it, what happened to the particles that allowed it to take up a smaller volume?
S: They’re still there, right, so they…just…formed a…..I don’t know.
I: Did we change the particles?
S: No. We didn’t change the particles.
I: What did we change?
S: We just compressed it. They’re still there.
I: So what did we change that allowed it—
S: The mass, umm, the volume. Well, if we changed the volume?
I: We did change the volume. So my question is if air is made up of particles, and we compressed the air, so we were able to take the same mass of air and put it in a smaller volume, what changed?
S: Don’t know. Don’t know.
I: Okay. Do you know what is between the particles?
S: No.
I: Okay. If the syringe were full of a liquid, like water, maybe, could we have compressed it?
S: No, it would come out the syringe when we pushed it up.
I: What do you think is different about a liquid as opposed to air that won’t let it be compressed?
S: Well, I don’t know, a liquid has more…I don't know, the liquid just has to come out.
I: What about a solid? Could we compress a solid?
S: Yes.
I: How could we compress a solid?
S: We could compress solid because it would just tighten up like air would, I would think.
I: If we compressed a solid, would the volume change?
S: No, I don’t think it would. It couldn’t go out the top.

49 Density

Student is given syringe and asked to pull back the plunger to a certain mark on the barrel.

I: Is there anything in the syringe?
S: Air.
I: And do you know what air is made of?
S: It’s…carbon and oxygen.
I: Carbon and oxygen?
S: Yeah.
I: Is air made of particles?
S: Yeah, I would say so.

Student is now asked to place his/her thumb over the end of the syringe barrel hole and push the plunger as far as possible without releasing the thumb.

I: What is the new volume of the air?
S: About 6.
I: Okay, so we were able to change the volume of the air?
S: Yes.
I: So what happened to the particles when we did that?
S: They were compressed.
I: And what does that mean? What happened to them when we say they were compressed?
S: They were pushed together more than they were before.
I: What’s between the particles?
S: Good question. It’s empty space…more air.
I: Empty space or more air?
S: I’d say more air.
I: Well, how does that happen? You have air particles and you’re pushing them together.
S: I don’t know. [Laughs]
I: Does air have mass?
S: I would say no.
I: Does it have density?
S: I would also have to say no, but I’m not quite sure.
I: Well, does it have volume?
S: [Student looks at syringe] Well, I guess it depends on the composition of the air. Where it’s in this area, it’s obviously got it.
I: So it has volume?
S: Yeah.
I: And when we pushed the syringe up you said it compressed it?
S: Yeah.
I: But it doesn’t have mass or density.
S: Well, obviously it has to if it has volume.
I: Well, then when we compressed it, did it change the mass?
S: Yes.
I: How did it change it?
S: It changed the pressure…I… I really don’t know.
I: Could you compress a liquid like that?
S: No. It would come out.
I: What do you think is different from a liquid and a gas?
S: Gas particles are floating.
I: What about a solid? Could you compress a solid?
S: It depends on the solid. Hard solid or soft solid? Some solids are composed that the particles can be pressed closer together.
I: Do you think there is a difference in how the particles are arranged in those solids that can be compressed?
S: Yes.
I: What’s the difference?
S: Some of them are space out more than others. In a hard solid, it’s tight.

39 Density

Student is given syringe and asked to pull back the plunger to a certain mark on the barrel.

I: Is there anything in that syringe right now?
S: No liquid, but there’s gas.
I: Okay, there’s no liquid, but there’s gas?
It’s sealed tight, so we’d hope there’s no gas in there, but…

But there’s a hole right there.

Oh. Well, there’s definitely gas in there then.

What kind of gas is in there?

The regular gas in which air is composed in. Carbon dioxide. Probably some nitrogen, some oxygen…

Okay, would you say that air is made of particles?

No, I wouldn’t say that air is made of particles, because it should be consistent. It should be mixed very thoroughly.

Are gases made of particles?

I would say no, but I know the correct answer. [Laughs] Particles, in my definition, no. But in the true definition of what gas is made of, then yes. Because you do have pieces of each element that compose a gas.

Okay, so we have air in here and air is made up of particles?

Yes.

Student is now asked to place his/her thumb over the end of the syringe barrel hole and push the plunger as far as possible without releasing the thumb.

What is our new volume?

The new volume is 10.

So what have we done to the volume of the air?

We have decreased it.

When we did that, what happened to the particles that make up the air?

The difference was released.

They were released?

Well, if we started with 15 and now it’s 10, the volume decreased. So it released. Maybe I’m not saying it right.

But you had your thumb over it, so…?

Oh, it was compressed.

It was compressed. When you compressed the air, was there a change to the particles?

No, there was not.

Okay. How were you able to decrease the volume?

By increasing the pressure.

And what change occurred to the particles that allowed you to by increasing the pressure to decrease the volume?

So when you say change of the particles…I don’t know what to say other than it’s being compressed or the density is increasing. If the volume decreased, then the density increased.

Did we change the mass?

No, we didn’t change the mass at all.

Is there still the same amount of air in there?

Yes.

Okay, so we have the same amount of air, but it’s taking up less space. So something changed with regard to the particles that allowed us to compress the air.
S: But wouldn’t that be the volume—the space it takes up?
I: Let’s try it this way: Did anything happen to the individual particles when we compressed it?
S: No. We changed the amount of space the particles take up.
I: Okay. What’s between the particles?
S: From 10 to 15?
I: Just in general, what’s between the air particles?
S: I may know the answer, but not the way the question is phrased. I guess molecules. Gas? I don’t know.
  Wait—I’m thinking of your question. What changed—the space, the area of the volume is what changed.
I: The space between or the space that each particle takes up?
S: Between. I’m sorry. I was trying to remember my definition of pressure.
I: Oh, okay. But you really don’t have an idea of what’s between those particles?
S: If it’s not space…
I: Is it space?
S: Well, from 0 to 15 I’d say space. From 10 to zero, it’s the space that changed. Don’t know really.
I: If I had liquid in here, could I compress that?
S: No. Because the volume won’t change.
I: What is it about a liquid that is different from a gas that won’t allow you to compress a liquid?
S: The ability of the molecules to move around.
I: What about the space between the particles? Is there space between liquid particles?
S: There is space…well, I would say no, because if there was space between the two, when you exert that pressure then you should be able to
I: What about a solid? Could I compress a solid?
S: A solid? Given the amount of space, yes. [Uses syringe to demonstrate that if she had some zinc pellets in the syringe, she could push the plunger up]
I: Are you actually compressing the solid if you do that?
S: No, the air.

