The CaSEbook Companion to "Introduction to Matter"

The 21st Century Center for Research and Development in Cognition and Science Education

This CaSEbook is designed to be a supplement to the "Introduction to Matter" unit of the Holt Science and Technology series. It has been developed as part of an experimental study in science education. Reproduction or dissemination of any materials in the CaSEbook Companion is strictly prohibited. The CaSEbook is intended for use in an experimental study being conducted by The 21st Century Center for Research and Development in Cognition and Science Education. More information on the center is available at http://www.cogscied.org/.

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Welcome

The 21st Century Center for Research and Development in Cognition and Science Instruction, the only one of its kind in the United States, was established with funding from the Institute for Education Sciences, a research arm of the United States Department of Education in July 2008. The main challenge for the Center is to incorporate cognitive science principles to existing middle school science curricula and measure the effectiveness of such modifications. Partnering in this endeavor with the Center is a team of cognitive scientists from the University of Pennsylvania, Temple University, and the University of Pittsburgh, who have created the materials in this binder.

If you have been given this binder, you are an integral part of this research study into "what really makes a difference for students learning science." Your faithful implementation of these modifications is critical to the research which will result in meaningful evidence of the effectiveness of the cognitive principles employed in the materials. Your experience using the materials in the classroom with your students and your feedback on their usage is the core of the work of the Center. We are grateful for your willingness to join us in this exciting endeavor. We hope you will find the opportunities to interact with these materials and with other teachers in your grade level to be both stimulating and satisfying. Thank you for joining the team.

The Center's main office is located in Conshohocken, Pa. For more information about the Center and its work, please visit our website at http://cogscied.org/.

How To Use This Binder

At the outset, we would like to thank our pilot teachers who contributed to the evolution of these materials. We have incorporated their thoughtful feedback about the organization of the materials to facilitate teacher use. We hope you find the binder user-friendly!

The first sections of the binder, the introductory materials, serve as an overview of the materials. After a brief description of the project in the Welcome, the remaining sections include a description of the Cognitive Science Principles employed in the modifications, the "Big Ideas" in the unit, Words Students Need to Learn, Table of Contents, and the Overview Calendar of "Introduction to Matter" materials.

The remainder of the binder is organized by chapter ordered by days. Each day has its own page listing the Big Idea, teacher and student materials needed, and activities of the day with suggested timing for them. This is followed by actual instructional materials for use on that day. Most days have a Warm-up, a powerpoint slide with follow-up questions in the notes section. They are designed to either review earlier work or to set the stage for that day's topic. This is followed by teacher notes that may include copies of the powerpoint slides for the Contrasting Cases along with teacher notes. Student worksheets for the Contrasting Cases are found in a separate section at the back of the Binder. Some days refer to the use of the Holt text. Teachers are encouraged to use the text in their normal fashion. Some days include copies of Visualization powerpoint slides. Visualizations are discussions about diagrams students encounter in the text. Again teacher notes are included with the powerpoint slides to guide the teacher in those discussions. Weekly quizzes are included with answer keys included on the day they are scheduled to be given. Student quiz masters are included in a separate file at the end of the Binder. Each section of a chapter ends with an End-of-Section Survey which lists the activities and provides space for comments. Teachers are encouraged to fill this Survey in as they go through the activities. These sheets will serve as the basis of discussion at the follow-up Professional Learning Community meetings that are scheduled during implementation.

Included with the Binder is a CD-Rom of powerpoint slides for the Contrasting Cases, the Visualization exercises, and Warm-ups. These are identified by chapter and day. Materials not provided in your Holt kit but required for doing the Contrasting Case activities such as the the rheoscopic fluid are also provided.

We hope you find the organization of the materials in the binder easy to use. As you use the materials, any feedback to improve the binder will be very much appreciated!

Cognitive Principles

The CaSE project approached the development of modifications using four areas of focus derived from current cognitive science research on student learning:

- Contrasting Cases
- Visualizations
- Prior Knowledge and Misconceptions
- Spaced Testing

Each of these draws on well-established principles of cognitive science and has been shown in previous studies to be effective in improving student learning in science.

