Matter and Energy for Growth and Activity

Teacher Edition

AAAS | Project 2061

NSTA press
National Science Teaching Association

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INTRODUCTION TO THE TEACHER EDITION

The Teacher Edition is designed to provide easy access to essential background information and support needed for using the *Matter and Energy for Growth and Activity* (*MEGA*) unit effectively in the classroom. Additional teacher support materials (e.g., videos and handouts) are provided online. The Teacher Edition and the online materials aim to provide both a "big picture" sense of the unit and its goals as well as the specific information and guidance needed to teach each lesson and carry out each activity.

Features of the Teacher Edition

At the unit level, the Teacher Edition lays out the overarching **Student Learning Goals for the Unit** and the central question students should be able to answer after completing all the lessons. It then outlines the disciplinary core ideas, crosscutting concepts, science practices, and performance expectations from *A Framework for K–12 Science Education* (the *Framework*) (National Research Council 2012) and the *Next Generation Science Standards* (*NGSS*) (NGSS Lead States 2013) that are targeted in the *MEGA* unit. In the **Design of the Unit** section, the Teacher Edition describes how research-based design principles influenced the development of the unit. The Content Storyline map provides a visual representation of the coherent story of science ideas that are drawn from *NGSS* core ideas and crosscutting concepts and take account of students' entering knowledge. A phenomena table summarizes the life and physical science phenomena that students explain using evidence from observations and data, models, and science ideas. This section also describes how science practices, including modeling and constructing explanations, are used to help students make sense of phenomena. **Unique Aspects of the Unit** describes the rationale for the unit's approach to the science content, including its choice of vocabulary used in the Student Edition. **Structure of the Unit** presents the overall design of the unit and describes the purpose and key features of each section of a lesson.

At the chapter level, each **Chapter Overview** describes the concepts developed in that chapter and provides a short synopsis of what students will do and think about in each lesson. At the lesson level, a **Lesson Guide** provides an overview of each lesson, including the key question, targeted science ideas and practices, materials, and advance preparation needed and a summary chart describing key phenomena—both firsthand observations and data—and representations used in each activity, the pedagogical purpose of each, and the intended observations students should make. The remaining pages of the lesson consist of facing **Student Edition and Answer Key** pages and **Teacher Talk and Actions** pages. Each Student Edition and Answer Key page reproduces the Student Edition page but also includes ideal student responses (in script text) written to reflect what students are expected to understand at that point in the lesson. The Teacher Talk and Actions pages provide a variety of information to help teachers facilitate the lessons, such as Safety Notes, background for teachers on the relevant science concepts, options for students who are more advanced or need more support, suggestions for managing classroom activities, and questions that can be used to elicit or clarify students' thinking. Each lesson concludes with a *Closure and Link* note on the Teacher Talk and Actions page that outlines a classroom discussion aimed at helping students gain perspective about what they now know and what questions remain.

A set of online resources available on the book's Extras page (*www.nsta.org/growthandactivity*) supplements the Teacher Edition with videos, photos, interactive media, handouts, and a list of supplies needed to teach the unit.

Student Learning Goals for the Unit

The overarching goal of the *MEGA* unit is for students to use important ideas about matter and energy, initially encountered in simple physical systems, to explain observable phenomena in the bodies of living organisms:

> To build body structures for growth and repair, living organisms produce polymers (and water molecules) during energy-requiring chemical reactions between monomers. Animals obtain monomers from their food, whereas plants make monomers from inorganic substances during energy-requiring chemical reactions that use energy from the Sun. The energy that both plants and animals use to produce polymers comes indirectly from energy-releasing chemical reactions such as the oxidation of glucose, fatty acid, and amino acid monomers and directly from the breakdown of ATP to form ADP and inorganic phosphate. The same energy-releasing chemical reactions provide energy for motion. While much of the energy released can be used for growth and motion, a lot of the energy is transferred as heat to the surroundings. Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as conditions change within some range.
>
> During both energy-releasing and energy-requiring chemical reactions, atoms are rearranged and conserved; therefore, total mass is conserved. The net amount of energy released or required reflects the difference between the total amount of energy that must be added to break bonds between atoms of reactant molecules and the total amount of energy that is released when bonds form between atoms of product molecules. As with atoms, energy is neither created nor destroyed during chemical reactions.

By the end of the unit, students will be able to answer the following unit question in terms of (a) the rearrangement and conservation of atoms during chemical reactions and (b) the use of energy-releasing chemical reactions to drive energy-requiring chemical reactions or processes:

> ***How do living things use food as a source of matter for building and repairing their body structures and as a source of energy for carrying out a wide range of activities?***

Alignment With National Science Education Framework and Standards

As noted earlier, the *MEGA* unit addresses important goals for science learning that are recommended in the *Framework* and *NGSS*. The science ideas displayed in text boxes in the content storyline that is shown in Figure 1 were drawn from the following disciplinary core ideas, crosscutting concepts, and science practices:

Disciplinary Core Ideas

Matter and Its Interactions (PS1)

Structure and Properties of Matter (PS1.A, Grades 8 and 12)

Chemical Reactions (PS1.B, Grades 8 and 12)

Energy (PS3)

Definitions of Energy (PS3.A, Grade 12)

Conservation of Energy and Energy Transfer (PS3.B, Grade 12)

Energy in Chemical Processes and Everyday Life (PS3.D, Grades 8 and 12)

From Molecules to Organisms: Structures and Processes (LS1)

Structure and Function (LS1.A, Grades 8 and 12)

Organization for Matter and Energy Flow in Organisms (LS1.C, Grades 8 and 12)

Ecosystems: Interactions, Energy, and Dynamics (LS2)

Cycles of Matter and Energy Transfer in Ecosystems (LS2.B, Grade 12)

Crosscutting Concepts

Systems and System Models (Grades 9-12)

Energy and Matter: Flows, Cycles, and Conservation (Grades 9-12)

Science Practices

Practice 2, Developing and Using Models (Grades 9-12)

Practice 4, Analyzing and Interpreting Data (Grades 9-12)

Practice 6, Constructing Explanations and Designing Solutions (Grades 9-12)

These *NGSS* elements are addressed throughout the *MEGA* unit, and all three dimensions of science learning—core disciplinary ideas, crosscutting concepts, and science practices—are carefully integrated to help students make sense of phenomena. Students model and construct evidence-based explanations about phenomena. The evidence comes from direct observations students make during classroom activities and from patterns in data reported in the scientific research literature that are simplified in the student text. Students use a variety of models to help them link the evidence to science ideas about atom rearrangement and conservation and about energy changes during chemical reactions within systems and energy transfers between systems.

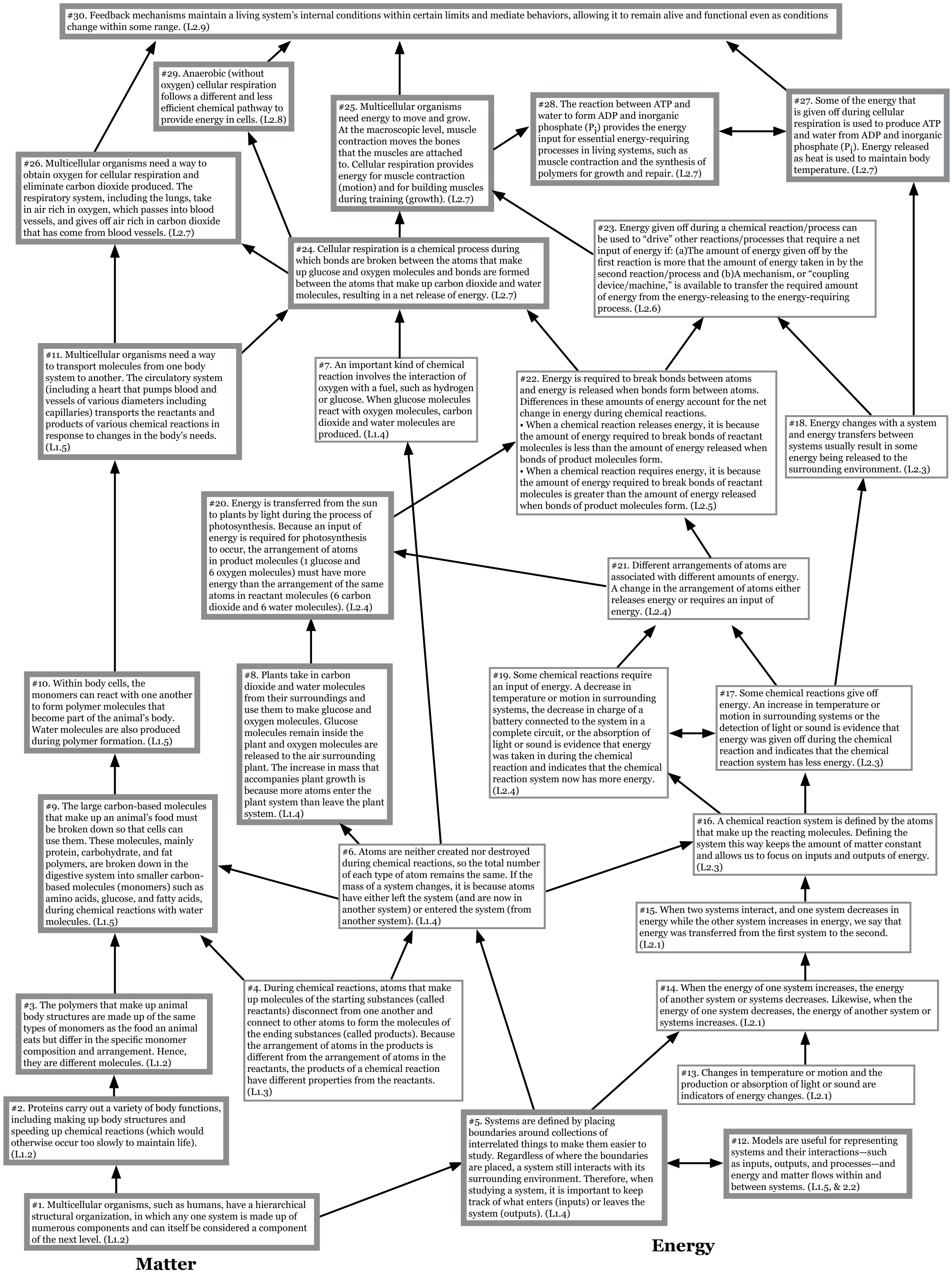
NGSS Performance Expectations

The unit contributes to the following high school performance expectations:

- Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. (HS-LS1-2)
- Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. (HS-LS1-6)
- Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. (HS-PS1-4)
- Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. (HS-LS1-5)
- Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. (HS-LS1-7)
- Construct and revise an explanation based on evidence for the cycling of matter and flow of energy [within organisms] in aerobic and anaerobic conditions. (HS-LS2-3)

Figure 1

Matter and Energy for Growth and Activity
Content Storyline



- Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. (HS-LS1-3)

Online resources available at *www.nsta.org/growthandactivity* provide specific details about which parts of science ideas and practices are targeted and describe and reference specific activities that contribute to each performance expectation.

Design of the Unit

The *MEGA* unit was developed by a team of scientists, educators, and curriculum developers at Project 2061 of the American Association for the Advancement of Science (AAAS) in partnership with media designers at the University of Utah's Genetic Sciences Learning Center. Development of the unit was guided by learning theory and research evidence showing that students' science understanding develops from (a) having a wide range of experiences with the natural world that are explainable by a coherent set of science ideas, (b) observing phenomena that are explicitly targeted to the science ideas and that address common student misconceptions, and (c) having an opportunity to interpret and make sense of what they experience in terms of those ideas. To help students generate conceptual understanding, however, teachers must guide them in generating ideas that are applicable across instances and in seeing how those generalizations are also useful for explaining other related phenomena. Consistent with these views, the *MEGA* unit supports student learning through lessons that focus on:

- a coherent set of ideas and connections among those ideas,
- preexisting ideas—both troublesome and helpful—that students are likely to hold,
- a variety of relevant and engaging phenomena, and
- activities that foster students' sense making and their ability to relate phenomena to the science ideas that explain them.

A Coherent Set of Ideas

The *MEGA* unit's development started by identifying a set of relevant disciplinary core ideas and crosscutting concepts in the *Framework* (National Research Council 2012) and then unpacking them into 30 discrete science ideas that are organized into a coherent content storyline for the unit.

Figure 1 represents the content storyline for the *MEGA* unit, mapping the progression of science ideas about matter on the left and energy on the right (see the Extras page at *www.nsta.org/growthandactivity* for a full-size version of Figure 1). Text boxes present the science ideas, and arrows indicate which science ideas contribute to other science ideas. Text boxes with thick borders show the life science ideas that make up the animal growth and activity storyline (Science Ideas #1–3, #9–11, and #24–30), the plant growth storyline (Science Ideas #8 and #20), and ideas about systems and models (Science Ideas #5 and #12) that students would need to make sense of phenomena involving matter and energy changes. These science ideas are based on high school core life science ideas and the crosscutting concept of systems and system models found in *NGSS* and the *Framework*.

Developers also integrated into the *MEGA* unit's content storyline several physical science ideas about matter and energy and additional ideas about systems drawn from *NGSS* middle and high school physical science core ideas and the crosscutting concept of energy and matter. Science Ideas #4, #6, and #7 show the prerequisite middle school matter ideas, and Science Ideas #13–19 and #21–23 show the prerequisite middle and high school energy ideas.

Students' Preexisting Ideas

Both the learning research literature and Project 2061's distractor-driven assessment items provided insights into misconceptions students might have when starting the *MEGA* unit. For example, *Making Sense of Secondary Science* (Driver et al. 1994) emphasizes the importance of instruction that takes account of students' ideas, describes studies that have investigated students' ideas through interviews, and reports on their findings. Life science sections on Cells, Food, Photosynthesis, Growth, Nutrition, and Respiration and physical science sections on Conservation of Matter, Mass, The Gaseous State, Combustion, Interaction, and Energy and Chemical Change provided valuable background information on naïve ideas students might bring to class. *Benchmarks for Science Literacy* (AAAS 1993) summarizes the published research on student misconceptions and learning difficulties on several topics relevant to the *MEGA* unit: Atoms and Molecules, Conservation of Matter, Chemical Reactions, Energy Transformations, Flow of Matter and Energy, Basic Functions, Reasoning, Models, and Detecting Flaws in Arguments. In addition, Project 2061's assessment items have identified misconceptions on these topics that are held by a national sample of middle and high school students (accessible at *www.assessment.aaas.org*).

Each misconception listed below is accompanied by the percentage of high school students who chose it out of four possible answer choices. As noted on the assessment website, the percentage of students holding these misconceptions in any given classroom could be higher or lower than the national sample. Different percentages for the same misconception result from differences in the appeal of distractors.

Food

- Food is a source of energy but not of building materials. (15%)
- Animals cannot store molecules from food in their bodies. (20%)
- Molecules from food are not stored in the fat tissue of animals. (20%)

Human Body Systems

- Blood does not carry simple sugar molecules to cells of the body. (31%)
- Capillaries are found only in internal organs, such as the lungs and intestines. (28%)
- Capillaries are only found in the extremities, such as hands and feet. (23%)
- Blood does not carry oxygen to the cells of the body. (17%)
- Simple sugars have to be broken down into smaller molecules before they can enter the cells of the body. (47%)
- Amino acids have to be broken down into smaller molecules before they can enter the cells of the body. (34%)
- Proteins do not have to be broken down before they can enter the cells of the body. (26%)

Because students holding these misconceptions might have difficulty following the life science content storyline, the *MEGA* unit includes activities that are designed to take account of them.

Not only did the pilot tests of the unit reveal students' misconceptions, they also showed that most students lacked critical prerequisite knowledge of chemical reactions and models for making sense of matter changes even in simple physical systems. Most students did not know that (a) new substances form during chemical reactions because atoms of reactant molecules rearrange to form products and (b) mass is conserved during chemical reactions because atoms are conserved. The following list illustrates both naïve and incorrect ideas identified by Project 2061's assessment items:

Chemical Reactions

- A chemical change is irreversible. (34%)
- The atoms of the reactants of a chemical reaction are transformed into other atoms. (40%)
- The products of a chemical reaction are the same substances as the reactants but with different properties. (19%)
- New atoms are created during a chemical reaction. (34%)
- Atoms can be destroyed during a chemical reaction. (21%)

Conservation of Mass

- Mass is not conserved in processes in which gases take part. If a gas is produced in a chemical reaction in a closed system, the mass decreases. (50% and 29%, depending on other answer choices)
- In a closed system, the total mass increases during a precipitation reaction. (49%)
- During biological decomposition in a closed system, the total mass of the system decreases. (32%)
- In a closed system, mass decreases after a solid has dissolved in a liquid. (20%)
- The mass of a closed system will increase if a new kind of atom is formed in the system. (19%)
- The number of different kinds of molecules, not the number of atoms, is conserved. (18%)

Prerequisite ideas about energy were also poorly understood. While more than half of middle and high school students understood that changes in motion, temperature, and light are all indicators of energy changes, fewer students (16–41% of middle school students and 18–49% of high school students, depending on the item) were able to apply that knowledge to chemical reactions (AAAS n.d.).

- Energy can be created. (28%)
- Energy can be destroyed. (19%)
- An object has energy in it that is used up as the object moves. (29%)
- Bond making requires energy. (52%)
- Energy is released when bonds break. (43%)

To address these gaps in students' knowledge, the *MEGA* unit's content storyline includes a set of middle and high school physical science ideas (see Figure 1) that are necessary if students are to build an understanding of matter and energy changes in living systems in terms of atoms and molecules.

Pre-test data confirmed that high school students starting the *MEGA* unit had a poor understanding of atom rearrangement and conservation, with a little over a third of them responding correctly to items aligned to those ideas. Only about 40% responded correctly to items assessing energy conservation.

The *MEGA* unit also takes into account students' readiness to carry out high school science practices of data analysis, modeling, and explanation. *NGSS* expects middle school students to be able to (a) analyze and interpret data from simple tables and graphs and draw conclusions about what the data do and do not show; (b) use physical models and drawings (though not chemical formulas or equations) to represent atom rearrangement and conservation during chemical reactions; and (c) construct valid explanations of phenomena involving changes in matter that use evidence, science ideas, and models to support claims.