Density 16

Student is given syringe and asked to pull back the plunger to a certain mark on the barrel.

I: Is there anything in the syringe?
S: Air.
I: What is air made of?
S: 75% N₂, 25% O₂, and since those aren’t exact numbers, some CO₂, some CO, other gases.
I: What are those substances made of?
S: Atoms or molecules.
I: Do you think atoms and molecules are particles?
S: They could be.
I: Do you think air is made of particles?
S: Yes. There are particles in the air.
I: Are there other things in air, too?
S: Yes.
I: Okay.

Student is now asked to place his/her thumb over the end of the syringe barrel hole and push the plunger as far as possible without releasing the thumb.

I: What is the new volume?
S: 5 mls.
I: Okay, so we started with 15 mls and now we have 5 mls. What happened to the air?
S: We condensed it.
I: It was condensed. Is there water vapor in there?
S: It wasn’t condensed. like that. It just got smaller.
I: Okay. Does air have mass?
S: [Long pause] I know there’s air pressure, but I don’t know that it has mass.
I: Does it have density?
S: Well, what we just did, when we compressed it, the volume got smaller, it had to get more dense, so it must have density.
I: So, the volume changed? So air has volume?
S: Well, yeah. We saw it.
I: Okay, so you’re saying we changed the volume and that changed the density?
S: Yes, that’s right.
I: So, do you think, given what you just said, that air has mass?
S: There’s a possibility.
I: Did we increase the pressure?
S: Yes.
I: What happened to the air particles in the syringe when we decreased the volume or increased the pressure?
S: They got closer.
I: How did that happen? Did we change the individual particles?
S: No, we gave them less area to move in so they had to get closer.
I: What do you think is between the air particles?
S: I’ve always wondered that myself.
I: No idea?
S: No.
I: Can liquids be compressed like that?
S: Yes.
I: They can. What do you think would happen if you put a liquid in there and tried to push the plunger?
S: The same thing that happens when you kink a hose. Pressure would build up and it would come out.
I: Why do you think that happens?
S: Because the pressure builds up.
I: What causes the pressure to build up? What is different about a liquid and a gas that doesn’t allow you to do the same thing with a liquid?
S: A liquid is more dense than air, so it fights for a way to move faster.
I: What about a solid? Can you compress a solid?
S: We compress cardboard at work
I: You mean you collapse a box down?
S: Yes, and then we put pressure on it.
I: So after you put the pressure on it, does it take up less space?
S: We squeeze the air out, but it really doesn’t take up less space, it just looks smaller.
I: So you change the shape?
S: Yes.
I: What is different about a solid compared to a liquid and a gas that doesn’t allow you to compress it the same way?
S: All the atoms and particles that are in the solid are already so close together and moving so slow that they don’t really have a place to go anywhere else.
I: And that’s different from a liquid and a gas?
S: Yes. In a gas they’re spread apart and flying around so they can get closer and closer, and in a liquid it’s that way a little.
APPENDIX I Solubility Interview Transcripts

81 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: Tell me what the sugar looked like when we started.
S: Grains of solid.
I: Grains of solid? Okay. And now, it’s dissolved in the water. Where did it go?
S: It dissolved in the water.
I: What happens when it dissolves in the water?
S: I don’t know.
I: How come we can’t see it anymore?
S: I have no idea. [Laughs]
I: No idea why we can’t see it anymore?
S: [Shakes head]
I: Well, is the sugar still in the beaker?
S: Yeah.
I: Where in the beaker do you think the sugar is?
S: Everywhere.
I: Everywhere in the beaker?
S: Yeah….
I: Okay. So let’s say that I identify a sugar molecule somewhere in the beaker, let’s say somewhere in the middle. And I leave for about an hour. When I come back, where do you think that sugar molecule will be?
S: Anywhere in there.
I: Anywhere in there? Is it moving around?
S: If you shake it.
I: If I shake it, it moves? Is it moving if I don’t shake it?
S: Yeah.
I: Okay, so what if I waited two hours?
S: Anywhere.
I: Three hours?
S: Same thing.
I: Same thing. So is it moving around in there or is it just staying in the same place all the time?
S: I think moving.
I: They’re moving? Okay. Would you call that a mixture?
S: Yes.
I: A solution?
S: Umm…yeah?
I: Would you call it a homogenous mixture?
S: Yes.
I: Is the density of the solution different from the density of the water we started with?
S: Yes, because the volume increased.
I: Because the volume increased?
S: Yeah.
I: So is the density greater or smaller than when we started?
S: Smaller, because the volume increased.
I: Okay. If we stuck that in the freezer and left it until it froze, how do you think the sugar would be distributed in the frozen material?
S: It would look like frozen water.
I: Would the sugar—you’ve said that the sugar is all through the solution. Would it still be all through it?
S: Yeah, I think so.
I: Suppose we kept putting sugar in there until it wouldn’t dissolve anymore. What do you think determines which sugar particles dissolve and which ones don’t?
S: [Raises eyebrows] Hmmmm
I: Any idea?
S: I don’t know that.
I: Well, let’s say we do that. So we have some sugar particles dissolved and some undissolved sugar on the bottom of the beaker. Have you seen that before?
S: [Nods]
I: Okay. Do you think the dissolved and undissolved particles could trade places? Could a dissolved particle recrystallize and an undissolved particle dissolve?
S: Yeah, I think.
I: You think they can trade places?
S: Yeah, I do.
I: Why do you think they might change places?
S: [Shakes his head and laughs] I don’t know. It’s just like that. Just because.
I: Okay, one last question: Do you think you could make up a solution that wasn’t made of a solid and a liquid?
S: Well, there has to be a liquid in it. Could be two liquids, but there has to be a liquid.

