INTRODUCING A NEW MIDDLE SCHOOL CURRICULUM

Toward High School Biology

Understanding Growth in Living Things

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About the *Toward High School Biology* Unit

This unit was developed to respond to a critical problem in science education that often leaves students unprepared for the challenges of high school biology. According to decades of research, a great many students—even some of the most talented—struggle to understand basic concepts about atom rearrangement and conservation during chemical reactions and have trouble applying these chemistry concepts to phenomena that occur in living systems. What is more, the curriculum materials that most students use do little to help them build a foundation of chemistry knowledge on which to build their understanding of biology.

The *Toward High School Biology* (THSB) unit is designed to address this problem. With support from the U.S. Department of Education’s Institute of Education Sciences, scientists and educators at AAAS’s Project 2061 and at BSCS developed THSB as a replacement or supplement unit. It is designed to help middle school students connect core ideas about chemical reactions to the biological phenomena of growth and repair in plants and animals.

Over the course of three years, nearly 2000 students and their teachers were involved in pilot and field tests of the unit. In a small-scale randomized control trial comparing matched pairs of classrooms, students using the THSB unit showed significant learning gains compared to those using their district curriculum. Findings also showed that students using the THSB unit held fewer misconceptions than their peers who did not use it, and their learning increased as their teachers became more experienced with the unit.

**How the THSB unit is different.** Guided by a set of research-based design principles, the THSB unit breaks new ground in several ways. By bringing together concepts from chemistry and biology, the unit takes a more integrated approach to science learning, giving students a better sense of how science happens in the real world where interdisciplinary research is the norm and traditional subject area boundaries no longer apply.

The new unit focuses on phenomena related to chemical reactions that take place in both physical and life science contexts, from the rusting of a metal bicycle to the production of muscles in humans. The goal is to help students understand what is happening at a molecular level, with an emphasis on overcoming the well-documented and persistent difficulties many students have in learning these ideas. Most existing curriculum materials tend to focus on seemingly unconnected topics (e.g., digestion, photosynthesis, cellular respiration) without giving students tools to understand how they are connected (all involve chemical reactions in which atoms are rearranged and conserved).

The THSB unit is also one of the first curriculum materials to be developed with the goals of the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) in mind. Alignment with NGSS requires that curriculum materials do much more than simply “cover” a set of specified ideas and skills, and few materials are available that fully support NGSS.

The THSB unit aligns closely to NGSS. It helps students understand and use core ideas about chemical reactions in nonliving and living systems; the crosscutting concept of matter conservation across physical and life science; and the science practices of data analysis, modeling, explanation, and communication to make sense of phenomena.

After observing correlations between increasing amounts of products and decreasing amounts of reactants during chemical reactions, students use a variety of models—from LEGO® bricks and ball-and-stick models to computer-generated simulations and chemical equations to illustrate those same reactions. Their models show that while atoms and molecules rearrange during chemical reactions...
to create new substances, the atoms themselves are not created or destroyed. By modeling different chemical reactions—beginning with simple reactions including iron rusting and the synthesis of nylon and then moving on to more sophisticated reactions involved in the growth of organisms—students are able to see for themselves that the same underlying principles of atom rearrangement and conservation apply. Using their data and reasoning from science ideas and modeling experiences, students are then able to construct their own evidence-based explanations of real-world phenomena.

Components of the unit. The THSB unit is available from NSTA Press, the publishing division of the National Science Teachers Association, and includes a Student Edition workbook and a Teacher Edition with 19 complete lesson plans and instructions for carrying out all of the activities. Additional print and digital instructional resources (e.g., substance data cards, chemical reaction mats, and photos and videos of phenomena) are available online. Molecular modeling kits and lab materials (e.g., vials, pipettes, scales, chemicals, etc.) are available separately.
Goals for the Unit

The overarching goal of the THSB unit is for students to apply ideas about what happens to atoms and molecules during chemical reactions to explain observable phenomena in nonliving systems and in the bodies of living organisms. Specifically, in order to grow and repair body structures, plants and animals build polymers through chemical reactions that link monomers and also produce water molecules. Animals get many of the monomers from breaking down other polymers in the foods they eat, whereas plants make monomers through other chemical reactions.

During all these chemical reactions, atoms are rearranged and conserved; therefore, total mass is conserved. By the end of the unit, students will be able to answer the following unit questions in terms of the rearrangement and conservation of atoms:

*How do living things grow bigger?*

*Where does all the extra stuff come from as living things grow bigger?*

Alignment with Science Education Framework and Standards

The THSB unit is designed to address core disciplinary ideas, science practices, and crosscutting concepts recommended as goals for learning in the National Research Council’s *A Framework for K-12 Science Education* (2012) and in NGSS. The core disciplinary ideas targeted in the unit are listed below and were drawn from the *Framework*, which provides a detailed description of them at each grade level. Science practices and crosscutting concepts, and performance expectations are drawn from NGSS (page numbers cited are from the print version of NGSS published by the National Academies Press).