Contrasting Cases

A typical way of teaching (in science, law, medicine, etc.) is through concrete examples or cases. Cognitive science research has found that some ways of using cases are much more effective for student learning than common practice in teaching with cases; these results can be very surprising to teachers (as they were to many researchers). One result is that asking students to compare across cases is much more effective than asking students to consider each case one at a time (Gentner, Loewenstein, & Thompson, 2003), with one study finding that a comparison between two cases leads to more learning than sequentially studying five cases. Case comparison helps students see the abstract ideas that are true across cases, rather than focus too much on what is specific to each case. This abstract understanding helps them transfer their knowledge to tests and other contexts (Gick & Holyoak, 1983).

Another interesting result relates to the timing of contrasting cases. In most textbooks, case comparison is usually placed as a homework task at the end of a unit of study, asking students to differentiate related ideas they have already learned about. Surprisingly, research has found that case comparison should be done before principles are introduced rather than as a form of practice (Bransford & Schwartz, 2001). The idea is that the case comparison helps students 'see' the critical features that are common across the cases. The students can then use these features to make sense of the principles and laws taught in a lecture, text, or experiment by relating the principles to the critical features they already know.

As a result, we have added contrasting cases early in the instruction of each chapter, to help students build a strong conceptual foundation to ground the instruction that happens later in the chapter. We have focused our choice of contrasting cases on the biggest ideas of each chapter. We have also tried to make the cases interestingly different so students can be surprised with the diversity of cases for which these ideas apply. You will also see that the tasks focus student attention on what is common across cases within a category, and on what is critically different across categories that need to be separated.

Visualizations
Students often fail to make the most of the images that they come across in educational settings. In some cases, they may skip images entirely while reading. When they do look at the images, they often lack the skills to fully appreciate them (Berthold & Renkl, 2009). For example, many teachers are surprised to find that students who are skilled in other ways are unable to follow the arrows, captions and labels in a complex diagram (Hegarty, Kriz, & Cate, 2003). When students do not understand these diagrams, they may come away with an inaccurate understanding of the content, and they might become more likely to skip diagrams entirely to avoid further frustration (Bartholomé & Bromme, 2009).

The visualization exercises are designed to address this problem in two ways. The first is to provide your students with explicit training in common elements of diagrams and other images. At the beginning of the unit, these exercises are very simple, focusing on identifying common elements of images and how to interpret them. As the unit progresses, the exercises build in complexity and become progressively more demanding.

The second thing these exercises are designed to do is promote better habits. Students will not only learn how to make sense of the difficult images they are often confronted with, they will also learn that they MUST make sense of these images. They will learn that once they start to pay close attention to them, the images will help them understand.

A hard copy of the exercises has been made available in your materials. In addition, for those teachers that have access to digital projectors, all of the exercises have been compiled in PowerPoint files. The exercises are usually quite short, generally requiring no more than five minutes to complete. Your daily schedule will give you an idea about when to conduct each exercise. Usually, the exercises are built around an image from the curriculum, and each exercise is intended to be conducted when you would naturally come to that image. We understand that classes have their own rhythm, and that running a classroom demands some room for discretion. For this reason we identify the best day for each exercise, but of course you should choose the best moment within that day. We also recognize that sometimes even more flexibility is required, so you may occasionally do an exercise on the day before, or the day after it is scheduled, but we strongly encourage you to try to do these exercises on the assigned day. It is also important to understand that these exercises should be done *in addition* to any instruction you would normally attach to a particular image. For example, if there is an exercise that focuses on the arrows within a diagram, this does not mean that you should pass up opportunities to explore other elements of the diagram, elaborate on the content addressed by the diagram, or anything else you would ordinarily do within the flow of your teaching.

We would like to make one final point. While developing these exercises, we often heard teachers predict that they would be "too easy," and that their students had already mastered these ideas, and might even feel put-off. Once they tried them, however, they were frequently surprised by the number of students who clearly needed this sort of instruction. Yes, some of your students will already be skilled with images, but many of them will not be, and for those who are not skilled, the problem runs quite deep.

Prior Knowledge and Misconceptions

Cognitive research shows that one of the strongest predictors of how well a student is likely to learn something is how the new learning is related to what the student already knows and to how their prior knowledge is organized (NRC, 1999, 2006). If the concepts to be learned and the way that they are organized match neatly with a learner's pre-existing knowledge base, then the learning is likely to be smooth and rapid. However, in science, students often lack relevant conceptual frameworks or have frameworks that are not developed enough to support new learning adequately. If students cannot relate new information to a meaningful framework, they will probably resort to memorizing terms that will quickly be forgotten or that will remain in isolation, unable to be connected to other knowledge or applied when relevant.