87 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: Describe the sugar before we started.
S: White, little particles.
I: Okay, now, we can’t see the sugar anymore, right?
S: Right.
I: So where did it go?
S: It melted into the water. Well, I don’t know if I’d use the word “melt.” It dissolves it. It made it into a liquid.
I: Okay. It made the sugar into a liquid?
S: Yeah.
I: If you could see the sugar molecules in the beaker, how would they be distributed in the beaker?
S: You mean in the bottom of the beaker?
I: Would they be in the bottom of the beaker?
S: If they weren’t all dissolved.
I: Okay, but since it is all dissolved, where would it be? There is still sugar in there, right?
S: Yes.
I: So even though we can’t see it, where are the sugar molecules? How are they distributed in the beaker?
S: In the middle, mostly.
I: So they’re not on the bottom?
S: I don’t think they’re on the bottom.
I: And they’re not on the top?
S: I don’t think they’re on the top.
I: Are there any on the bottom?
S: There could be.
I: Suppose we let that sit there for about an hour and then come back. Where would the sugar molecules be then?
S: On the bottom…there’s some more like, in the liquid. I don’t think they’d be on the top.
I: What if we waited two hours?
S: So…so, if it did sit, would it, like rise up?
I: Why would it rise up?
S: I’m thinking of when I make tea and stuff with sugar in it…
I: Does the sugar rise up when you make tea?
S: It does at a little bit…you know the foam?
I: Oh, the foam.
S: Well, I guess that’s not sugar. ‘Cause I know if you put water on it, or warm water, it will dissolve.
I: How about this: Is there ever a point in time, if you let it sit here long enough, that the sugar will be at the bottom?
S: Yeah, I think over a period of time.
I: How long?
S: I have no idea.
I: Okay.
I: Would you call this a mixture?
S: Yes.
I: Would you call it a solution?
S: Yeah, I would.
I: Would you call it a homogeneous mixture?
S: Yeah, I think I would.
I: Okay. Is the density of this solution different than the density of the water we started with?
S: Yes.
I: Okay, is it bigger or smaller?
S: Smaller.
I: And why is that?
S: Because we added sugar to the water.
I: And how does that make the density smaller?
S: Say that again?
I: How does adding sugar to the water make the density smaller? What changed upon addition of the sugar that made the density smaller?
S: Hmmmmm.
I: Well, let’s try this: Do you have a mathematical equation for density?
S: You mean mass or volume?
I: Yes. So did either mass or volume change when we added the sugar?
S: The volume changed. No—wait—Yeah, the volume.
I: Okay, If I took this solution and put it in the freezer and left it there until it froze, would the distribution of sugar molecules change? Where would you expect to find the distribution of sugar molecules after it was frozen?
S: At the bottom.
I: Okay, why at the bottom?
S: Because I would think that when it froze, the sugar would go to the bottom because it’s more…it’s particles that are solid, so I think it would go down to the bottom.
I: Suppose that we put so much sugar in there that some if did not dissolve, so we have sugar sitting on the bottom of the beaker. So some sugar is dissolved and some is not. What determines which sugar particles dissolve and which do not?
S: The….the um…I don’t know.
I: Well, what do you think?
S: I think that the sugar that doesn’t dissolve is…So, why doesn’t it dissolve and why does it dissolve, is that what you want to know?
I: Yes.
S: That’s a good question. I really don’t even know how to answer.
I: Okay, well, say we have some that’s dissolved and some that’s undissolved, could those particles ever change places?
S: Yes, I think so.
I: Okay, could you have a solution that wasn’t made up of a solid and a liquid?
S: Yes.
I: Can you give me an example?
S: Hmmm.
I: What’s the definition of a solution?
S: When you mix two things together.
I: Are solutions always in liquid form?
S: Yes.
49 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: Where did the sugar go?
S: It was dissolved into the water.
I: It was dissolved into the water. Can you tell me what that means?
S: Basically, it was broken down because of the water.
I: If we could see the sugar molecules and the water molecules, where would the sugar be? How would it be distributed in the beaker?
S: It would be just all throughout the beaker. I’m not sure if it’s evenly mixed, ‘cause we obviously can’t see it, but I think it’s all throughout.
I: Do you think it’s even?
S: Probably.
I: If I left it for an hour and came back, where would the sugar be then?
S: It would be in the same place. It would still be dissolved.
I: What about two hours or three hours?
S: I don’t know. I would guess it would still be dissolved.
I: Would you call that a mixture?
S: Yes.
I: Is it a solution?
S: [Pause] Yes.
I: Is it a homogeneous mixture?
S: I’m not really sure.
I: Okay. Is the density of that solution different than the density of the water we started with?
S: Yes.
I: In what way is it different?
S: It’s more dense because of the sugar.
I: More dense because of the sugar? What about the sugar made it more dense?
S: We added the sugar.
I: Right, but how did that change the density?
S: The mass is different. We increased the mass.
I: Okay. Let’s say we stuck this in the freezer and left it there until it froze. How do you think the sugar molecules would be distributed in the frozen product?
S: I’m not…I would say they’d still be distributed evenly.
I: Suppose we add more and more sugar until some of it does not dissolve, so we’ve got some sugar sitting on the bottom of the beaker and some dissolved. What do you think determines which sugar particles dissolve and which do not?
S: [laughs] I have no idea. I’d guess it’s just when they’re added.
I: Do you think that a dissolved and an undissolved particle could change places?
S: No.
I: Could there be a solution that was not made up of a liquid and a solid?
S: Two different types of liquids.
I: How about solids? Could you make a solution of two solids?
S: I’m sure you could if you tried.
I: How about gases?
S: That would be harder.
I: How about a gas and a liquid?
S: I don’t think they would ever completely mix.

39 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: In your own words, describe what the sugar looked like before you dissolved it.
S: It looked like the individual particles that made up the sucrose.
I: Now, we dissolved it, and we can’t see the sugar anymore. Where did it go?
S: It’s still in the beaker. It didn’t go anywhere.
I: Okay, why can’t we see it?
S: Because of the state of the solubility. The sugar has been equally mixed with the water, making a new solution.
I: How are the sugar molecules distributed in the water?
S: You mean is it even?
I: Is it?
S: Yes. It’s even. Because of ...because it’s soluble.
I: If we let that beaker sit there for about an hour, where would the sugar particles be then?
S: Depending on the temperature of the water in addition to how well I first prepared it—wait let me change that. If I evenly distributed the sugar into the water and it’s mixed well, then when we come back in an hour it would be the same. In other words, no sugar will be on the bottom. But the sugar mixes better with water at room temperature than cold, so if for some reason that the water decreases it’s temperature, then the sugar molecules will be on the bottom.
I: What about in two hours or three hours? Would the sugar particles still be evenly distributed?
S: As long as the temperature is held constant, I would think so.
I: Are the sugar molecules moving?
S: Yes.
I: Are the water molecules moving?
S: I don’t think so. They may be, but I don’t think they are. They may be moving to evenly mix with the sugar, so the answer may be yes. I don’t think they’re moving though.
I: If I took that and froze it, put it in the freezer until it froze, then where would the sugar molecules be in the frozen product?
S: Okay, hmm. That [points to beaker] is no longer sugar and water. It’s now sugar water. So when you freeze it, you’ll have ice cubes that’s composed of sugar and water that is equally distributed.