Ideally, middle school students would have engaged in observing, modeling, and explaining phenomena involving chemical reactions in simple physical systems, such as those explicitly targeted in the eight-week *Toward High School Biology* (*THSB*) unit (AAAS 2017) that is a precursor to the *MEGA* unit. Pre-test data involving high school students who had not used the middle school *THSB* unit showed that students were struggling with using models, evaluating experimental designs, and drawing conclusions from experimental data, with only about 35% of students answering correctly on items assessing these practices. Classroom observations revealed that students were not able or inclined to reason with LEGO or ball-and-stick models to show how atoms disconnect from one another and connect to other atoms to form different molecules without the creation or destruction of any atoms. Nor did they demonstrate an ability to use models and science ideas about atom rearrangement and conservation to explain phenomena.

Phenomena

The *MEGA* unit is designed to provide students with opportunities to experience phenomena directly and, for phenomena that can't be observed directly, to examine data collected by scientists that can serve as evidence for the science ideas and for their explanatory power. The phenomena and data include numerous examples from both physical and life science contexts, with simple physical science phenomena typically used first to help students generate science ideas that are then applied to more complex biological phenomena. Table 1 lists science ideas found in the overarching goal of the unit (p. vi), examples of relevant physical and life science phenomena that are used in the *MEGA* unit to support those ideas, and the lessons (e.g., L1.3) in which they are used.

Each lesson includes tasks and questions that help students (1) make sense of observable phenomena and data using models of underlying matter and energy changes within systems and transfers between systems and (2) apply science ideas developed in simpler physical systems to living systems. By the end of the unit, students should be able to explain the growth and activity of all living things in terms of changes in the arrangement of atoms that result in energy changes within systems and energy transfers between systems and to recognize that the changes in matter and energy that they observe do not violate conservation principles.

Table 1. Life and Physical Science Phenomena in *MEGA* Unit

To build body structures for growth and repair, living organisms produce polymers (and water molecules) during energy requiring chemical reactions between monomers. Animals obtain monomers from their food, whereas plants make monomers from inorganic substances during energy-requiring reactions that use energy from the sun.	
Life Science Phenomena	**Physical Science Phenomena**
• Food is needed for an infant and a body builder to grow, a wound to heal, and cells to divide in culture. L1.1 • Common breakfast foods contain protein, fat, and carbohydrate polymers that are made up of amino acid, fatty acid, and glucose monomers. L1.2 • A plant gets bigger and develops more body structures as it grows. L1.4 • Isotopic labeling experiments show that the carbon atoms of glucose that plants use to build body structures for growth come from carbon dioxide in the air. L1.4 • Experiments measuring levels of polymers and monomers in digestive, circulatory, and muscular systems over time show that the protein, fat, and carbohydrate polymers used to build body structures are synthesized (along with water molecules) from amino acid, fatty acid, and glucose monomers that are digestion products of protein, fat, and carbohydrate polymers found in food. L1.5 • In the presence of light, an aquatic plant produces oxygen (based on splint test) and uses carbon dioxide (based on limewater test). L1.4 • An aquatic plant produces more oxygen when grown under a 100 w light bulb than under a 60 w light bulb. L2.4	• When a candle burns in air, the mass of the candle decreases. L1.3 • When a candle burns in air, two new substances are produced—a gas that turns limewater cloudy (CO_2) and a liquid that turns cobalt chloride paper from blue to pink (H_2O). L1.3 • When a battery is connected to water in a complete circuit, the mass of the water decreases and two new substances are produced—a gas that ignites a glowing splint (O_2) and a gas that makes a burning splint pop (H_2). L1.4 • When glucose ($C_6H_{12}O_6$) reacts with oxygen (O_2) in an open system, the mass decreases and two new substances are produced—a gas that turns limewater cloudy (CO_2) and a liquid that turns cobalt chloride paper from blue to pink (H_2O). L1.4 • When a moving ball collides with a stationary ball, a sound is heard, the stationary ball starts moving, and the moving ball stops. L2.1 • When a flask of hot water is immersed in a beaker of cold water, the temperature of the cold water increases, and the temperature of the hot water decreases. L2.1 • Coffee grounds move when a loud sound starts and stop moving when the sound stops. L2.1 • A solar-powered toy car moves farther under a 100 w light bulb than under a 60 w light bulb. L2.1 • More oxygen gas (O_2) and hydrogen gas (H_2) are produced from water (H_2O) when water is connected in a complete circuit to a new 9-volt battery than to a used battery. L2.4 • When ammonium thiocyanate and barium hydroxide react, the temperature of the surrounding system decreases. L2.4

The energy both plants and animals use to produce polymers comes indirectly from energy-releasing chemical reactions such as the oxidation of glucose, fatty acid, and amino acid monomers and directly from the hydrolysis of ATP to form ADP plus inorganic phosphate.	
Life Science Phenomena	**Physical Science Phenomena**
• Body builders synthesize more protein in an arm undergoing resistance training than in the other arm not undergoing resistance training. L2.7 • When a solution of ATP was added to a system containing amino acids and other necessary molecules for building proteins, proteins were made. L2.7 • The dry cell mass of *Lactococcus lactis* increases without oxygen but increases more over 14 hours with oxygen than without oxygen. L 2.8 • When *L. lactis* bacteria were grown on glucose in the absence of oxygen, the glucose concentration decreased, and the amount of lactic acid produced increased. L2.8	• The energy released when candle wax ($C_{11}H_{24}$) reacts with O_2 in a beaker to produce CO_2 + H_2O warms the beaker and surrounding air. L2.3 • The energy released when glucose ($C_6H_{12}O_6$) reacts with O_2 in a bottle to produce CO_2 + H_2O increases the motion of the bottle. L2.3 • When hydrogen and oxygen gas react in a bottle, light and sound are emitted, and the bottle's motion increases. L2.3
The same energy-releasing chemical reactions provide energy for motion.	
Life Science Phenomena	**Physical Science Phenomena**
• Limewater turns cloudy faster after 5 minutes of vigorous exercise than after 5 minutes at rest. L2.7 • The amount of oxygen taken up by thigh muscle increases with exercise time. L2.7 • Thigh muscle glucose uptake increases with time and exercise intensity. L2.7 • Isolated muscle fibers do not shorten when glucose + oxygen is added but do shorten when a solution of ATP is added. L2.7 • As the intensity of exercise increases, the concentration of glucose in the blood decreases, and the concentration of lactic acid increases. L 2.8	The physical science phenomena in the previous row that were used to develop the role of energy-releasing chemical reactions in the growth of organisms were also used to develop their role in providing energy for motion.

While much of the energy released can be used for growth and motion, a lot of the energy is transferred as heat to the surroundings.	
Life Science Phenomena	**Physical Science Phenomena**
• Thigh muscle temperature increases with exercise time. L2.7	• When a person lands on one end of a seesaw, lifting a person up on the other end, the second person doesn't rise as high as the first person started. L2.6 • A battery warms up as it provides energy to produce hydrogen and oxygen from water. L2.6 • When gasoline reacts with oxygen in a car engine, the hood of the car warms up. L2.6

Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as conditions change within some range.	
Life Science Phenomena	**Physical Science Phenomena**
• Despite predicted increases in muscle temperature, based on extrapolating from the muscle temperature increase observed in 3 minutes of exercise, the temperature of runners decreased by 1.5 °F after a 4-mile run. L2.9 • Despite predicted decreases in blood glucose and O_2 and increases in blood CO_2 and H_2O, based on an understanding of reactants and products of cellular respiration, data show that measured levels of these substances stay within a fairly narrow range. L2.9	See the Extras page at *www.nsta.org/growthandactivity* for a lesson on feedback in a simple physical system that could be used with students who may have difficulty with the idea of negative feedback.

Science Practices and Sense Making

Using scientific practices to help make sense of phenomena is central to the design of the *MEGA* unit. Students (a) analyze data they have collected or data from published scientific studies and reflect on what conclusions can be drawn from the experiments or on what additional data they could collect to test their predictions of phenomena; (b) use a variety of models to get ideas about the underlying causes of phenomena; and (c) use evidence, science ideas, and models to explain phenomena.

Data analysis. Students analyze data in nearly every lesson and use findings to support claims. For the matter story, firsthand observations; patterns in data; and inferences from tests of various substances provide evidence that chemical reactions have occurred, what the reactants and products are, and where in the body the reactions occur. For the energy story, students collect and analyze data about changes in temperature and motion in simple physical systems and then use changes in temperature and motion as indicators of energy changes associated with chemical reactions. Calorimetry is introduced to show how energy changes in chemical reactions are measured, enabling comparison of the amount of energy released when various fuels react with oxygen, the energy requirements of important biological reactions, and considerations about which energy-releasing reactions could drive the energy-requiring reactions and processes. Each chapter culminates in a lesson where students use findings as evidence to construct and revise a model.

Modeling. Students use data to construct and revise models. For the matter story, data about various body systems are used to construct hierarchical models of the components, revealing that each system is composed of organs composed of cells that are composed of polymers composed of monomers that are composed mainly of carbon, hydrogen, oxygen, and sometimes nitrogen atoms. A comparison of polymers making up body cells to polymers available in food suggests the kinds of chemical reactions that need to occur, and data from scientific papers provide evidence for which reactions do occur and where, allowing students to revise models of how food contributes to growth.

Students use **model-building activities** and **chemical equations** to model atom rearrangement and conservation during chemical reactions that lead to the production of new substances in closed and open systems. Students manipulate LEGO or ball-and-stick models to convert molecules of reactants into molecules of products and weigh models in sealed versus open baggies to represent mass conservation and changes in measured mass. They use word equations with chemical names (e.g., glucose reacts with oxygen to form carbon dioxide and water) and equations with chemical symbols and formulas ($C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$).