Science often extends everyday understanding to new levels that cannot be directly seen or experienced in everyday life. For example, much of biology and chemistry involves learning about entities and processes at a microscopic level. To make sense of this, students need to add new levels of concepts and explanatory systems to their understanding of the natural world and then work out how those levels are connected to their pre-existing views of the world (Smith et al. 1997). Several of the modifications in this unit are aimed at helping students develop new frameworks to help them take in scientific ideas that involve new levels of explanation.

Science also involves very large variations in scale. Evolution and some kinds of geological processes, for instance, happen over very, very long periods of time. Space is unimaginably vast. Cells, molecules, and atomic particles are inconceivably small. Learners must stretch their ability to think about large and small magnitudes that extend far beyond their everyday experience. A number of the modifications made throughout this unit, including many of the visualization activities, are designed to help students recognize when extreme scales are relevant and to develop tools for interpreting them in more meaningful ways.

One of the biggest challenges for teaching and learning arises when students have an entrenched misunderstanding that conflicts with the material to be learned. When a larger conceptual/explanatory system is in conflict with new learning, cognitive researchers often say that the student has a *misconception* (Carey, 1991, 2009). As cognitive scientists use the term, a misconception is more than a common factual error or a mistaken belief. It's not just that a student is viewing an isolated concept in a different way; instead, a larger system of concepts and the causal or explanatory frameworks in which they are embedded actively conflict with the material to be learned.

In science, there are a number of misconceptions that are well-documented and very common. Many students, including college students who have successfully completed relevant science courses, have persistent misconceptions in some areas of science. These misconceptions seem intuitive and self-evident to them. In contrast, understanding the causal mechanisms of modern scientific theories is often less intuitive and requires developing more detailed and complex explanatory systems.

Misconceptions tend to be entrenched and automatic in students' thinking, and they are resistant to change. It's important to be aware of them to make sure that teaching and learning activities emphasize scientifically correct views and do not reinforce the misconceptions. However, it's also important to recognize that misconceptions are not easily changed: simply explaining to students that their ideas are incorrect is usually not effective. Countering misconceptions is generally a long, gradual process, in which a new causal/explanatory structure is constructed and applied repeatedly with the students at the same that the students' incorrect alternative way of looking at things is challenged.

The modifications made to the curriculum have been designed with these kinds of learning challenges in mind. The order of concept presentation differs somewhat from the sequence found within the Holt text. The modified materials start with Chapter 3 to help students begin to understand that geologic processes happen over very, very long periods of time. Similarly, the rock cycle is introduced at the end rather than the beginning of Chapter 2 to enable students to build understanding of each formation process before examining how they relate to one another. Places where common misconceptions are likely to arise are addressed in the teacher materials accompanying the modifications. Throughout the unit, the modifications are intended to make the "big ideas" in each chapter more accessible, meaningful, and coherent to middle school students.

Spaced Testing

A large frustration for teachers is how quickly students forget what they have been taught. Cognitive science research has shown that forgetting can be dramatically reduced by occasional revisiting of old concepts in later tests (Rohrer & Pashler, 2007). This practice is called spaced testing, where the test of a concept is spaced out over time rather than massed all in a short amount of time. The longer you want students to remember something, the more important it is to spread out the time between tests.

Another related result is the value of testing per se. Students and teachers often assume that simply re-reading or re-lecturing on prior materials is sufficient for improving retention of material. In addition, with the current high-stakes testing environment, many people feel that students are over-tested. Indeed, when done poorly, testing can have negative effects (e.g., reinforcing the wrong concepts or more superficial levels of understanding). However, cognitive science research has found that, when done well, testing does actually help students better remember material over-and-above spending the same amount of time just revisiting the material (Roediger & Karpicke, 2006). There is some suggestion that short answer questions help more than multiple choice, but both are helpful (McDaniel, Anderson, Derbish, & Morrisette, 2007).

In our modifications, you will see that we have a number of embedded assessments designed to provide timely feedback to you as the teacher and to help improve student learning. First, we have daily warm-up questions at the beginning of most lessons, which are meant to bring to mind prior concepts most relevant to the lesson of the day. Often these concepts are from the previous day, but sometimes they come from earlier weeks of instruction. We use short answer formats because no official grading is required and this format is best for learning. The provided slides include correct answers to support a brief in-class discussion after students have written out their attempts; this provides students with quick feedback on their answers and they can begin the lesson with a more solid foundation.