I: Let’s say that I added more sugar to this beaker. And I add so much that it won’t all dissolve, so that there is some sugar dissolved and some sugar sitting on the bottom of the beaker.

S: Okay.

I: What do you think determines which particles of sugar are going to dissolve and which one won’t dissolve?

S: The ones with the greater amount of particles –it will depend on the volume of the water.

I: Okay. Suppose we have some sitting in the bottom that is undissolved and we also have some dissolved. Do you think that an undissolved particle and a dissolved particle might ever trade places?

S: Yes, but you’re going to have to have a force to make that take place, which is going to be more stirring.

I: You called this a solution. Is it a mixture?

S: A mixture? Hmmm. Chapter one…Yes.

I: Is it a homogeneous mixture?

S: Okay…homogeneous mixture. That’s gonna be when you break it down, if you break those two apart—No. It’s heterogeneous.

I: Could you have a solution that was not made up of a solid and a liquid?

S: Yes. you could have two liquids.

I: Okay. Is there any other way?

S: Not sure.

I: Could you make a solution with a liquid and a gas?

S: That’s how carbonation is made, right?

I: Would you call that a solution?

S: No, I wouldn’t call that a solution.

I: Could you have a solution made up of just gases?

S: No.

08 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: Describe what the sugar looks like [before we dissolved it.]

S: Small, white pieces of solid

I: Okay, the sugar is in the beaker, but we can’t see it anymore. Where did it go?

S: It melted in the water.

I: It melted in the water? Okay. Is sugar made of particles?

S: Yeah, but it comes in a big stick, I don’t know what it’s called.

I: Sugar Cane?
S: Yes.
I: Okay, the sugar is made of particles. Is the water made of particles?
S: No.
I: But the sugar particles dissolved in the water. So how do you think the sugar particles are distributed in the water? Are they at the top or at the middle or at the bottom?
S: Everywhere.
I: What if we left it sitting for an hour. Where would the sugar particles be then?
S: Still everywhere.
I: What if we came back after two or three or four hours?
S: Still everywhere.
I: Are the sugar particles moving?
S: I don’t know. I think so.
I: Do you think the water particles are moving?
S: No.
I: Would you call that a mixture?
S: Yeah.
I: Would you call that a solution?
S: No.
I: Would you call that a homogeneous mixture?
S: Yeah.
I: Let's suppose that I took that beaker and put in a freezer and kept it there until it froze. Where would the sugar particles be then?
S: Everywhere.
I: Okay. Let's say I put more and more sugar in the beaker until some of it won't dissolve. So we have some dissolved particles and some undissolved particles. What do you think determine which particles dissolve and which do not?
S: The ones that are in the water dissolve.
I: Okay, but they are all in the water. Some sugar is sitting on the bottom of the beaker undissolved and the rest is dissolved.
S: It takes time to dissolve it.
I: Do you think eventually they would all dissolve no matter how much sugar I put in there?
S: No. Like a pound would not dissolve. But it takes time to dissolve.
I: If I had some undissolved sugar on the bottom and some dissolved in the beaker, do you think the dissolve and undissolved particles could change places?
S: Yeah. The undissolved will dissolve in a couple of minutes.
I: Could you make up a solution that wasn’t made up of a solid and a liquid? Like here we made a solution that was made from a solid, the sugar, and a liquid, the water. Could you make a different kind of solution?
S: No.
83 Solubility

Student is given a beaker of water and some table sugar and asked to dissolve a small quantity of sugar in the water.

I: Describe sugar before we mixed it in.
S: White particles
I: Okay, now that it’s dissolved, we can’t see it anymore. So where did it go?
S: It’s soluble in water, so it became a compound.
I: It became a compound…I’m not sure what you mean by that.
S: Okay, well, it broke down into small particles, I guess you could say.
I: How come we can’t see those particles?
S: I don’t know. [Looks very perplexed]
I: Well, let me ask you this: Is the water made of particles?
S: Yes, water is made of hydrogen and oxygen particles.
I: Okay. So when we mixed the sugar in there, how do you think the sugar is distributed in the beaker?
S: You know. umm
I: It’s still in there, right?
S: Yeah.
I: So where do you think the sugar molecules are?
S: I think they’re attached to…Sucrose is made of what? C₂₂H₁₂O₁₁?
I: I’m not sure of the formula, but it is a compound made up of carbon, hydrogen, and oxygen, yes.
S: I don’t know where they’re at.
I: Do you think, for example, that all of the sugar molecules are on the top, or on the bottom, or in the middle?
S: I think they are evenly distributed.
I: Okay. If I let it sit there for an hour, where would the sugar molecules be then?
S: I don’t think it would change.
I: What about if I waited three or four hours?
S: I don’t think it would separate.
I: Would you call that a solution?
S: Yes.
I: Would you call it a mixture?
S: It is a mixture, but it’s a homogeneous mixture.
I: Is the density of this solution different than the density of the water we started out with?
S: Yes.
I: In what way is it different?
S: We added something to it.
I: How did the density change? Higher or lower?
S: I’m not sure.
I: What did we change that changed the density?
S: I don’t know the density of sugar, so I can’t be sure…
I: So you aren’t sure if it’s higher or lower?
S: Okay.
I: Suppose I put this in the freezer and leave it in there until it freezes. How will the sugar particles be distributed in the frozen product?
S: Same as they are now.
I: Okay. Let’s say we add more sugar to this and we keep adding sugar until no more will dissolve. So we have some dissolved sugar and some undissolved sugar sitting on the bottom of the beaker. What do you think determines which particles dissolve and which do not?
S: Well, I guess the number of atoms, well I guess not atoms, but the number of carbons and oxygens and hydrogens.
I: Do you think the dissolved and undissolved particles could ever trade places?
S: No, I don’t think so.
I: Are the sugar particles moving?
S: Yes.
I: Are the water particles moving?
S: Yes.
I: Could we make a solution that was not made up of a solid and a liquid?
S: Two liquids.
I: Any other kinds?
S: Well, you could use anything. Whether it’s going to mix together or not…you could tear up paper and…well, I guess that wouldn’t be a solution, but a mixture could be from anything.
APPENDIX J  Phase Change Interview Transcripts

All students interviewed on this concept watched a video showing a beaker of water as it was heated until the water boiled. The water was allowed to boil for 20 minutes, and the students were informed that the process they were watching took place over a 40 minute time frame from start to finish.

