SCIENCEFUSION

RESEARCH-BASED APPROACH

REVISED 7/3/18

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INTRODUCTION

Houghton Mifflin Harcourt® *ScienceFusion*®, for students in Grades K through 8, is an interactive science program that delivers a holistic science experience, based on investigation and application across print, digital, and hands-on resources. The purpose of this document is to demonstrate clearly and explicitly the scientific research base upon which *ScienceFusion* was built. The program was designed following the principles of effective multimedia instruction in order to harness its potential for all students, and for learners of science in particular.

This report is organized around the following strands:

- Engineering and STEM;
- Three-Dimensional Learning;
- Writing to Learn;
- Vocabulary;
- Scaffolding;
- Metacognition;
- Engaging in Inquiry;
- Advantages of Blended Learning/Multimedia for Teaching Science; and
- Principles of Design for Effective Blended Learning/Multimedia Instruction.

To help readers make the connections between the research and the *ScienceFusion* program, the following sections are included within each strand:

- **Defining the Strand.** This section summarizes the terminology and provides an overview of the research related to the strand.
- **Research that Guided the Development of *ScienceFusion*.** This section identifies subtopics within each strand and provides excerpts from and summaries of relevant research on each subtopic.
- **From Research to Practice.** This section explains how the research data is exemplified in the ScienceFusion program.

The combination of the major research recommendations and the related features of *ScienceFusion* should help readers better understand how the program incorporates research into its instructional design.

A complete reference list of all works cited is provided at the end of this document.

STRAND 1:
ENGINEERING AND STEM AT K–8

Science, technology, engineering, and mathematics (STEM) workers drive our nation's innovation and competitiveness by generating new ideas, new companies, and new industries. . . . Science, technology, engineering, and mathematics workers play a key role in the sustained growth and stability of the U.S. economy, and are a critical component to helping the U.S. win the future.

(Langdon, McKittrick, Beede, Khan, & Doms, 2011, p. 1)

DEFINING THE STRAND

STEM, an acronym for the academic disciplines of science, technology, engineering, and mathematics, became a broader programming initiative launched by the National Science Foundation in the 1990s to promote an integrated approach to the instruction of these subjects within K–12 schools (Bybee, 2010b).

Within the *Frameworks for K–12 Science Education* and *Next Generation Science Standards*, engineering is promoted to equal status among the traditional natural sciences (National Research Council, 2012; NGSS Lead States, 2013; Sneider, 2012). NGSS formally introduces and reinforces engineering and engineering design throughout the K–12 science curriculum as one of the standards' Disciplinary Core Ideas. Research shows that instruction in engineering design and problem solving is beneficial to students in many ways, including increased engagement and collaboration, more direct involvement in science, and greater likelihood that students will ultimately pursue STEM-related careers (Moore, Glancy, Tank, Kersten, & Smith, 2014; Sneider, 2015; Turner, Kirby, & Bober, 2016).

As explained within the *Next Generation Science Standards* (NGSS Lead States, 2013), STEM education is vital; the world has changed dramatically since state science education standards' guiding documents were developed two decades ago. During that time, many advances have occurred in science and science education, as well as in the innovation-driven economy. The U.S. has an insufficient K–12 talent pipeline leading to the science and engineering fields, with too few students entering STEM majors and careers at every level (National Academy of Sciences [NAS], 2011).

The *Framework* and NGSS emphasize that it is imperative for students in the 21st century to understand the interconnectedness and mutually supportive links among science, engineering, technology, and society, and how these relationships evolve over time in response to need and impact (NRC, 2012; NGSS Lead States, 2013).

There has also been, in recent years, an increased focus on including computing and computational thinking, including programming and coding, within K–12 classrooms. Learning to code in particular comes with multiple benefits to students, including building problem-solving and higher-order thinking skills and increasing accessibility of computer literacy to traditionally underserved populations such as girls, students from minority backgrounds, and students with disabilities (Huerta, 2015; Israel, Wherfel, Pearson, Shehab, & Tapa, 2015).

