INTRODUCTION

The Importance of Matter and Molecules

This unit is designed to teach sixth grade students about one of the most fundamental and important theories in physical science: the kinetic molecular theory. The essential idea of the kinetic molecular theory is a simple one: All matter is made of tiny particles, atoms and molecules, and those particles are constantly in motion.

Although this idea is simply stated, the ramifications have proved rich and complex. All of modern chemistry is devoted to developing our understanding of these particles and their interactions. The kinetic molecular theory also plays a fundamental role in physics, in biology, in geology, and in meteorology. In other words, it is impossible to understand most of modern science without a good understanding of the kinetic molecular theory.

Unfortunately, many middle and high school students do not have a good understanding the kinetic molecular theory, and their understanding of all branches of science suffers as a result. In the research of the Michigan State University IRT, they have investigated college students' or adults' understanding of a variety of scientific topics. Over and over, they have found that these older students encounter fundamental difficulties because they do not have an adequate understanding of the kinetic molecular theory. Our scientific understanding of heat and temperature, for instance, or respiration and photosynthesis, or ecology, or weather, is based on the kinetic molecular theory. Many students never develop an adequate understanding of the kinetic molecular theory.

Thus this unit is designed to address an important deficiency in middle school science curricula. Because many students do not acquire an adequate understanding of kinetic molecular theory in middle school, they are not adequately prepared for science courses in high school and beyond. With the help of this unit, we feel that is possible to improve this situation.

Students' Learning About Matter and Molecules

In preparing this unit a great deal of research was done. The researchers interviewed and tested many students to see how they understood matter and molecules.

The research helped the researchers understand why the kinetic molecular theory is so difficult for many students. The research shows that most students do not enter middle school devoid of ideas about matter and molecules. In fact, they have developed a great many theories about the "stuff" that the world is made of, and what its properties are, and how it changes. These ideas are based on the students' personal experiences, so they make sense to the students and are often strongly held. Unfortunately, students' theories are generally different from the kinetic molecular theory, and sometimes incompatible with scientists' understanding of the world.

The presence of student's alternate ways of thinking makes learning science a far more difficult and complex process than you might normally imagine. Understanding the kinetic molecular theory requires student to do far more than absorb new information; instead, they must reassess and change their common sense, everyday understandings of the world. Sometimes they must abandon misconceptions or habits of thought that have served them well all their lives in favor or new and unfamiliar ideas. This complex learning process is one that researchers have labeled a process of *conceptual change*.

The researchers at the IRT tried to develop a detailed understanding of the conceptual changes that students must go through to understand the kinetic molecular theory. Relevant parts of this detailed list of conceptual changes are presented and discussed at the beginning of each lesson cluster in this Teacher's Guide, and this list is used to guide the development of all the materials that make up this unit. Most of the conceptual changes on the detailed list can be grouped around four main themes, or big ideas that the students must master in order to understand the kinetic molecular theory. These four main themes and the conceptual changes associated with each are discussed below.

1. Understanding the nature and properties of matter. The kinetic molecular theory is a theory about matter; we do not believe that non-materials things such as love, or light, or temperature are made of molecules. Thus students must be able to separate matter from non-matter in order to know when the kinetic molecular theory is applicable.

   There is a standard definition that is supposed to help students do this: "Matter is anything that has weight and takes up space." Unfortunately, this definition does not help most students very much. Many students believe that gases such as air and helium are weightless. On the other hand, they commonly believe that forms of energy such as heat and light take up space. Thus most middle school students cannot reliably separate matter from non-matter.

   There are other problems, too. Many students are familiar with the terms, atoms and molecules, and with the idea that matter is made of tiny particles. There are a great many ideas, however, that they are unclear about. Just how tiny are molecules? Is a molecule smaller than a speck of dust--smaller than a cell? Is there air between air molecules? Are all molecules moving, even in solids like ice and rocks? Is there just one kind of molecule or are there many different kinds? How many different kinds of molecules make up pure water? sea water? air? The list of possible questions goes on and on, and middle school students have developed beliefs about many of these questions: often beliefs that are in conflict with the kinetic molecular theory.