Second, we have end-of-section quizzes, which include some questions from prior chapters, further encouraging long-term retention of the concepts. Here we also encourage you to go over the quiz results with students the next day. We use multiple-choice to enable quick grading and looking at patterns across students.

Third, we have cumulative end-of-unit tests, which ask students to have a basic understanding of the big ideas from many weeks of instruction, providing a basis for improved retention many months later.

Finally, we have an end-of-year test which asks students to study for and bring back to mind content from earlier in the year, greatly increasing the chances that they will remember this information for years to come. End-of-unit and end-of-year tests will be distributed and graded by the project team at the appropriate times. The warm-up and end-of-section quizzes are provided to you with the other unit materials, so you can embed them in your ongoing instruction and use the results immediately to help reinforce and assess students' learning in progress.

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Introduction to Matter – Big Ideas

days 1 & 2

- Solids and liquids can be described by certain properties, but a given solid or liquid may not have all of those properties. For example, many solids are hard, but some can be molded.

day 3

- Gases are a kind of matter and, like solids and liquids, they can be described by certain properties.
- Gases take up space, and they are compressible (can be squeezed into a smaller space).

day 4

- Matter is anything that has mass and takes up space.
- Objects with more mass feel heavier than objects with less mass.
- The amount of space something takes up is called volume.
- Displacement is a procedure for measuring volume.

days 5 & 6

- The spring scale measurement is different on the moon than on Earth, but the balance measurement is the same.
- Mass is the amount of matter in an object or sample. (day 6 only)
- Weight changes when gravity changes, but mass stays the same. (day 6 only)

day 7

- Mass and volume change with sample size. If the sample size doubles, the mass and volume of the sample double as well.

days 8 & 9

- Mass is the amount of matter in an object or sample.
- Density is the amount of matter in a given amount of space.
- Density does not change with sample size. It is a property of the material that makes up the sample.
- Liquids form layers based on density because lighter (less dense) liquids float on top of heavier (more dense) liquids. (day 9 only)
- Objects that are less dense than water will float in water. (day 9 only)

day 11

- Displacement is a procedure for measuring volume.
- Density does not change with sample size. It is a property of the material that makes up the sample.

day 12

- A physical change does not change the identity (chemical composition) of an object or material.

day 13

- A chemical change occurs when a substance changes into one or more new substances with different properties.

days 15 & 16

- All matter is made up of particles that are always moving.
- These particles are attracted to each other, sort of like magnets or static electricity.
- The particles of a solid move slowly, and the attractions pull them so close together that they can only vibrate and wiggle in place.
- The particles of a liquid move faster. The attractions hold them near each other, but they have room to slide past each other and move randomly from place to place.
- The particles of a gas move very fast, so the attractions have little effect. The particles bounce randomly and spread out in all directions, so gases contain a lot of empty space. (day 16 only)

day 17

- States of matter are the physical forms that matter can take. They include solid, liquid, and gas.
- Different states have different physical properties that are caused by the arrangement and movements of particles.

day 18

- Gases behave in predictable ways in response to changes in pressure, volume, or temperature.
- Gas behaviors are caused by the movements of gas particles.

day 21

- Matter can change from one state to another.
- Change of state is a physical change that requires the gain or loss of energy.

day 22

- Air that is not in a container with a fixed volume expands when heated and contracts when cooled.
- Air that is in a container with a fixed volume can't expand or contract, so heating causes an increase in air pressure and cooling causes a decrease in air pressure.

days 23 & 24

- The temperature of a substance does not change when the substance is changing from one state to another.

day 26 & 27

- Compounds are made up of elements, but their properties are different from the properties of the elements they contain.

day 28

- An element is a pure substance that cannot be physically or chemically separated into simpler substances.

day 31

- A compound is a pure substance made up of two or more elements that are chemically combined.

day 32

- Compounds are made up of elements, but their properties are different from the properties of the elements they contain.
- Compounds can be separated into elements or simpler compounds by chemical changes.

days 33 & 34

- Compounds are made up of elements, but their properties are different from the properties of the elements they contain.
- Compounds always have the same composition.
- Mixtures can be made up of elements, compounds, or both, and their composition can vary.