Energy changes within systems are represented with bar graphs and system boxes. In bar graphs, shown in Figure 2, the difference in the heights of the energy bars for the reactants and the products indicates whether the chemical reaction releases energy or requires a net input of energy. In a system box, shown in Figure 3, the higher-energy state is written on the line at the top of the box and the lower-energy state is written on the line at the bottom of the box. A curved vertical arrow within a system box that connects higher-energy state and lower-energy state is used to represent the direction of the energy change. For example, in a system box that represents higher-energy reactants interacting to form lower-energy products, an arrow pointing downward would indicate that energy is given off during the chemical reaction or process. An arrow pointing upward would indicate that energy is required for the chemical reaction or process to occur, such as a tennis player going from being at rest to moving.

Figure 2. Example of a Bar Graph

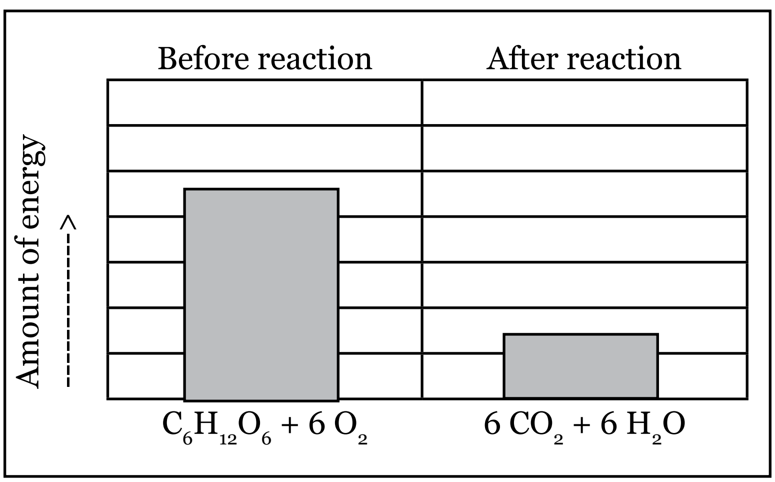
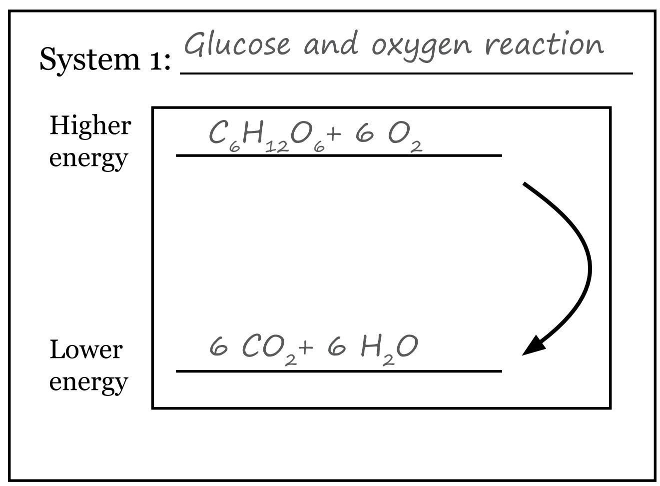
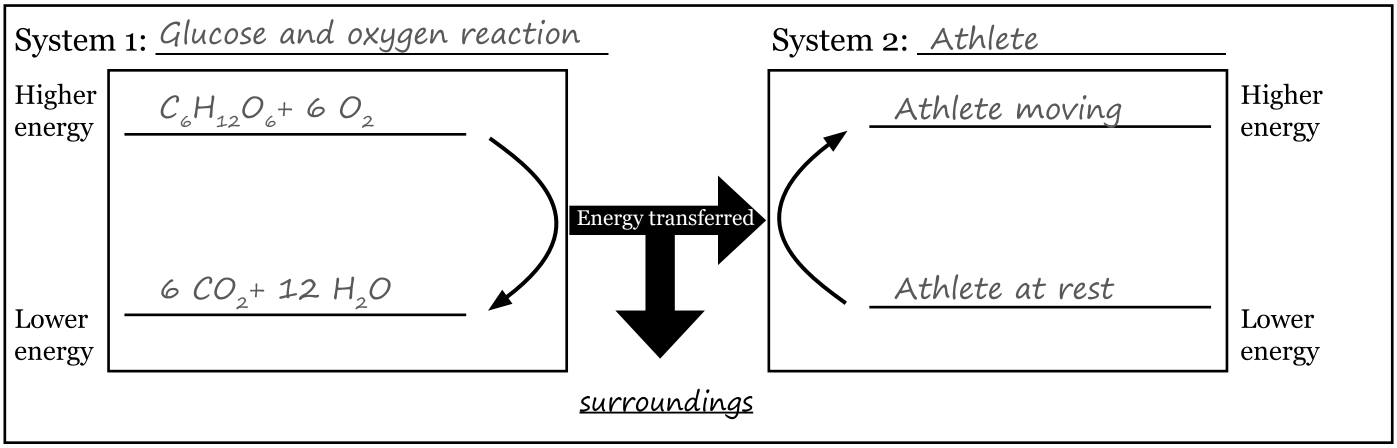


Figure 3. Example of a System Box



Energy transfer from one system to another system is represented with an energy transfer model, shown in Figure 4, that includes two or more system boxes and a thick arrow connecting pairs of boxes. The direction of the arrow between system boxes indicates the direction of energy transfer, which is always from the energy-releasing chemical reaction or process to the energy-requiring chemical reaction or process. Thick arrows are also used to represent energy transferred as heat from a system to its surroundings.

Figure 4. Example of an Energy Transfer Model



Constructing explanations. The *MEGA* unit engages students in constructing scientific explanations of phenomena, building on the support provided for this practice in the precursor middle school *THSB* unit, which uses the cognitive apprenticeship model (Brown, Collins, and Duguid 1989; Collins, Brown, and Newman 1989) to support students in constructing explanations. Teachers can refer to *THSB* for guidance on helping students develop their ability to construct evidence-based explanations, but a brief overview of how the *THSB* unit addresses this key science practice follows.

In the beginning of the *THSB* unit, students are provided with an example of a valid explanation, and the essential elements of an explanation—claim, relevant science ideas, and evidence that will be linked to the claim using science ideas—are defined. The early *THSB* lessons also establish Explanation Quality Criteria that students can use in judging an explanation's quality and introduce a template to remind students about the essential elements and help them organize their thinking and writing. After students experience modeling activities, a new element is added to the explanation template—models/modeling as tools for thinking about how something might work—and from then on students are expected to include appropriate models in their reasoning. The cognitive apprenticeship cycle is then repeated using the full explanation template. As the unit proceeds, students are reminded to use ideas about atoms in their explanations and to be sure that their explanations meet the Explanation Quality Criteria. The explanation template is faded in the *THSB* Student Edition but is available in the *THSB* Teacher Edition if the teacher feels the students still need it. At the end of the unit, the scaffolding is completely removed except for a reminder that students can use science ideas from anywhere in the unit to support their claims. Strategies used in the *THSB* unit may be helpful if students have had little or no prior experience constructing explanations. The *THSB* Teacher Edition and web-based teacher resources support teachers in helping students construct evidence-based explanations. The Teacher Edition provides ideal responses for each explanation task and for each element of the explanation template. Roseman, Herrmann-Abell, and Koppal (2017) include examples of rubrics for explanation tasks recommended for use as embedded assessments.

Nature of Science

Students have opportunities throughout the unit to experience how science works. They analyze and interpret data they collect as well as data from published studies, and they use data and reasoning from models to develop evidence-based explanations in ways that are consistent with what is expected of scientists. Students are repeatedly asked to list examples of phenomena they have observed in class that are consistent with presented science ideas and are told that the reason they can legitimately use the science ideas to support explanations of similar phenomena is that the science ideas are consistent with a wide range of observations and data—not just the small number they examined in class. Lesson 2.7 briefly recounts the discovery of the role of the ATP + $H_2O \rightarrow ADP+P_i$ reaction in coupling cellular respiration to muscle contraction.

Nonetheless, the *NGSS* note that while integrating science practices, core ideas, and crosscutting concepts "sets the stage for teaching and learning about the nature of science" (NGSS Lead States 2013, p. 97, Appendix H), engaging in such activities is not sufficient. Students would also need to reflect on their model-building, data analysis, and explanation activities and to compare their work to the work of scientists, which would likely involve examination of historical case studies. While the history of the discovery of the role of ATP in muscle contraction is fascinating, partly because the discovery involved scientists working in isolation during World War II who were unable to share their work or read about the work of others for several years, given the time that these additional activities would require and the risk they might pose to the coherence of the content storyline, we reluctantly decided not to focus more instructional time on the nature of science learning goals. However, doing so would be a way to increase the sophistication of the unit for students who readily grasp the targeted ideas.

Unique Aspects of the Unit

Understanding some of the thinking that went into the design of the *MEGA* unit and what the unit is intended to do can help to support students in achieving the unit's learning goals. This section briefly describes the development team's rationale for decisions about how the science ideas (drawn from disciplinary core ideas and crosscutting concepts) would be integrated in the unit and what vocabulary students would be expected to know and use.