   One central goal of this unit, therefore is to help students identify and describe matter in its various states (solid, liquid, and gas) and to understand the molecular composition of a variety of different kinds of matter.

2. Identifying and describing physical changes in matter. Although kinetic molecular theory plays an essential role in our understanding of chemical changes such as burning, respiration and photosynthesis, or growth and decay, chemical changes are not discussed in this unit. Rather than chemical changes, where molecules are created and destroyed, this unit focuses on physical changes, where intact molecules are simply rearranged. Examples of such physical changes include thermal expansion and contraction, the

compression and expansion of gases, dissolving, and changes of state such as melting and condensation.

We have found that many students do not fully understand even the non-molecular aspects of these physical changes in matter. Even students who correctly use words like "dissolved" and "evaporated," for example, may mean by those words that some bit of matter has entirely ceased to exist, rather than that it continues to exist in an invisible form. Students also have trouble distinguishing between similar physical changes such as melting and dissolving. Condensation is an especially difficult phenomenon for many students; they find it very difficult to understand where the water comes from that forms dew on the grass or fog in the air.

Therefore another essential goal of this unit is to help students recognize a variety of different physical changes in matter and describe what is happening to the substances that are changing.

3. <u>Developing molecular explanations for observable properties and phenomena.</u> The importance of kinetic molecular theory lies in its explanatory power. This theory enables us to develop detailed and convincing explanations of the physical and chemical properties of substances, as well as many events or phenomena in the world around us that would otherwise be mysterious.

   Many students assume that there is a fairly simple and straightforward relationship between the properties of a substance and the properties of its molecules. They may believe, for example, that ice is made of cold, hard molecules and that ice melts because the molecules become warmer and turn into liquid. The power of the kinetic molecular theory, however, lies in our understanding that the molecules themselves do <u>not</u> change during physical changes in substances such as melting. Physical changes involve changes in the arrangement and motion of the molecules, but not changes in the molecules themselves.

   Therefore, a third goal, and perhaps the most important goal for the unit is to help students explain observable phenomena and observable properties of matter in terms of the arrangement and motion of molecules.

4. <u>Describing and explaining the world around us.</u> Our final goal involves our beliefs not just about kinetic molecular theory, but about science in general. We believe that both the interest and the power of science derive from the ability of scientific theories to help us describe, predict, explain, and ultimately to control our world. This implies that scientific knowledge should help students to describe and explain the real world, the world that they see around them every day.

   Unfortunately, most students do not experience scientific knowledge in this way. They learn instead that science classes are places where they must learn bits and pieces of obscure information: Atomic symbols, or molecular formulas, or whatever. They learn that their own ideas and their own reasoning do not count. Instead, they must reproduce those bits and pieces of information on demand--rarely more than one word at a time!

Understandably, this leaves many students alienated from science, and unaware of the power and the beauty that scientific knowledge can hold.

Therefore, our final goal is to help students use scientific knowledge to develop their own personal descriptions and explanations of real-world phenomena, and thus to appreciate how interesting and useful scientific knowledge can be.

Planning and Using This Unit to Teach About Matter and Molecules

Achieving the goals described above is not easy. Students (and sometimes teachers) must work through a difficult process of conceptual change in order to achieve each goal. Because the process of conceptual change is so difficult and complex, there is not a simple way that students can work their way through it. A variety of different, complementary approaches are necessary. Therefore, the Matter and Molecules unit includes several different components, each designed to help students in a different way. Each of these components, its purposes, and recommendations for teaching strategies that will help make it more effective and described below.

Scheduling

The length of this unit depends, of course, on how quickly or how thoroughly you teach. The lessons are generally designed to take about one 45 minute class period each. Since there are 35 lessons in the unit, you should probably allow at least 7 weeks to teach the entire unit. Tests, reteaching difficult ideas, and supplemental activities could make the unit last longer.