91 Phase change

I: What were those bubbles that we saw?
S: The bubbles?
I: Yeah.
S: Hmmm...(Long pause)
I: Okay, let’s start here: What was in the beaker?
S: Hydrogen and oxygen
I: Was in the beaker?
S: Well, H₂O, water.
I: Okay, water was in the beaker. So when it started boiling and we saw those bubbles, those big bubbles, what were those bubbles made of?
S: Something was evaporating.
I: Okay, what was evaporating?
S: Either hydrogen or oxygen.
I: So do you think that the bubbles were hydrogen or oxygen?
S: I’m not sure. Do you want me to guess?
I: Yeah…go ahead. Just tell me what you think was in there.
S: Hmmmm. (Long pause)
I: Well, how do you think those bubbles form?
S: Well, it’s a physical change. Yeah…everything is going to get evaporated, so it is hydrogen and oxygen.
I: So when water boils, it changes into hydrogen and oxygen?
S: No…. well, yeah. It starts out being hydrogen and oxygen. Each water is made of two molecules of hydrogen and one molecule of oxygen.
I: Okay, so are the bubbles hydrogen and oxygen then?
S: No, maybe it’s H₂O gas. No, wait maybe one of them is burned away..one of them evaporates and the bubbles are hydrogen or oxygen. I’m not sure.
I: Okay. Can all substances boil?
S: Yeah.
I: So could you boil alcohol?
S: Hmmm. Well, you don’t have to heat alcohol for it to evaporate. It just evaporates.
I: Oh, okay. Is there a difference between evaporating and boiling?
S: Well, boiling is you’re getting it to the state of evaporation.
I: What happens when something evaporates? Do you know how things evaporate?
S: Hmmmm…. (Long pause) I don’t think we studied that yet.
I: Okay, let’s move on. Could you boil copper?
S: Well, copper isn’t made of gases. The thing with water is it’s made from gases, so it changes from state to state. But if you melt—if you heat copper—you could turn it from solid to liquid.

I: What if you keep heating it after that?

S: Well, see, because it’s made of an element that’s iron, well, not iron, but metal. Copper’s a metal. So I don’t know if it will evaporate the way gas and water evaporate.

I: Okay, what about steam? Do you know what steam is? (Student is an EFL student.)

S: It’s evaporated water before it goes up into the air.

I: So is it water vapor?

S: Yeah.

I: Could you boil water vapor?

S: Well, you can only boil liquids. Vapor is a gas, so you can’t boil it.

I: What if I put a drop of methanol on the table top and it evaporates? Where does it go?

S: It sticks on stuff. I mean, it doesn’t go anywhere…it’s not lost. It’s…It ummm…it breaks down into gases and we can’t see it.

I: Breaks down? What do you mean when you say it breaks down?

S: Well, I guess when you keep the alcohol bottle closed, it’s not in contact with oxygen. Well, um, there’s not a temperature change, so why does it evaporate out of the bottle but not in the bottle, I guess?

I: Well, what if you left the bottle open?

S: It would evaporate, wouldn’t it? So, um, it’s just a physical change.

I: Alright, suppose I had a glass of iced tea and I set it on my desk. If I leave it sitting there, eventually it will have a clear liquid on the outside of the glass. Have you seen that before?

S: Yes.

I: What is that liquid?

S: You mean, like…. condensation?

I: Okay, do you know what the liquid is?

S: Well, the iced tea is water with tea in it. Water with tea colored taste into it when you boil the water.

I: So is that what’s on the outside of the glass?

S: What’s on the outside of the glass is because of the temperature change. ‘Cause it’s warmer outside, so it’s been heated from the outside, so it evaporates…well, it doesn’t evaporate, but it collects on the outside, but it’s the same water that was inside.

I: The same water that was inside the glass? So it comes from inside the glass?

S: [Looks puzzled] Well, I think it comes from inside. It can’t come from inside because there is no opening.

I: Well, if it doesn’t come from inside the glass, where might it come from?

S: Well, if it’s cold inside and warm outside, maybe something is collecting on the glass.
But I know that over time there is less water inside—less tea inside. Like, when you leave it for awhile there will be less inside because what is outside used to be inside, kind of? Is that right?

I: Well, I agree with you that over time, some will be missing. How is it missing?
S: It evaporates.
I: Okay, it evaporates. So is that the same liquid that’s on the outside?
S: Well, where else would it come from? You start with water in the glass and the only water there is in the glass, so the water on the outside must come from the inside from the temperature change.
I: Okay.

81 Phase Change

I: Referring back to the video, you said the bubbles were \( \text{H}_2 \), is that right?
S: Right.
I: From the water? Does it come from the water?
S: Yeah. Water has hydrogen and oxygen.
I: Okay, so when it boils…
S: It’s hydrogen and oxygen.
I: So the bubbles are hydrogen and oxygen?
S: Yeah.
I: Can you boil alcohol?
S: I don’t know….Yeah, I guess.
I: Would it make bubbles?
S: Yeah, I guess.
I: Have you ever seen it boil?
S: No, I’ve never seen it.
I: Okay, well, if it did make bubbles, what do you think those bubbles would be made of?
S: I don’t know what alcohol is made of…some water and other stuff…I don’t know.
I: Could you boil—can anything boil?
S: No, not solids.
I: Can’t boil solids?
S: Hmm.
I: Let’s say you wanted to boil some copper. Could you think of a way to do that?
S: I don’t think so.
I: What about mercury? It’s a liquid.
S: No, it would just evaporate.
I: Okay, what about steam?
S: No, it’s already a gas.
I: Okay, can all substances freeze?
S: Some substances….no.
I: No? Could you freeze a gas?
S: Yes, I think so. You could get it to liquid then freeze it.
I: Okay. When you freeze a substance, do the molecules stop moving?
S: No.
I: So the molecules in a solid are moving?
S: [Laughs] I don’t know about that.
I: Well, let’s look at it like this: Are the molecules in a gas moving?
S: Yeah, because the gas is moving like this [gestures with hands back and forth, up and down]
I: Are the molecules in a liquid moving?
S: Yeah.
I: When a liquid changes to a solid, do the molecules stop moving?
S: They don’t stop.
I: So you think the molecules in a solid are moving?
S: Yeah.
I: Is there a difference in the way that they move in a solid, liquid, or gas?
S: I don’t know….I don’t know.
I: You don’t know?
S: [Shakes head]
I: Okay, that’s fair.
I: Let’s say I put a couple of drops of methanol on the table top. You’ve used methanol in the lab right?
S: [Nods]
I: What will happened if I let it sit there?
S: Nothing. Well, how long are you going to let it sit there?
I: Let’s say I let it sit there for 5 minutes. Will it go away.
S: No, nothing will happen.
I: Okay. Have you ever seen alcohol evaporate?
S: No.
I: Oh…have you seen water evaporate?
S: Yes. [Gestures toward video monitor] When it was boiling.
I: Okay, when it was boiling. Do you have to heat to heat something to make it evaporate?
S; No, but the sun will do it.
I: Oh, the sun does it?
S: Yeah.
I: Okay, suppose that I have a glass of iced tea and I sit it on my desk and go away for about 15 minutes, and when I return, there is a clear liquid on the outside of the glass. Have you ever seen that happen?
S: Yes.
I: What is that liquid?
S: Water.
I: Where does it come from?
S: From the ice.
I: From the ice that’s inside the glass?
S: Yeah. Just like the ice melts.
I: The ice melts inside the glass?
S: [Nods]
I: And then how does the water get outside the glass?
S: It just gets out.
[Both laugh]
I: It just gets out?
S: It’s humidity.
I: Humidity?
S: Yeah.
I: Okay.