Integrating Physical and Life Science Ideas and Crosscutting Concepts

The *MEGA* unit takes an approach to teaching about matter and energy changes that resembles the approach the *THSB* unit takes to teaching about matter changes, which studies have shown to be successful in improving students' three-dimensional learning (Herrmann-Abell, Koppal, and Roseman 2016; Roseman, Herrmann-Abell, and Koppal 2017). In contrast to traditional biology units, the *MEGA* unit targets ideas about matter and energy changes in chemical reactions in both simple physical systems and complex biological systems in the same unit. It introduces difficult ideas first in simple physical systems that allow firsthand observations before having students apply them to complex biological systems that require inferences from data. Unit activities use similar models to represent matter and energy changes within systems and energy transfers between systems in both simple physical and complex biological systems. This integration of physical and life science content enhances the explanatory power of the science ideas and is consistent with recommendations of *NGSS* in general and in particular with its crosscutting concepts related to matter and energy and systems and system models. Content support is provided in both the Teacher Edition and in professional development to help biology teachers become confident teaching all aspects of the unit.

Matter. The matter story in Chapter 1 engages students in considering how protein, carbohydrate, and fat polymers from food become protein, carbohydrate, and fat/lipid polymers making up their body structures. The molecular structures of these polymers appear quite complex, even after students realize that they are made up of similar monomers. So, the chapter devotes two lessons to having students use ideas about systems and various models to represent atom rearrangement and conservation to explain how products form from reactants in simple physical systems. Students are then able to model the processes involved in converting polymers from food to polymers needed to grow and repair body structures and to appreciate the roles of various body systems in these processes.

Energy. Once students can explain how changes in matter during chemical reactions contribute to biological growth and repair, they examine evidence of energy changes in the same reactions and try to explain where the energy comes from or where it goes in each case. As with the matter story, students generate energy ideas in simpler physical systems and apply them to more complex biological systems. By the end of Chapter 2, students are modeling energy transfers from the cellular respiration system to the system of proteins involved in muscle contraction, to the system that makes polymers for growth and repair, and to the surroundings as heat.

Chemical reactions. The examples of chemical reactions students observe were carefully chosen to accomplish several purposes:

- Provide phenomena in simple systems to enable students to review middle school prerequisite science ideas about BOTH matter and energy, such as the energy-releasing reaction between hydrogen and oxygen molecules to form water molecules and the energy-requiring reaction between water molecules to form hydrogen and oxygen molecules.
- Support high school science ideas about BOTH matter and energy, mainly energy-releasing reactions between carbon-based molecules and oxygen to produce carbon dioxide and water, the energy-requiring synthesis of glucose monomers and oxygen from carbon dioxide and water, and various energy-requiring reactions between monomers to produce polymers for building body structures (plus water molecules).
- Introduce students to tests of substances in simple systems that can be used to provide evidence of the production or use of those same substances in more complex systems (e.g., the combustion of candle wax can be carried out in the classroom and used to demonstrate the results of simple tests for carbon dioxide and water that later provide evidence that a similar reaction—oxidation of glucose to produce carbon dioxide and water during cellular respiration—occurs faster when muscles exercise).
- Illustrate that chemical reactions in simple physical systems can provide insights into reactions in complex biological systems.

Table 2 lists the chemical reactions used in the *MEGA* unit and provides an instructional rationale for the use of each.

Table 2. The Role of Chemical Reactions in *MEGA*

Reaction Equation	Rationale for Use of Reaction
Candle wax and oxygen → carbon dioxide and water	Energy-releasing reaction that allows collection and testing of reactants and products
Ammonium thiocyanate and barium hydroxide → water, ammonia, and barium thiocyanate	Energy-requiring reaction with product whose identity can be determined by odor
Magnesium and oxygen → magnesium oxide	Atom rearrangement easily modeled
Water → hydrogen and oxygen	Simple tests for reactants and products, atom rearrangement easily modeled
Glucose and oxygen → carbon dioxide and water	Simple tests for reactants and products, atom rearrangement easily modeled

Carbon dioxide and water → glucose and oxygen	Chemical reaction carried out by plants provides life science example
Protein polymer and water → amino acid monomers	Digestion example
Amino acid monomers → protein polymer and water	Biosynthesis example
Carbohydrate polymer (starch) and water → glucose monomers	Digestion example
Glucose monomers → carbohydrate polymer (glycogen) and water	Biosynthesis example
Fat polymer (triglyceride) and water → monomers → fat or lipid polymer and water	Digestion and biosynthesis example

Systems. The unit develops ideas about systems and the usefulness of "systems thinking" to understanding human body systems at several levels of biological organization and changes in matter and energy within and between systems. Students examine hierarchical levels of structural organization of the human body. They use what they learn about the importance of paying attention to inputs, outputs, and boundaries of systems to understand how interactions between molecules within cells lead to matter and energy changes in organs and body systems that in turn lead to observable changes in matter and energy in the human organism as a whole. The unit stops short of extending systems thinking and ideas about matter and energy changes to ecosystems, but this could be done in a subsequent unit on ecosystems.

Human body systems. The unit focuses on components of five human body systems that are needed to tell the basic story of where and how ingested food is used to build and repair body structures and the contributions of different body systems to maintaining homeostasis, even during intense exercise. For example,

- The small intestine of the **digestive system** is where food polymers are digested to monomers—e.g., carbohydrates to glucose, fats to fatty acids and glycerol, proteins to amino acids—that are absorbed into blood vessels of the **circulatory system.**
- Amino acids are taken up by muscle cells of the **muscular system** and used to build muscle proteins.
- Glucose monomers are taken up by cells of the liver (**digestive system**) and muscle (**muscular system**) and used to build glycogen polymers that store glucose for later use in cellular respiration.
- Fatty acids are taken up by fat cells of the **integumentary system.** Fatty acids are used to build phospholipid components of cell membranes and used to build triglycerides that store fatty acids for later use in cellular respiration.
- The **respiratory system** brings oxygen needed for cellular respiration to blood vessels of the **circulatory system** and removes carbon dioxide produced during cellular respiration in all body cells. During exercise, breathing becomes faster and deeper and the heart beats faster to increase the supply of oxygen to cells and increase the removal of carbon dioxide.
- Increased needs for glucose during exercise result in breakdown of glycogen to glucose in both

liver (**digestive system**) and muscle (**muscular system**), thereby maintaining the level of blood glucose and muscle glucose needed for cellular respiration.

- Muscle cells of the **muscular system** increase the rate of cellular respiration to provide increased energy for muscle contraction during exercise. Some of the energy from cellular respiration increases the temperature of the cells' surroundings.

- To counteract temperature increases, surface capillaries of the circulatory system dilate to increase heat dissipation by the skin of the **integumentary system.** Evaporation of water from the skin surface transfers energy from the body to its surrounding environment.

Regulation/homeostasis. The unit's final project engages students in predicting the effect of intense exercise on concentrations of the reactants and products of cellular respiration and on body temperature, designing experiments to test their predictions, and then consulting reference materials to explain why the data they collect or examine do not match their predictions. Although students are not expected to develop a sophisticated understanding of how our bodies maintain concentrations within a safe range, their explanations should describe the contributions of various body systems and their components.

Vocabulary

We have intentionally limited the number of technical terms to those that students need to communicate about their experiences. As a result, the unit avoids several terms typically used in middle and early high school classrooms (e.g., *element, compound, ion*) while using other terms that are less typical (e.g., *monomer, polymer*). The terms *element*, *compound*, and *ion* are not needed for students to communicate their ideas about atom rearrangement and conservation, although students do need to correctly use the terms *atom* and *molecule* to do so. The terms *monomer* and *polymer* are used instead of alternatives like *small molecule* and *large molecule* because they convey more precisely the common components of different carbohydrates and proteins and how they can be assembled from or disassembled to a small number of building blocks. We also leave out some details that are more likely to confuse than to help students develop and communicate their ideas. For example, solutions are referred to as *liquids* and ionic compounds are referred to as *molecules*.

The unit expects students to understand and correctly use the following terms in **bold:**

Atoms and **molecules.** While students may have already been taught definitions of these terms, many do not consistently distinguish them in their talking or writing or in their use of models. It is essential for students to know that atoms make up molecules, not the other way around. The unit expects students to know that an individual atom is represented by a ball or chemical symbol, that different colored balls or symbols represent different types of atoms, and that two or more balls or chemical symbols linked together represent molecules.

Monomers and **polymers.** Rather than relying on vague descriptions like "small and large molecules," which provide no information about how the small and large molecules are related, we opted to introduce the terms *monomer* and *polymer*. Using these terms in the context of chemical reactions involved in nylon formation, protein formation, glycogen formation, and lipid formation highlights their similarities (e.g., all involve formation of polymers and water molecules from monomers) and eliminates the need for students to know the names of most of the specific monomers involved (e.g., specific fatty acids, specific amino acids). However, students are expected to know that **glucose** is the monomer used to build **carbohydrate polymers** such as starch and glycogen and **amino acids** are the monomers used to build **protein polymers.** The term glucose is singled out so that students can distinguish its formation (during **photosynthesis**) from its use to make polymers needed to build plant body structures for growth. Because the term *carbohydrates* refers to both polymers and monomers, accuracy requires that we use the term *carbohydrate polymers*. Students are expected to know that proteins (such as actin and myosin, which are involved in muscle contraction, and amylase, which is involved in carbohydrate digestion), fats, and lipids (such as phospholipids, which are used to build cell membranes) are **polymers.**

Chemical reactions. Students are expected to know that chemical reactions produce **products** from **reactants** and that products have different **characteristic properties** than the reactants because they are made up of different molecules, but that the molecules making up the products are made from the atoms of the reactants. (Irreversibility is not a criterion for distinguishing chemical reactions from other changes—this is a common misconception.) Students are expected to know that **photosynthesis; aerobic** and **anaerobic cellular respiration;** and **digestion** and **synthesis** of carbohydrate, fat, and protein polymers involve chemical reactions.