These standards are addressed throughout the THSB unit, and all three dimensions of science learning—core disciplinary ideas, science practices, and crosscutting concepts—are carefully integrated in each chapter. Students 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 and summarized for students in the unit. Students use a variety of models to help them link the evidence to core ideas about atom rearrangement and conservation during chemical reactions in nonliving and living systems.

Disciplinary Core Ideas from the Framework

**Physical Science, Structure and Properties of Matter (PS1.A, p. 108, Grade 8):**
All substances are made from some 100 different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Pure substances are made from a single type of atom or molecule; each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

**Physical Science, Chemical Reactions (PS1.B, p. 111, Grade 8):**
Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change.

**Life Science, Organization for Matter and Energy Flow in Organisms (LS1.C, p. 148, Grade 8):**
Plants, algae, and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and
water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. Animals obtain food from eating plants or eating other animals. Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.

Science Practices from NGSS, Volume 2, Appendix F

Practice 4, Analyzing and Interpreting Data (p. 57)
Analyze and interpret data to provide evidence for phenomena. (Grades 6-8)

Practice 2, Developing and Using Models (p. 53)
Develop and/or use multiple models to predict and/or describe phenomena. (Grades 6-8)

Practice 6, Constructing Explanations and Designing Solutions (p. 61)
Apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events. (Grades 6-8)

Practice 8, Obtaining, Evaluating, and Communicating Information (pg. 65)
Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s). (Grades 6-8)

Crosscutting Concepts from NGSS, Volume 2, Appendix G

Energy and Matter: Flows, Cycles, and Conservation (p. 86)
Matter is conserved because atoms are conserved in physical and chemical processes...(Grades 6-8)

Performance Expectations from NGSS, Volume 1

The THSB unit contributes to the following middle and high school Performance Expectations:

- Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. (MS-PS1-2)
- Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. (MS-PS1-5)
- Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism. (MS-LS1-7)
- Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms. (MS-LS1-6)
- 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)

References


Use of Phenomena, Data, and Representations

The phenomena and data presented in the THSB unit include numerous examples from both living and nonliving contexts. The unit gives students opportunities to both experience phenomena directly and to examine data collected by scientists that can serve as evidence for the science ideas and/or for their explanatory power. The unit also uses a variety of representations of atoms, molecules, and chemical reactions—physical models such as LEGO® bricks and ball-and-stick model kits; images of physical models and space-filling models; and equations using chemical names, symbols, and formulas.

By the end of the unit, students should be able to translate fluently among these representations and use them to communicate what happens during chemical reactions. The unit includes tasks and questions that help students (1) explain observable phenomena and data using accepted science ideas and models of underlying molecular events and (2) apply science ideas developed in nonliving contexts to living contexts, thus making visible a coherent science content storyline for the molecular basis of growth and repair in living organisms.

Some examples of phenomena, data, and modeling activities from the unit:
Structure of the Unit

Each chapter of the THSB unit is organized around one or more of the targeted NGSS core disciplinary ideas and crosscutting concepts. Students develop their understanding as they engage in the science practices of analyzing and interpreting data, building and using models, constructing explanations, and reading scientific texts to obtain information and evidence.

Every lesson in the sequence supports students in achieving the chapter learning goal, starting with an examination of the ideas and thinking students have as they begin a lesson. Students have multiple experiences with the ideas that atom rearrangement accounts for the production of new substances and atom conservation accounts for mass conservation. Chapters 1 and 2 help students develop an understanding of chemical reactions by focusing on simple, nonliving systems. In Chapter 3 and 4, the central concepts developed in the first two chapters are applied to the more complex context of growth and repair in living organisms. Many students require multiple examples to develop deep understanding of general principles; students are not expected to grasp a new idea the first time they encounter it.

Chapter 1 (Lessons 1.1–1.6) develops science ideas related to the properties of substances and the production of new substances during chemical reactions and the molecular explanation for their production. Students first encounter the concepts in reactions involving only small molecules and apply them to reactions involving the formation of large macromolecules (polymers) and water molecules from small carbon-based molecules (monomers). Polymer formation is an important type of chemical reaction for understanding growth in living things. Students develop explanations of phenomena using evidence from their observations and reasoning from science ideas and models.

Chapter 2 (Lessons 2.1–2.3) develops science ideas about mass conservation during chemical reactions and its molecular explanation. Students revisit the reactions they examined in Chapter 1, focusing on what happens to the mass when the reactions are carried out in closed versus open systems. They use models to visualize why even though atoms, and therefore total mass, remains the same (is conserved) during chemical reactions, the measured mass of a system can change if reactants or products enter or leave the system.

Chapter 3 (Lessons 3.1–3.5) applies the concepts of atom rearrangement and conservation to plant growth and repair: Through chemical reactions, plants build glucose monomers from carbon dioxide and water molecules they take in from the environment and link those glucose monomers to make the carbohydrate polymers (cellulose and starch) that are used to build body structures. A plant’s measured mass increases even though total mass is conserved. The increase in a plant’s mass comes from mass in its environment (mainly from carbon dioxide gas): The more atoms that are added to a plant’s body, the fewer atoms are in its environment.
Chapter 4 (Lessons 4.1–4.5) applies the concepts of atom rearrangement and conservation to animal growth and repair: Through chemical reactions, animals digest protein polymers in their food to amino acid monomers and use the monomers to build different protein polymers, which are primarily used to make up their body structures. An animal’s measured mass increases even though total mass is conserved. The increase in an animal’s mass comes from mass in its environment (mainly from the food it eats): The more atoms that are added to an animal’s body, the fewer atoms are in its environment. In a capstone lesson, students apply ideas about atom rearrangement and conservation in chemical reactions to the growth of mushrooms on a fallen dead tree.