14 Phase Change

I: What are those bubbles that we saw?
S: Those bubbles are…gas. Gas escaping. Hydrogen gas escaping from the water.
I: Okay. So the bubbles are hydrogen gas escaping from the water? Coming from the water molecules?
S: Yes.
I: Is there anything else in the bubbles?
I: Okay. What kind of substances can you boil? Can you boil any substance?
S: Hmmm. Not all substances. I guess they’d have to have a specific heat. I guess I’d say that only liquids can boil.
I: Well, suppose I had a piece of copper. Could I boil that?
S: Well, you could put it in water and boil the water. But as far as the copper itself…I guess you could break it down to a liquid and then boil it.
I: Could you boil steam?
S: I don’t think so, because steam is being let off from a boiling substance.
I: Do all boiling substances let off steam?
S: Ummm. Yeah.
I: What is steam?
S: Steam is the evaporating…I guess it would be anything that evaporated from a boiling substance.
I: Okay. So you don’t know a chemical make up for steam?
S: No…
I: Are there different kinds of steam?
S: Well, maybe a visible steam and an invisible steam. I don’t really know.
I: Okay. Can all substances freeze? For example, could you freeze a gas?
S: I think…you could freeze all substances except for maybe solids, because in solids the molecules are already….the molecules are…ugh…stable. When you freeze something, the molecules get kind of stable…they pause…stop moving and in a solid they’re already…you know.
I: Do the molecules stop moving in a solid?
S: (LONG pause.) Yeah.
I: Okay. You’re familiar with methanol? You’ve used it in the lab?
S: Yes.
I: Okay. If I put a drop of methanol on the table and walked away for a few minutes, what would happen?
S: It would evaporate.
I: Okay, and when it evaporates, where does it go?
S: It goes into the atmosphere and the surrounding air.
I: And how does it do that?
S: Chemical break down. It gets introduced into other substances…nitrogen and oxygen and other stuff pretty much just elevates it into the air.
I: Okay.
I: What’s the difference between evaporation and boiling?
S: Maybe specific heat temperature? When you boil you take it to a different temperature degree. Because of the heat, it causes the evaporation of the water to increase while…I guess the difference would be specific heat and temperature.
I: Okay. So could you evaporate a liquid without heating it?
S: Ummm.
I: Like water, for example. Could you evaporate water without heating it?
S: Yeah.
I: Okay. Suppose I had a glass of iced tea and I set it on the table and left it there for a bit. When I come back, there will be a clear liquid on the outside of the glass. Have you ever seen that?
S: Yes.
I: What is that liquid?
S: Condensation.
I: Where does it come from?
S: I guess the temperature. Since the glass has ice in it, the container is cooler than the temperature of the surroundings, it causes the cold to expand…to try to expand around the room and try to get the room temperature to drop a few degrees, so I guess the condensation comes from the colder temperature and the warmer surroundings.
I: Do you know what the condensation is made of?
S: Ummm.
I: Do you know what substance that is?
S: No.

83 Phase changes

I: So, what are the bubbles we just saw?
S: I have no idea.
I: No idea?
S: Well, they have to be some kind of gas.
I: Okay. Well, it was water boiling, so what might they be?
S: Maybe it’s the water particles turning to a gas.
I: Well, what do you think it is? What happens when you boil something?
S: It starts to bubble.
I: Okay. Do all things bubble when they boil?
S: No, they don’t.
I: Okay. Well, let’s assume that these bubbles are a gas. What do you think they are? What do you think the options are?
S: Taking that it’s water. Could be H2O, or oxygen.
I: Oxygen from the water?
S: Yes.
I: Okay. What other kinds of substances can boil (besides water)?
S: Substances? Are we talking like a piece of wood or…
I: Well, that’s a valid question. Let’s say it this way: Could you boil alcohol?
S: I would assume so.
I: Can solids boil?
S: No.
I: Why not?
S: Because they’re solid.
I: So what would happen if you heated a solid?
S: It would just get hot.
I: Could you ever heat it enough to get it to boil?
S: Yeah, well, I mean…If it was a metal, you could heat it and if it got hot enough it would melt.
I: What would happen if you kept heating it after that?
S: [Laughs] I guess it would boil.
I: Based on that, could you boil copper?
S: I would think so.
I: What about steam? Could you boil steam? Do you know what steam is?
S: Steam is a gas.
I: Okay, could you boil steam?
S: I don’t think you could boil a gas. It’s a gas.
I: Do you know what gas steam is?
S: It’s..CO2 isn’t it? Why are you asking that?
I: I’m finding that a lot of people don’t know what steam is.
S: Well, I really don’t know what it is.
I: Can all substances be frozen?
S: Yes.
I: Could you freeze copper?
S: I think so. You freeze it and the particles can’t move around.
I: SO the particles in solids aren’t moving?
S: Right.
I: Okay. Can you freeze gases?
S: No, I think I remember learning in chemistry that in a cold situation, gases just move slower.
I: Could you ever get a gas cold enough to freeze it? What would happen if you cooled a gas way down. You indicated that the molecules in a gas slow down when it’s cooled. What would eventually happen?
S: They’d stop moving.
I: You’re familiar with methanol?
S: Yes.
I: If I put just a drop of methanol on the table top and walked away for ten minutes, what would happen?
S: It would evaporate.
I: Is evaporation different from boiling?
S: I think so. Evaporation…well, you boil to evaporate so it all gets gone, but I think…methanol…wow…
I: Could you boil methanol?
S: Yes.
I: Could you evaporate water?
S: Yes. But methanol evaporates a lot faster than water.
I: Do you have to heat water to evaporate it?
S: Yes.
I: Let’s say I have a glass of iced tea and I set it on the table. I leave for while and when I come back, there’s a clear liquid on the outside of the glass. Have you ever seen that?
S: Yes. Condensation.
I: What is that liquid?
S: Some kind of exchange between the atmosphere and the coolness of the glass.
I: Do you know what the liquid is?
S: It’s water particles.
I: How did it get there?
S: What?
I: How did it get on the outside of the glass?
S: [Laughs] I have no idea.
I: Did it come from the inside of the glass?
S: No. it did not. It comes from the atmosphere and the outside of the glass.
I: Okay, so it’s due to…?
S: Temperature change.