Mass conservation and **measured mass.** Students are expected to know that while the **total mass** of the reactants and products does not change during a chemical reaction (total mass is **conserved**), the **measured mass** may change if one or more substances enter or leave the **system.** The term measured mass is introduced to help students understand why conservation principles aren't violated during biological growth; that is, the added mass must have come from somewhere outside the system being measured (the plant or animal's body). As a bridge to calculating the mass of the glucose + oxygen chemical reaction system before and after the reaction, students count and weigh LEGO models of the hydrogen + oxygen chemical reaction system before and after the reaction. This helps students visualize that both mass and atoms (though not necessarily molecules) are conserved during chemical reactions.

Chemical bonds. The *MEGA* unit expects students to learn that **chemical bonds** connect atoms making up molecules but not types of bonds or parts of atoms that are involved in bonding. Although most of the chemical reactions introduced involve breaking and forming covalent bonds, students are not expected to know this term or to know that each bond involves an electron pair. For the matter story, students learn that bonds between reactant molecules must break and new bonds must form in order to produce product molecules. For the energy story, students are expected to learn that **bond-breaking always requires energy** and **bond-forming always releases energy,** contrary to the incorrect idea in some textbooks that bond-breaking releases energy.

Energy changes and **conservation.** The unit is consistent with the *NGSS* approach to energy in focusing on **energy changes** within **systems** and **energy transfer** between systems rather than focusing on naming forms of energy and energy transformation. Even though the *NGSS* core ideas occasionally talk about chemical and mechanical energy, the *MEGA* unit does not expect students to identify any forms of energy. Students are expected to recognize four indicators of energy changes: changes in temperature, changes in motion, appearance or absorption of light, and production and absorption of sound. Students are expected to know that a decrease in energy somewhere is always accompanied by an increase in energy elsewhere, but they are not expected to show quantitatively that those two amounts must be the same.

Rates of chemical reactions. The *MEGA* unit does not focus on rates of chemical reactions or factors affecting rates. Understanding why, for example, all reactant molecules don't react at once or why the reaction doesn't stop once the "higher-energy" molecules have reacted requires a mental model of the Boltzmann distribution curve, how it shifts with temperature, and why remaining molecules redistribute. These ideas go far beyond *NGSS* expectations.

Enzymes. The unit does not attempt to explain how enzymes or other types of catalysts speed up chemical reactions, but it does include enzymes as examples of protein polymers that carry out functions of cells.

Systems and **models.** *Benchmarks for Science Literacy* (AAAS 1993) characterizes the role of systems and models and other common themes as tools for thinking across disciplines and clarifies what the focus of instruction should be.

> *The main goal of having students learn about systems is not for them to be able to talk about systems in abstract terms but to enhance their ability and inclination to attend to various components of particular systems in attempting to understand how the system as a whole works.* (p. 262)

In *MEGA* Chapter 1, students begin to think about systems by examining components of various human body systems (organs, cells, substances, polymers, monomers, atoms). Next, they examine simple chemical reaction systems as contexts for learning to use ideas about system inputs and outputs to keep track of substances and their atomic/molecular components. Finally, they use their knowledge of body systems and chemical reactions to model how polymers from food are digested to monomers, how monomers get to where they are used, and how the monomers are converted to polymers that become part of body structures. In Chapter 2, students apply ideas about system inputs and outputs to model energy changes within systems and energy transfer between systems. The culminating lesson engages students in considering the role of human body systems in helping to maintain levels of glucose, oxygen, carbon dioxide, and water in muscle cells so that cellular respiration can increase in response to exercise needs and in helping to ensure that energy released as heat is transferred from muscle cells to the body's external environment.

Science practices. The unit expects students to understand and correctly use the following terms in **bold** related to making sense of phenomena:

Models. Students should know that a model is a simplified version of some thing or process that we hope can help us understand it better. Whether models are physical, mathematical, or conceptual, their value lies in suggesting how things either do work or might work. When a model does not mimic the phenomenon well, the nature of the discrepancy is a clue to how the model can be improved.

Evidence. Students are expected to know that **data** from observations and measurements can be used as evidence for a claim if the data are relevant to the claim and can be confirmed by others. Students are also expected to know that a **model** can be useful for suggesting how the thing being modeled works, but there is no guarantee that ideas suggested by models are correct if they are based on the models alone. Consequently, while ideas from models should be consistent with claims, they do not provide evidence to support claims.

Explanation. As noted in the *NGSS*, "the goal of science is to construct explanations for the causes of phenomena" (NGSS Lead States 2013, p. 60, Appendix F). By the end of the unit, students should be able to explain changes in matter and mass during biological growth in terms of the rearrangement and conservation of atoms and to explain how living things obtain energy needed for growth and motion in terms of energy transfer from energy-releasing chemical reactions to energy-requiring chemical reactions or processes.

Structure of the Unit

The unit consists of an introductory lesson and 14 additional lessons organized into two chapters. Chapter 1, which consists of five lessons, is designed to help students develop an understanding of the role of atom rearrangement and conservation in chemical reactions that contribute to biological growth, starting with chemical reactions in simple physical systems that involve small molecules and then applying what they learn to chemical reactions in living systems that involve converting polymers from food into polymers used to build body structures. Chapter 2, which consists of nine lessons, is designed to help students develop an understanding of energy changes during chemical reactions, energy transfer, and conservation, first in simple physical systems and then in complex biological systems involved in the motion and growth in living organisms. The last lesson ties together the matter and energy stories by having students consider how the body maintains a fairly constant internal environment during exercise despite chemical reactions that involve changes in matter and energy.

Both Chapters 1 and 2 begin by engaging students with familiar phenomena that will drive learning over the chapter—starting with observable phenomena, such as bodybuilding and wound healing in Chapter 1 and athletes performing amazing feats in Chapter 2, followed by examining data that provide evidence of phenomena that can't be observed directly. Students then construct and use models to make sense of the phenomena (e.g., how various body systems contribute to converting food to biopolymers or how energy released during cellular respiration transfers energy to move muscles), and they revise their models to take account of new data. After generating important science ideas based on their observations and data, students then try to apply them in new contexts.

Each lesson of the *MEGA* unit consists of carefully sequenced activities designed to (1) draw upon students' prior knowledge and experiences relevant to classroom activities, (2) support students as they investigate and make sense of phenomena and data, (3) guide students in modeling and explaining phenomena in terms of underlying molecular mechanisms, (4) provide opportunities for students to apply or extend science ideas and practices to new phenomena, and (5) help students synthesize their ideas and reflect on changes in their thinking.

Section Headings and Purposes

Each lesson is designed with particular features that are denoted by their section headings.

What do we know and what are we trying to find out?

This introductory section situates the lesson in the content storyline by making links between science ideas of previous lesson(s) and the key question of the current lesson. This section does not "give away the answers" but provides students with some sense of what they will be working toward understanding in the lesson.

Key Question

Each lesson begins with and returns to a key question that the lesson is designed to answer. The key question aligns with the lesson's main learning goal and frames the students' inquiry. The key question is posed at the beginning of the lesson to give each student a chance to express his or her initial ideas and to give teachers a sense of the range of ideas students hold. At the end of the lesson, the question is posed again and student responses provide a way to monitor their progress.

Activity

Each lesson includes activities designed to engage students with phenomena and representations relevant to the learning goals. Some phenomena, particularly those in nonliving systems, can be observed directly and others, particularly those occurring in the bodies of living organisms, require inferences from data. Activities also engage students in modeling invisible aspects of the phenomena, particularly atom rearrangement and conservation and energy changes and transfer. Each activity includes questions to focus and guide students in observing and interpreting the phenomena. Activities are structured to encourage discussion by having students work either with a partner or a small group.

Participating in a whole-class discussion at the end of the activity can help students reach consensus on their observations of phenomena, data, and models and on the science ideas that emerge from their interpretations of them.

Science Ideas

At critical points in the unit, particularly after students have developed ideas based on phenomena, data, or models, students are asked to generalize across their experiences. Only then are relevant science ideas introduced to students as generalizations about how the world works based on a wider range of observations and data. Students have opportunities to compare the ideas they are developing with established science ideas and find examples from their work that support the science ideas.

Science ideas are used in writing explanations, so they will often precede an activity in which explanations are evaluated or developed. Or, they may precede a Pulling It Together section in which students are expected to construct an explanation of related phenomena.

Pulling It Together

These questions provide opportunities for students to individually (1) revisit and answer the lesson key question or related questions to summarize their current understanding or new learning, (2) use and apply the ideas they are developing to a new context or phenomenon, or (3) begin to link the ideas to the next lesson(s). The linking question elicits students' ideas and predictions about the key question of the next lesson or about how an idea developed in nonliving contexts might apply to growth or activity in living things.

Closure and Link

This feature, included only in the Teacher Edition, is intended to summarize what students have learned in the lesson or chapter and what unanswered questions they will tackle in the next lesson or chapter. Teacher notes outline the main points that should surface in a teacher-led discussion and questions that should grow out of what students have just learned.