day 36

- A mixture is a combination of two or more substances that are not chemically combined.
- Mixtures can be separated by physical changes.

day 37

- A solution is a mixture in which one substance dissolves in another substance.

day 38

- Different factors can affect the rate at which sugar dissolves.

day 39

- Concentration is the amount of solute dissolved in a solvent, often measured in grams of solute per milliliter of solvent (g/ml).

day 40

- Flame color is a property that can be used to identify specific elements within compounds.

days 43 & 44

- Atoms and molecules are the particles that make up matter.
- Atoms can combine to form molecules, and molecules are made up of atoms.

day 45

- It is possible to gather information about something without actually seeing it.

day 46

- An atom is the smallest particle into which an element can be divided and still be the same substance.

day 47

- All atoms have mass.
- Atomic number is the number of protons an atom contains.
- All atoms of the same element have the same atomic number.

day 48

- Isotopes are atoms of the same element that have different numbers of neutrons.

day 49

- Isotopes of the same element have the same atomic number but different atomic masses.

Words Students Need to Learn

Introduction to Matter contains some important science terms that students need to learn. These words and their meanings are listed in the table below. The first two columns show where in the textbook each word is introduced. The word “material” is not from the book, but is introduced on page 22 of the overview, in the description of the *Predict Displacement* contrasting case demo.

This table is intended for your use only. Research shows that it is not effective to simply give students a list of words and definitions to memorize. Rather, it is important to introduce each word carefully, make sure students understand the meaning and can describe it in their own words, and follow up with multiple exposures and assessments.

Feel free to revise each definition to include words and ideas that are familiar to your students. Subsequent warm-ups will ask students to review these words and their meanings, and we encourage you to look for additional opportunities to do so. It is particularly effective to get students to talk about closely related concepts and identify similarities and differences between them. For example, what’s the same and different about volume and mass? Both are properties of matter. Volume is how much space something takes up, and mass is how much matter something contains. Mass depends on volume and kind of material.

chp	page	word	meaning
1.1	4	matter	the "stuff" that makes up the physical part of the universe; anything that has mass and takes up space
1.1	4	volume	the amount of space something takes up; how much a container holds or can hold; a 3-D measure of size; often measured in milliliters or cubic centimeters
1.1	o-22	material	the kind of stuff something is made of
1.1	7	mass	the amount of matter in an object or sample; depends on how big it is and what it’s made of; often measured in grams
1.1	7	weight	a measure of the force of gravity acting on an object; depends on the mass of the object and the strength of gravity; often measured in Newtons
1.2	10	physical property	a feature of an object or material that can be observed or measured without changing its identity (chemical composition)
1.2	11	density	the amount of matter in a given amount of space; heaviness-for-size; a physical property of the material that makes up an object or sample; often measured in grams per milliliter or grams per cubic centimeter
1.2	14	physical change	a change in one or more physical properties of an object or material; does not change its identity (chemical composition)
1.3	16	chemical property	the ability of a substance to undergo a specific type of chemical change; eg, flammability, reactivity with oxygen

chp	page	word	meaning
1.3	17	characteristic properties	the features that are most useful in identifying a material; do not change with sample size (volume); density is a characteristic property
1.3	18	chemical change	a process that changes a substance's identity (chemical composition); forms one or more different substances
2.1	33	solid	state that has a definite volume and a definite shape; particles vibrate and wiggle in place
2.1	34	liquid	state that has a definite volume but not a definite shape; particles slide past each other and move randomly from place to place
2.1	35	gas	state that does not have a definite volume or shape; particles bounce randomly and spread out in all directions
2.2	36	temperature	a measure of how fast particles of matter are moving; when something gets warmer, its particles move faster and bounce harder; when it cools, its particles move slower and bounce less hard
2.2	37	pressure	a force or set of forces that is spread out over a surface (a force is a push, pull, or similar action)
3.1	56	pure substance	an element or compound that contains only one type of particle; all particles of a pure substance are alike no matter where they're found or what size sample you're working with
3.3	66	solution	a mixture in which one substance (solute) dissolves in another substance (solvent)
4.2	89	atomic mass unit (amu)	a unit used to measure the mass of atoms and molecules

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Overview of Introduction to Matter (days 26-50)

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