Lesson Features

Each THSB lesson is 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; (3) guide students in developing, analyzing, and critiquing explanations (e.g., those of a hypothetical student, of their peers, and of the scientific community) in light of their experiences; (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.

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 students’ inquiry. Responding to the key question at the beginning of the lesson gives each student a chance to express his/her initial ideas and to give teachers a sense of the range of ideas their students hold. Responses to the key question at the end of the lesson can be used to monitor students’ progress.

Activity

Each lesson includes activities designed to engage students with phenomena and representations relevant to the learning goals. Some phenomena, particularly those in non-living 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. 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.

Some activities consist of short readings and questions to (1) help students make sense of ideas presented in text, (2) encourage students to ponder what they have just read in manageable chunks, and/or (3) help students use and apply the ideas they have read in the text. Other activities provide opportunities for students to learn to construct and evaluate explanations they encounter in the unit and in their everyday lives. 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 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, and/or models, relevant science ideas are introduced to students as generalizations about how the world works based on a wider range of observations and data than they have experienced. Science ideas are derived from NGSS disciplinary core ideas and crosscutting concepts. Students have opportunities to compare the generalizations they were asked to make about their observations of phenomena with these established science ideas and find examples from their work that support the science ideas.

Science ideas are used in constructing 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.

**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 and/or new learning, (2) use and apply the ideas they are developing to a new context or phenomenon, and/or (3) begin to link the ideas to the next lesson(s). The linking question elicits student ideas and predictions about the key question of the next lesson or about how an idea developed in nonliving contexts might apply to growth in living things.

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**About the Teacher Edition**

The Teacher Edition is designed to provide easy access to essential background information and support needed for using the THSB unit effectively in the classroom. The Teacher Edition aims 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.

**A Unit Overview** describes the overarching goal of the unit, the central questions students should be able to answer, and the core disciplinary ideas they should understand after completing the unit. In addition to describing the alignment of the unit with the NRC Framework and NGSS, the Overview includes a **Content Storyline** map representing where in the unit specific science ideas are developed and how the ideas build on each other from chapter to chapter.

**Unique Aspects of the Unit** describes the rationale for the unit’s approach to the science content, including its use of science terminology in the Student Edition. **Student Edition Conventions** presents the design principles guiding the development of lessons and describes the purpose and key features of each section of a lesson.

At the chapter level, the **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. **Background Knowledge for Teachers** provides information about key ideas to be
developed in the chapter, as well as what phenomena, data, and models may be used to develop and/or illustrate those ideas. **Prerequisite Knowledge for Students** describes assumptions about where students are likely to be in their understanding of the science ideas that are central to each chapter and identifies knowledge from other disciplines (e.g., English and Language Arts) that students are expected to have. **Common Student Ideas and Misconceptions** outlines a small number of common confusions and misunderstandings from the research literature and from Project 2061’s experiences in previous work that may be encountered in teaching the unit. There are more listed in each lesson.

At the lesson level, a **Lesson Guide** provides an overview of the lesson, including the key question; target sciences ideas and practices; materials and advance preparation needed; and a **Summary Chart** describing key phenomena, data, and models used, intended observations, and the pedagogical purpose of each.

The remaining pages of the lesson consist of facing **Student Edition Page** and **Answer Key** and **Teacher Facilitation Notes** pages. Each Student Edition Page and Answer Key page includes the Student Edition page plus ideal student responses (in gray text) written to reflect what students are likely to understand at that point in the lesson. Each page of the Teacher Facilitation Notes includes a time estimate for each activity. Teacher Facilitation Notes also include **Teacher Talk and Actions**, strategies for facilitating each page of the Student Edition, including partner/small group work, prompts for whole-class discussion, issues/ideas to highlight, and additional **Science Notes** for the teacher to be aware of. Each lesson concludes with **Closure and Link**, which is a description of the discussion that should arise at the end of each lesson or chapter.

**Availability of the THSB Unit**
The THSB unit is published by the NSTA Press and can be ordered from the NSTA Science Store at https://www.nsta.org/store/product_detail.aspx?id=10.2505/9781681404431.
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“The developers of Toward High School Biology have focused the materials to support teachers in providing students with a three-dimensional learning experience that the NGSS envision. In the unit, students will need to make sense of some unusual phenomena, such as egg-eating snakes or hydrogen peroxide bubbling on a wound, which will engage students as they learn and use important scientific ideas and practices.”

— Joseph Krajcik, PhD, Lappan-Phillips Professor of Science Education and Director of the CREATE for STEM Institute, Michigan State University

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