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The following page has a blank explanation chart that students can use as a writing scaffold. For an example of how to develop the practice of explanation writing, see Chapter 1 of the Teacher Edition of the THSB *unit.*

Question	
Claim	
Science Ideas	
Evidence	
Models	

Explanation:

Getting Started

Matter and Energy Changes in Our Bodies

Teacher Edition

Lesson Guide
Getting Started: Matter and Energy Changes in Our Bodies

Focus: This introduction frames the unit and sets out the key question that the unit will help students answer.

Unit Key Question: How do living things use food as a source of matter for building and repairing their body structures and as a source of energy for carrying out a wide range of body functions?

Target Idea(s) Addressed

None

Science Practice(s) Addressed

None

Materials

None

Advance Preparation

None

Getting Started: Matter and Energy Changes in Our Bodies

What do we know and what are we trying to find out?

Our bodies are capable of some amazing feats, from setting an Olympic record to just staying alive while we sleep! Think about it: Every second of every day, our bodies are carrying out all kinds of activities that enable us to grow, work, play, think, create, communicate, and rest and repair ourselves. But what makes all of these activities possible? Where does the "stuff" come from to build an athlete's body or to repair a broken leg or heal a wound? Where does an athlete get the energy needed to run a marathon? How do our own bodies get the energy they need to keep us alive and functioning properly and to build and repair body structures while we sleep?

Ever since you were a child, you've probably been told that eating the right food will help you grow and give you lots of energy. In fact, it is estimated that American adults eat about 2,000 pounds of food each year! Some athletes eat much more than that when they are preparing for or participating in competitions. It's clear that something happened to all that food once it was consumed (we don't look like the food we eat, for example), but what? How does food provide building material and serve as fuel that keeps our bodies functioning?

To answer these questions, we need to know more about matter that makes up our body structures and the changes in matter and energy that take place inside us. In doing so, we will see that the same scientific ideas that explain matter and energy changes in simpler nonliving systems, such as a car or a battery, can also be used to explain matter and energy changes in more complex living systems, such as our bodies.

Teacher Talk and Actions

In this unit, we will observe examples of growth and motion and apply important science ideas about matter and energy to explain our observations:

- In Chapter 1 we will examine changes in matter that take place in our bodies as we consume food and grow—from the observable macroscopic level down to the invisible molecular level—and construct models to help us think about and explain where and how these changes occur.
- In Chapter 2 we will examine and model how energy changes in both simple physical systems and complex biological systems can make something happen. We will look at some examples, such as how a chemical reaction in a battery makes a toy car move, and then use what we learn to model and explain related phenomena in living organisms, such as how chemical reactions in our muscles make our bodies move and grow.
- The unit's final lesson brings together what we've learned to investigate how the body maintains a nearly constant internal environment during exercise despite changes in matter and energy.

By the end of the unit, you should be able to answer the Unit Key Question below. For now, brainstorm some ideas for answering the question with your class. We will return to this question at the end of the unit.

Unit Key Question: How do living things use food as a source of matter for building and repairing their body structures and as a source of energy for carrying out a wide range of body functions?

Teacher Talk and Actions

Chapter 1

Making Sense of Matter Changes Involved in Human Growth

Teacher Edition

Chapter 1 Overview

Chapter 1 tells the basic story of how our bodies convert molecules from food into molecules that make up our body structures, including the role of various body systems in carrying out the chemical reactions involved and moving reactants and products from place to place. Although students may be familiar with names of organs of various body systems, they are probably unaware of the molecules that make up the organs, giving them their structure and carrying out their functions. All these molecules need to be produced if humans are to grow and repair. The story is both abstract and complex, requiring (a) an understanding of the body from the observable macroscopic level to the invisible molecular level, (b) the ability to use a model of atom rearrangement during chemical reactions to explain how body molecules can be made from food molecules that often have very different properties, and (c) the ability and inclination to consider the inputs and outputs of a system when trying to figure out what the reactants and products are, where they come from and where they go, and which atoms rearrange during the chemical reaction.

Students make sense of a variety of phenomena related to growth and repair. For the idea "To grow and repair, living organisms need to build body structures that are different from polymers in their food," students observe, model, and explain how

- protein polymers making up human muscles, skin, and blood differ from proteins making up eggs, milk, soybeans, and wheat;
- glycogen polymers in liver and muscle differ from starch; and
- fat polymers that make up body fat and cell membranes differ from fat polymers in butter.

For the idea "During chemical reactions in both simple physical and complex living systems, atoms of reactants rearrange to form products; mass is conserved because atoms are conserved," students observe, model, and explain how new substances can be produced and mass can change when

- both a candle and a marshmallow react with oxygen to form carbon dioxide and water;
- ammonium thiocyanate reacts with barium hydroxide to form ammonia, water, and barium thiocyanate;
- water molecules react to form hydrogen molecules and oxygen molecules; and
- an aquatic plant produces glucose and oxygen from carbon dioxide and water.

For the idea "In the digestive system protein, carbohydrate, and fat polymers react with water to form monomers that are transported by the circulatory system to components of other body systems where the monomers react to form body polymers (and water)," students observe, model, and explain the following:

- As the amount of ingested protein decreases in the human gut, amino acid levels increase first in the gut and then in surrounding blood vessels.

• Shortly after humans were injected with the amino acid ^{14}C-phenylalanine, the ^{14}C atoms were found to be part of myosin protein.

• Two hours after eating ^{14}C-starch, the level of ^{14}C-glucose in human blood increases.

• The concentration of glycogen in rat liver increases from 10 minutes to 30 minutes after glucose infusion.

• An hour after rats are injected with ^{14}C-glucose, ^{14}C-glycogen is found in liver and muscle.

Lesson Overviews

Lesson 1.1 frames the matter story, the focus of Chapter 1, by engaging students in considering matter changes involving growth (videos of bodybuilding, a growing child, wound healing, cells reproducing in culture) and motion (athletes competing in an event). This provides an opportunity for students to express their ideas and for teachers to find out their students' initial ideas.

Lesson 1.2 starts with what students know about body systems—mainly external macroscopic components that can be observed directly (e.g., skin and hair), proceeds to internal organs that are observable in photographs (e.g., muscles, intestines, heart, lungs), zooms in to microscopic cells that make up some of the organs, then to the submicroscopic macromolecules (polymers) that make up cells and the types of monomers that compose them, and finally to the mainly 4–5 types of atoms that make up the monomers. The goal of the lesson is to provide evidence that polymers from food (e.g., ovalbumin from egg white, casein from milk) are different from polymers making up human body structures (e.g., hemoglobin for red blood cells, keratin for hair, collagen for skin, actin and myosin for muscles), which motivates the question of how our bodies accomplish the necessary conversions. The lesson concludes by noting that the next two lessons will give students a chance to observe and model chemical reactions in simple systems to prepare them to explain how our complex body systems convert polymers from food into body structures in Lesson 1.5.

Lesson 1.3 reviews the prerequisite middle school idea that new substances are produced during chemical reactions because atoms of molecules of reactants rearrange to form products, using examples involving molecules reacting in simple systems where the production of a new substance can be readily detected to provide evidence that a chemical reaction has occurred (e.g., barium hydroxide + sodium thiocyanate produces ammonia that can be detected by its odor, a burning candle produces carbon dioxide and water that can be detected with limewater and cobalt chloride tests, respectively) and the conversion of reactants to products can be easily modeled with LEGOs, ball-and-stick models, and chemical formulas. This serves as a review for students who have used the *THSB* unit in middle school. Students who have not used *THSB* or a comparable unit may need additional experiences with observing and modeling chemical reactions before they are ready to apply this knowledge to more complex changes in matter in living organisms. Even though the lesson uses examples from physical systems, a Pulling It Together question foreshadows the reaction that living cells use to obtain energy by asking students to consider similarities between reactants and products of a candle burning and what happens in our bodies.

It is not a goal of this lesson for students to learn to use chemical formulas to balance equations. For many students, the distinction between subscripts and coefficients is abstract and unnecessary and may distract them from learning the basic idea that atoms can rearrange but are conserved during chemical reactions. Until students can easily relate the chemical formulas to physical models, it's best to stick to physical models. Students should be encouraged to use their LEGO models to visualize atoms disconnecting from each other and connecting to different atoms and to notice that, as with their models, atoms aren't created or destroyed in the process.

Lesson 1.4 builds on the middle school idea that atom conservation explains mass conservation and extends it to having students consider the usefulness of keeping track of a system's inputs and outputs for explaining why a change in the mass of a system does not violate conservation principles. As in the previous lesson, simple physical systems are used that clearly show gases leaving a system (when water decomposes, hydrogen and oxygen gases produced leave the system) and students use LEGO models to show why the decrease in the mass of the system can be accounted for by the increase in mass of the surroundings. Ideas about system inputs and outputs are then used to help students explain why conservation principles are not violated when a marshmallow burns in air or when an aquatic plant produces bubbles of oxygen (and glucose) from water and dissolved carbon dioxide. The lesson also provides a framework for constructing valid explanations that will be a review for students who experienced *THSB* but not necessarily for students who used other middle school science curriculum materials. Students who have not previously learned to construct explanations will likely need instruction and additional opportunities to practice constructing explanations of related phenomena and to receive feedback.