Phase Changes 16

I: What were those bubbles?
S: I always understood it was the oxygen coming out.
I: Okay, oxygen coming out of?
S: The water.
I: Oxygen coming out of the water?
S: Yes, water is hydrogen and oxygen and the heat makes them separate.
I: So when water boils, it’s decomposing into hydrogen and oxygen?
S: And water vapor.
I: Okay.
I: Can other substances besides water boil?
S: Yes.
I: Can all substances boil?
S: No.
I: What kinds of substances can’t boil?
S: Well, wood doesn’t boil very well.
I: [Laughing] Okay. That’s true. What about alcohol?
S: I’ve never tried to boil alcohol, I don’t know.
I: What about a piece of copper? Could I boil that?
S: Yeah, I’m pretty sure you could melt it down and then boil it.
I: Okay. What about steam? First of all, what is steam?
S: Steam is what is coming off of things that are boiling.
I: So can steam boil?
S: I don’t know.
I: What do you think?
S: I really don’t know.
I: Okay, when you define the word steam—when a liquid is boiling and something is coming off the top, is that always steam?
S: That’s what I always thought.
I: Okay. Does steam have a definite chemical composition?
S: No.
I: Can all substances freeze?
S: No.
I: What kinds of things can’t freeze?
S: Vodka.
I: Vodka? It doesn’t freeze? What is you got it really, really cold?
S: Well, I guess if you went way below zero, it would freeze. I guess if you got to Kelvin zero everything would freeze.
I: Could you freeze a solid?
S: You could freeze the water vapor in the air onto a solid, but I don’t know if a solid could actually be frozen. Solids are moving really slow, so I don’t know if the particles would actually stop moving.
I: When something freezes, so the particles stop moving?
S: I’m not sure about that. I don’t know. I thought they just moved really, really slow.
I: You’re familiar with methanol from the lab. right?
S: Not sure.
I: The alcohol?
S: Yes.
I: Suppose I put a drop of methanol on the table top and leave for ten minutes. What will happen to the methanol?
S: It will evaporate.
I: Okay, it will evaporate. What is the difference between evaporation and boiling?
S: [Long pause] Boiling is a speeded up process of evaporation.
I: What other things besides alcohol could you evaporate?
S: All sorts of liquids.
I: Do you have to heat to evaporate?
S: That’s part of it, but ice cubes in the freezer evaporate over time.
I: So, when a liquid evaporates, where does it go? Because we can’t see it anymore.
S: It turns into a vapor. Vapors rather than steam...steam we can see, because it’s more condensed than a vapor but vapors we can’t see.
I: Okay, so say I had a glass of iced tea and I set it on the table top and walk away for about twenty minutes and when I come back, there’s a clear liquid on the outside of the glass. Have you ever seen that happen?
S: Yes.
I: What is that liquid?
S: Well, the glass of iced tea is cold, so the water vapor in the air condenses on to the glass.
I: So the liquid on the glass is…?
S: Water.
I: And it comes from where?
S: The air.
I: Do you know how it gets there?
S: Condensation.
I: How does that work?
S: I just know condensation, I don’t know…
I: You can’t define condensation?
S: I guess when enough water vapor builds up to form a liquid.

02 Phase Change

I: So, what were those bubbles we saw in the boiling water?
S: Air bubbles.
I: Air bubbles? How did the air get in the water?
S: All water has air dissolved in it.
I: Oh, okay. What makes the bubbles rise to the top?
S: Heat. The hot air is not as dense as the water, so the air bubbles rise to the surface.
I: Well, suppose the water boiled for a really long time? Would all the air that was dissolved in the water eventually be gone?
S: I guess so.
I: Would we still see bubbles then?
S: Hmmm...Yes, as long as the water is still boiling—if it hasn’t evaporated away.
I: Well, if all the air that was dissolved in the water is gone, where would the bubbles be coming from at that point?
S: Ummm. I think it, like, well, it comes from the air at the surface. It’s always dissolving back in.
I: Okay. Can all substances boil?
S: All liquids can, I think.
I: Could you boil a solid, like a piece of copper, for example?
S: You’d have to get it really hot.
I: Could you get it hot enough to boil?
S: Ummmm. Yeah, I think so. It would melt first, though.
I: Okay. Could you boil steam?
S: I don’t think so…No, it’s a gas.
I: Do you know what kind of gas steam is?
S: What do you mean? I don’t know about different kinds of gases.
I: Oh, I mean do you know, for example, the chemical make-up of steam?
S: I think it depends on the, uh, the, the substance. Steam is what you get when something is boiling.
I: Oh, okay. So when a liquid boils you get steam?
S: Yes.
I: And so you don’t think steam could be boiled?
S: I don’t think so.
I: Okay.
I: What if I put a drop of methanol on the table top here and then walked away for a few minutes? What would happen to it?
S: Not sure what methanol is.
I: I think you used methanol in the lab. Do you recall? It’s an alcohol.
S: Oh, the stuff in the bottle with the green lid?
I: Yes, that’s it. Do you remember it?
S: I think so.
I: So what do you think would happen if I put a drop on the table top?
S: It evaporates kind of fast.
I: What happens when something evaporates?
S: It disappears into the air.
I: Hmmmm. Disappears? Can you explain that?
S: Not sure how to explain it, but it, like vaporizes.
I: Is it different from boiling?
S: Well, you have to heat to boil.
I: Do you have to heat to evaporate?
S: Not always.
I: Do you have to heat to evaporate water?
S: There has to be heat or energy, I guess, from somewhere, but you don’t have to have it on a burner.
I: Where might the heat come from?
S: The environment.
I: Okay. Well, could you boil methanol?
S: Well, it’s a liquid, so I’d say yes.
I: Can all substances freeze?
S: Well, not solids, really. Freezing just slows the molecules down.
I: Can a gas be frozen?
S: Yeah, if you cool it to a liquid, then when it gets cold enough the molecules will stop moving. Then it’s frozen.
I: So when something freezes the molecules stop moving?
S: Yeah, I think so.
I: So, then are the molecules in a solid moving at all?
S: No….well, I’m pretty sure they’re fixed and not moving.
I: Okay.
I: Suppose I had a glass of iced tea and I set it on the desk for awhile. Eventually, a clear liquid will appear on the outside of the glass. Have you ever seen that?
S: Sure.
I: Okay, what is that liquid?
S: Water.
I: Where does that water come from?
S: From condensation.
I: Oh, condensation. How does that happen?
S: Ugh…Something about the temperature being different. The glass is cold from the ice and the air around it is warmer, so water deposits on the glass.
I: Where does the water come from?
S: The temperature change.
I: Okay, the temperature change causes the water to be there, but do you know where the water comes from? Is it from inside the glass?
S: I don’t know. I don’t think so, but it could be, because there is water there.
I: Well, is there anywhere else it might come from?
S: Yeah, the air, maybe. I guess there is water in the air. Yeah, the air. That is where it comes from, I’m pretty sure.
I: And you think it's somehow caused by a temperature change?
S: Yeah, but I really can’t explain how.
I: Okay.
Multiple Choice Item
Item Name: Rectangular Solid
Concept(s): Density