The Science Book: Reading with Understanding.

The first part of this unit is the Science Book, or student text. This text is written to explain the important ideas about matter and molecules discussed above in a way that will help students learn with understanding. Reading about the kinetic molecular theory with understanding, however, is a difficult task for most students. They can truly understand only if they successfully work through the process of conceptual change; that is, they must actively integrate the information in the Science Book with their own previous ideas, sometimes realizing that their previous ideas were incorrect and changing them accordingly.

Both our research and the work of other researchers indicates that no matter how well a textbook is written, many students normally fail to read it with understanding. The reason is that many students do not normally process the information in the text in an active way. Teachers can make a great deal of difference in how students read and process textbooks. By helping your students to ask the right questions and think actively about what they read, you can help them understand the Science Book much better than they otherwise would.

In particular, we recommend a set of teaching strategies based on the work of Annemarie Palincsar and Ann Brown, who have found that student comprehension can be greatly increased if students engage in the following activities as they read:

1. Summarizing: Developing brief summaries of the passage that they just read.

2. Generating questions: suggesting questions that address important ideas (as opposed to minor details) in the passage they just read.

3. Clarifying: Identifying statements or ideas that are unclear or confusing to them and asking questions that help them resolve their difficulties.

4. Predicting: Making predictions about the contents of the next lesson or passage that they will read.

We would add to Palincsar and Brown's list, a fifth activity, applying, or trying to figure out how the ideas in the text can be used to describe, or predict, or explain events or observations that the students make about the world around them.

There are a variety of strategies that you can use to help your students engage in these important activities. The simplest is just to use these activities as a guide to class discussions of the Science Book. After you and the class have finished reading each lesson, call on students in your class and ask them to summarize, generate questions, clarify, make predictions, and apply the ideas in the lessons that they just read.

There are also other ways that you can involve students in these activities. You might want to have students write summaries, questions, clarification's, predictions, or applications, then share what they have written with the class. You could also sometimes have the students working with each other in small groups, sharing summaries, questions, clarification's, predictions, and applications with each other. Regardless of how you do it, though, you can greatly enhance the effectiveness of the Science Book by helping your students to engage in these activities as they read it.

The Activity Book: Writing Descriptions and Explanations.

This unit is based on a basic belief about the nature and purposes of scientific knowledge: We believe that science was developed for the purposes of describing and explaining natural phenomena. This means that an important part of teaching science consists of giving students the chance to practice their own descriptions and explanations. For that reason, this unit includes an Activity Book containing many questions that require students to write out descriptions or explanations.

Although this writing is essential for student learning, it is also a lot of work, for the students and for you. We would like to give you a few suggestions about how to make the work load manageable while still giving the students plenty of practice in developing descriptions and explanations.

You do no have to check every activity and question set yourself (though you certainly can if you want to). It is important for students to answer all of the questions, but there are a variety of ways that they can get practice and feedback in answering these questions without your having to read every student answer. This will also enhance cooperative learning strategies. For example:

1. Students can answer their questions individually, then meet in groups of three to compare their answers and develop a group consensus answer. The group consensus answers can then be compared in a class discussion.

2. Groups of students working together on a question set of a laboratory activity can develop a group of consensus answers. The group consensus answers can then be compared in a class discussion.

3. Students can check each other's papers. It is possible for students to learn a great deal from a class discussion that focuses on what qualities make an answer acceptable or unacceptable.

4. Student answers can be used as a basis for class discussion rather than individual checking. You can solicit a variety of answers from the students, and lead the class in a discussion of the merits of each answer.

You can probably think of a variety of other arrangements that will work equally well. What is important is that students keep writing and discussing their descriptions and explanations, with enough feedback from you or from each other to help them understand their mistakes and improve the quality of their descriptions and explanations.