Lesson 1.5 brings students back to the central question of the chapter, asking them to apply what they have learned about atom rearrangement and conservation in simple systems to consider how our body systems work together to convert polymers from food into polymers making up our body structures. Students draft initial models of the processes involved and the location of each process in the body and then use experimental data from published papers to revise their models. Because the link between reactants and products of chemical reactions occurring in the body cannot be observed directly, students learn to identify reactants and products by drawing inferences from data, some of which use isotopically labeled reactants, so the fate of labeled atoms can be traced. (Students who have used *THSB* have already learned about the value of the isotopic labeling technique in linking reactants to products and have used yellow labels on physical models to show how carbon atoms from CO_2 could become part of glucose and then cellulose.) The lesson concludes the basic story of how matter changes during chemical reactions contribute to the growth of living organisms.

Lesson Guide
Chapter 1, Lesson 1.1
Matter Changes in the Human Body

Focus: This lesson frames the chapter by engaging students in considering matter changes in videos involving growth and repair. Students will have several opportunities to revise and expand their ideas throughout the chapter.

Key Question: How can we detect changes in the matter that makes up the human body?

Target Idea(s) Addressed
None

Science Practice(s) Addressed
Obtaining, evaluating, and communicating information

Materials
Video 1: *Bodybuilder,* Video 2: *Child Growing,* Video 3: *Wound Healing,* Video 4: *Cells Reproducing in Culture*

Advance Preparation
Observe videos and decide how you plan to show them (e.g., all or only parts).

Phenomena, Data, or Models	Intended Observations	Purpose	Rationale or Notes
Activity 1 Time-lapse photos of bodybuilder, child growing, wound healing, and cells dividing in culture	• The body of the bodybuilder is getting visibly larger and more massive. Muscles are probably increasing in size. • The infant is increasing in size and mass. External body structures are increasing in size/mass (e.g., more skin, hair, teeth). Internal body structures are probably increasing in size as well (e.g., muscles, bones, heart, stomach). • New material is appearing at the site of a wound as it heals. • Cells in culture are reproducing. Prior to dividing, each cell increases in mass. (Students should observe that the cells aren't merely dividing, they are also growing prior to dividing so that the total mass of all the cells is increasing.)	Give students the opportunity to observe phenomena involving changes in matter (all involving increases in matter). Begin to develop students' abilities to carefully observe phenomena from the perspective of matter changes and to distinguish evidence from their own observations from inferences.	

Lesson 1.1—Matter Changes in the Human Body

What do we know and what are we trying to find out?

As you probably learned in middle school, all matter—including the matter making up your own body—is made up of atoms that are usually connected into molecules. Substances differ from one another because they are made up of different molecules. For example, a rusty bicycle does not look like a new bicycle because rust is made up of different molecules than the original shiny bicycle. Tarnished silver jewelry looks black because the black tarnish is made up of different molecules than the original silver.

Such changes are easy to observe because they involve color changes and occur in plain view. What about changes in living things? Consider changes that have taken place on the outside of your body as you've grown from a small baby to the young person that you are today. In addition to your being bigger and having teeth, the shape of your nose has probably changed and your hair color may be different. You can see and measure these changes easily. But what about changes that may be going on inside your body or in parts of your body that are too small to be visible? In this lesson, you will watch videos showing an athlete preparing for competition, a child growing, a wound healing, and cells reproducing in culture. As you watch, look for clues that can help you determine whether a change in matter is taking place.

Answer the Key Question to the best of your knowledge. Be prepared to share your ideas with the class.

Key Question: How can we detect changes in the matter that makes up the human body?

Teacher Talk and Actions

Activity 1: Observing the Human Body

In this activity, you will observe changes that occur in human bodies as they carry out various activities.

Procedures and Questions

1. Observe the videos. In Table 1.1 below, record your observations in the second column (Observations). Watch the videos again if you need to. Each time you view the video add any additional observations you make to the table.

Table 1.1. Observable Changes in the Human Body

Video	Observations	More, Less, or the Same Number of Atoms?
Video 1 – Bodybuilder	The bodybuilder's body is getting bigger. He appears to have more muscles, but we can't actually see the muscles under his skin.	More
Video 2 – Child Growing	The child is getting taller and has more hair and teeth. We might infer that his muscles and other internal body parts are increasing in size/mass.	More
Video 3 – Wound Healing	The wound heals. New skin/scar tissue formed to repair the cut.	More
Video 4 – Cells Reproducing in Culture	Cells reproduce (grow and then divide) to form more cells.	More

Teacher Talk and Actions

The purpose of Video 4 is to encourage students to think about the relationship between body growth and cell growth. The following questions may be helpful in guiding the discussion:

- Are the cells growing? How do you know? (Students may reason that cells must grow before they divide. If not, then the cells would get smaller and smaller as more and more divisions occur.)
- Where does the matter for the cell growth come from?
- Do you think cell growth and division are contributing to the growth of the bodybuilder? Explain.
- Do you think cell growth and division are contributing to the repair of the wound? Explain.

2. We know that all matter is made up of atoms and molecules, including our bodies and the cells that make them up. Predict whether the number of atoms increases, decreases, or stays the same in each video. Enter your prediction in the third column of the table and answer the questions below.

a. In which videos did you predict the number of atoms in the body would increase? Where do you think the atoms came from?

I think the additional atoms in the bodybuilder and child growing videos came from the food the person ate. (Scar tissue could also have come from food the person ate.)

I'm not sure where the atoms came from for cells reproducing. Perhaps there were atoms in the surrounding medium that provided food for the cells.

b. In which videos did you predict the number of atoms in the body would decrease? Where do you think the atoms went?

Mass doesn't seem to be decreasing in any of the videos, so I didn't predict that the number of atoms would be decreasing in any of the videos.

c. In which videos did you predict the number of atoms would not change? Why do you think so?

Maybe the number of atoms in the body didn't change as scar tissue formed if the atoms used to form the scar tissue came from another part of the body. The video doesn't provide evidence for this.

d. How could you test your predictions?

We could measure the mass of each person or the cells before and after. Because atoms have mass, increases or decreases in atoms would be reflected in the mass.

Teacher Talk and Actions

Question for advanced students:

If you wanted to make a video in which the number of atoms in the body would decrease, what could you video and why?

I could video an athlete running a race because the athlete exhales CO_2 and breathes in O_2, and each CO_2 has a C atom that makes it heavier than O_2.

This question provides an opportunity for students to think about weight loss and for you to learn whether they think that gases have mass. Students are not expected to know the answer, which they will learn about in Chapter 2.

Pulling It Together

Discuss these questions as a class. Write any notes you have in the space below.

1. Based on Activity 1, what are some of the changes in matter that take place in our bodies that keep us alive and functioning properly?

Wound healing, building muscles, and repairing/replacing diseased cells/tissues

2. What do we still need to know to help us answer Question 1?

We don't know how our bodies make new skin or muscle.

Teacher Talk and Actions

Closure and link to subsequent lessons:

In this lesson, we observed examples of people growing and repairing their bodies and cells dividing. We talked about some changes in matter that we observed, but some of the videos didn't provide evidence that the amount of mass was changing. Because the human body is so complex, it can be challenging to determine how matter changes and where the matter we use to build and repair our bodies comes from. We will start by looking at the matter that makes up our bodies, how it is organized, and how it compares to the food we eat. Doing so will give us ideas about changes that must occur for our bodies to convert molecules making up our food to molecules making up our body structures.

Matter and Energy for Growth and Activity

Teacher Edition

"Engaging and yet rigorous ... the unit also offers plenty of support to help teachers integrate fundamental physical science concepts about matter and energy into a biological context. Much needed and well done!"

—Marlene Hilkowitz, former biology teacher in the Philadelphia School District, now a Drexel DragonsTeach Master Teacher at Drexel University

How do our bodies manage to heal wounds, build the stamina to run marathons, and give us the energy—even while we're sleeping—to keep us alive and functioning? *Matter and Energy for Growth and Activity* prompts high school students to explore fascinating questions like these. It takes a new approach to teaching essential ideas about food, human body systems, matter and energy changes, and chemical reactions.

Developed by a team of scientists and science educators and then tested in classrooms, the 14 phenomena-based lessons in this book follow a coherent sequence. They unfold in two main sections: (1) making sense of the matter changes involved in human growth and (2) making sense of the energy changes involved in human growth and activity.

Matter and Energy is unique because it does the following:

- **Targets important ideas about changes in both physical and biological systems within the same unit.** The book first engages students in seeing the usefulness of the ideas in making sense of phenomena in simple physical systems. Then it shows how to apply these ideas to make sense of related phenomena in complex biological systems. This interdisciplinary approach reflects the way science is practiced in the real world.
- **Supports all three dimensions of the *Next Generation Science Standards*.** Disciplinary core ideas, crosscutting concepts, and science practices are all integrated in this unit.
- **Emphasizes important relationships between mathematics and science.** Students interpret data sets and graphs to provide evidence for claims. They also do simple computations to explain puzzling phenomena—for example, why does energy have to be added to ignite a marshmallow even though the burning marshmallow releases lots of energy?
- **Builds on the middle school unit *Toward High School Biology* (also published by NSTA Press).** Together the two units help students deepen their understanding of matter and energy changes in plants and animals and the role of chemical reactions in the growth, repair, and activity of living organisms.

Matter and Energy for Growth and Activity, Teacher Edition provides in-depth guidance and answer keys for teachers using these experiential lessons. A set of online resources includes interactive media, videos, and handouts. The Student Edition has all the student handouts with teaching tips and sample answers removed. Between both books, you have the support you need to help your students turn abstract ideas into applicable knowledge—a critical first step in learning.

GRADES 9–12

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