Which of the following substances has the lower density? (Both are rectangular solids drawn to scale.)

<table>
<thead>
<tr>
<th>Choice</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substance A has the lower density because it has a larger volume.</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Substance B has the lower density because it has a smaller volume.</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Substances A and B. have the same density because their masses are equal.</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>There is not enough information to answer the question.</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.75 Post 0.64
Item discrimination: Pre 0.29 Post 0.29
Multiple Choice Item
Item Name: Compressed Air - Density
Concept(s): Density

A glass cylinder contains compressed air as illustrated in tube A. If the plunger is pushed down as in tube B, will the density of the air change?

<table>
<thead>
<tr>
<th>Freq</th>
<th>Freq</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>The density of the air sample will not change; only the pressure will change.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>The density of the air sample will not change; The density of air, like that of any given substance, is a constant.</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
<td>The density of the air sample will increase because the volume of the sample will decrease.</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>The density of the air sample will decrease because the volume of the sample will decrease.</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>None of the above.</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.50 Post 0.54
Item discrimination: Pre 0.29 Post 0.71
Suppose you have the power to do anything. How could you make an object more dense?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>18</td>
<td>Decrease the volume by compressing the object.</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Remove some of the mass.</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Put it in a smaller container</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>None of the above</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.79 Post 0.64

Item discrimination: Pre 0.43 Post 0.71
Multiple Choice Item
Item Name: Sinking Block
Concept (s): Density

A block of an unknown substance is placed in beaker A, which is filled with distilled water. The block sinks. The same block is then placed in beaker B, which is also filled with distilled water. Will the block float in beaker B?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>22</td>
<td>The block will not float in beaker B. The new volume of the water does not affect the density.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>The block will float in beaker B. The volume of the water has changed, so the density of the water has changed.</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>The block will float in beaker B. The volume of water relative to the size of the block has increased.</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>There is not enough information to answer this question.</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.86 Post 0.79
Item discrimination: Pre 0.29 Post 0.57
Multiple Choice Item
Item Name: Transfer Liquid
Concept(s): Density

An unknown liquid is contained in beaker A. Will the density of the liquid change if it is transferred to beaker B?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>The density of the liquid will decrease because its volume will increase.</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>The density of the liquid will increase because its volume will increase.</td>
</tr>
<tr>
<td>23</td>
<td>18</td>
<td>The density of the liquid will remain the same.</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>There is not enough information to answer this question.</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.82 Post 0.64
Item discrimination: Pre 0.00 Post 0.57
Multiple Choice Item
Item Name: Displace Water
Concept(s): Density

Consider the two rectangular solids below. If both have a mass of 25.0 grams and both sink in water, which would you expect to displace a greater volume of water?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>The density of the air sample will not change; only the pressure will change.</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>The density of the air sample will not change; The density of air, like that of any given substance, is a constant.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>The density of the air sample will increase because the volume of the sample will decrease.</td>
</tr>
<tr>
<td>25</td>
<td>22</td>
<td>The density of the air sample will decrease because the volume of the sample will decrease.</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>None of the above.</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.89 Post 0.79
Item discrimination: Pre 0.29 Post 0.57
Multiple Choice Item
Item Name: Dissolved Salt
Concept (s): Density and Solution

If you dissolve 1 pound of salt in 20 pounds of water, which of the following statements will be true?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>The density of the resulting solution will be the same as that of the water.</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>The density of the resulting solution will be less than that of the water because the volume of the solution will be greater than that of water.</td>
</tr>
<tr>
<td>22</td>
<td>19</td>
<td>The density of the resulting solution will be greater than that of the water because the mass of the solution will be greater than that of the water.</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>There is not enough information to answer the question.</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.79 Post 0.68
Item discrimination: Pre 0.57 Post 0.71
Multiple Choice Item  
Item Name: Dot Concentrations  
Concept(s): Density, Solution

Figure 1 represents 1.0 L of water with sugar dissolved in it. Which of the following best represents how it will look upon addition of 1.0 L of water.

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Item difficulty:  
Pre 0.71  
Post 0.68

Item discrimination:  
Pre 0.71  
Post 0.57
Multiple Choice Item
Item Name: Salt Water Freeze
Concept(s): Solution, Phase Change

Suppose you freeze some salt water from the ocean. What is the composition of the resulting solid?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Salt</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>H₂O</td>
</tr>
<tr>
<td>20</td>
<td>19</td>
<td>Salt and H₂O</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>Salt water cannot be frozen</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.71 Post 0.68
Item discrimination: Pre 0.43 Post 0.43
Multiple Choice Item
Item Name: Bubbles in H₂O
Concept(s): Phase Change

Suppose you observe water that has been boiling for 20 minutes. What are the bubbles you see composed of?

<table>
<thead>
<tr>
<th>Freq Pre</th>
<th>Freq Post</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9</td>
<td>H₂O</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>H₂ and O₂</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>Air</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>H₂O, H₂, O₂, and air</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>CO₂</td>
</tr>
</tbody>
</table>

Item difficulty: Pre 0.36 Post 0.32
Item discrimination: Pre 0.86 Post 0.71