Some questions are intended primarily for the purpose of eliciting students' ideas about topics that they have not yet studied and may only partially understand. These questions should <u>not</u> be graded on a right-or-wrong basis; they should be used as a basis for discussion by small groups of students or by the whole class.

Lesson Cluster Review Questions and Tests: Monitoring and Feedback.

The last question set in each lesson cluster contains questions reviewing the content of the entire lesson cluster. If you grade those question sets, which are packaged separately so that they can be taken up or used as tests, you should be able to do an adequate job of monitoring the progress of individual students.

Your materials also include two tests, one covering Lesson Clusters 1-4 (State of Water, Other Solids, Liquids and Gases, Air Around Us, and Compressing and Expanding Air), the second covering Lesson Clusters 5-9 (Explaining Dissolving, Heating and Cooling, Expansion and Contraction, Explaining Melting and Solidifying, Explaining Evaporation and Boiling, and Explaining Condensation). Since each lesson cluster builds on ideas from previous lesson clusters, you should review or reteach ideas that your students are having trouble understanding as revealed by their performance on the review question sets or the tests.

Overhead Transparencies: Discussing Important Questions.

The unit also contains a set of overhead transparencies that are designed to help you develop class discussions about key ideas in the unit. These transparencies are listed immediately after the Table of Contents of this Teacher's Guide. Each transparency is illustrated and discussed at the lesson where we feel that it could appropriately be introduced. (Although we encourage you to use transparencies whenever you feel appropriate, several times, if necessary.)

Each of the transparencies has two layers. The bottom layer poses a question about a situation. You should encourage students to express their ideas about that situation and the answer to the question. After your students have tried to answer the question and you are aware of how they think, you can add the second overlay to give them a scientific answer to the question.

You will find that your students' answers are sometimes very different from those in the science book. These differences are often the result of misconceptions that a surprisingly large number of students firmly believe. For the students to see the differences, it is essential for the students to have a chance to answer the questions and discuss the contrasts. Students must see these contrasts explicitly so they understand the need for abandoning their naive ideas in favor of the more sophisticated scientific conceptions.

The transparencies will work most effectively if you encourage an atmosphere in your classroom where students feel safe in expressing ideas they are not sure of, and where students know that their ideas are valued even if they are not entirely correct.

Activities and Demonstrations: Connecting Scientific Ideas with the Real World.

Every lesson cluster includes at least one hands-on activity for students to do or a demonstration for students to observe; most lesson clusters have more than one. The Activity Book contains questions for students to answer about each activity and demonstration. The materials and teaching suggestions for each activity and demonstration are listed in the section on that lesson in this Teacher's Guide. A master list of materials for all lessons is included at the front of each cluster of lessons.

Charts and Posters: Helping Students Remember and Organize Key Ideas.

The unit also includes one chart (on the inside back cover of the Science Book and this Teacher's Guide) and three posters (listed after the Table of Contents). These charts and posters present in tabular or graphic form some key ideas that your students will need to refer to over and over throughout the unit. We therefore recommend that you introduce each of these charts and posters as it becomes relevant, then refer to it whenever appropriate after that time.

Videotape: Illustrating Key Ideas.

Some ideas, especially those involving molecular motion, are difficult to envision from still pictures. We therefore have selected a videotape that illustrates these ideas in a more active way.

The videotape is an episode entitled "Making Dew" taken from The Voyage of the Mimi television series. This segment shows how the crew of the Mimi designed and used solar stills when they were shipwrecked on an island that contained no fresh water. This section should be shown in connections with Lesson 9.3. This tape is available through the Science Resources Center for a three-day check out. Contact the Science Resources Center to arrange for check out.

Unit Introduction

You may want to discuss with your students some things that not matter. These may include the vacuum of outer space, forms of energy such as light and heat, or abstract concepts such as temperature, force, and love.

If some students are still confused, stress that any solid, liquid, or gas is matter. If something is not a solid, liquid, or gas, it is not matter.