ScienceFusion offers an integrative approach to STEM instruction that features prominence of engineering and coding within students' dynamic experience of the program.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

The Status of STEM

Research has established a strong link between STEM education and continued scientific leadership and economic growth in the United States (NAS, 2011). Science, technology, engineering, and mathematics significantly impact our economy, health, societal well-being, and political policy (NRC, 2011a).

Accompanied by economic and environmental crises and concerns about ability of the U.S. workforce to remain competitive and innovative in an increasingly globalized market, STEM education became a focus of planning and policy at federal, state, and local levels in the early 21st century (Katehi, Pearson, & Feder, 2009; Tsupros, Kohler, & Hallinen, 2009). Reports such as *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academy of Sciences, 2011) stressed the critical need for improving K–12 instruction in fields of science, technology, engineering, and mathematics. According to the U.S. Department of Commerce (Langdon et al., 2011), since the start of the 21st century, growth in STEM jobs has been three times faster than growth in non-STEM jobs, and STEM jobs pay 26% more than non-STEM jobs; yet there is an abundance of open positions in these fields—and not enough qualified people to fill them. "The primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering . . . 4 percent of the nation's workforce is composed of scientists and engineers; this group disproportionately creates jobs for the other 96 percent" (NAS, 2011, p. 4).

An increasing number of jobs at all levels—not just for professional scientists—require knowledge of STEM, while employers from wide-ranging industries lament that job candidates lack those necessary skills. Therefore, individuals employed outside of STEM occupations also face growing demands for knowledge in science, technology, engineering, and mathematics (NRC, 2011b).

The vital importance of STEM extends well beyond the workplace. As explained in the National Research Council's 2011 report *Successful STEM Education: A Workshop Summary:*

> What students learn about the science disciplines, technology, engineering, and mathematics during their K–12 schooling shapes their intellectual development, opportunities for future study and work, and choices of career, as well as their capacity to make informed decisions about political and civic issues and about their own lives. A wide array of public and personal issues—from global warming to medical treatment to social networking to home mortgages—involves science, technology, engineering, and mathematics (STEM). Indeed, the solutions to some of the most daunting problems facing the nation will require not only the expertise of top STEM professionals but also the wisdom and understanding of its citizens. (p. 1)

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

STEM Exposure is Essential in Children's Early Lives and Education

Though historically STEM programming at the elementary level has in the United States been limited at best, the ability most children have to focus on sustained explorations or learning activities is often underestimated; effective inquiry-based projects can deeply engage even young children for extended periods of time, beyond a single session (NRC, 2007). Even before they begin formal schooling, young children have the capacity and motivation to observe, explore, and discover the mathematics and science they encounter in their daily lives, as well as capacities to develop conceptual knowledge and use reasoning and inquiry; early engagement with the thinking processes associated with STEM areas provides an important foundation for later learning (Bybee, 2011; NRC, 2007 & 2012).

Research demonstrates that early exposure to STEM initiatives and activities can have a positive impact on children's perceptions of these fields and that a proactive effort to capture students' interests in STEM at the lower grades sets them up for completion of advanced coursework through secondary school (DeJarnette, 2012). It is especially important that girls and students from underrepresented populations are encouraged to participate in and pursue STEM-related experiences—and that the experiences and materials made available are appealing so as to attract a wider range of students (Katehi et al., 2009; McLaughlin, 2009).

Best Practices in STEM Education

"Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges. Yet too few U.S. workers have strong backgrounds in these fields, and many people lack even fundamental knowledge of them. This national trend has created a widespread call for a new approach to K–12 science education in the United States" (NRC, 2012, p. 1).

NRC's 2011 report *Successful K–12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics* outlines the following goals for STEM instruction:

- Expand the numbers of students who ultimately pursue advanced degrees and careers in STEM fields and broaden the participation of women and minorities in those fields;
- Expand the STEM-capable workforce and broaden the participation of women and minorities in the workforce; and
- Increase STEM literacy for all students, including those who do not pursue STEM-related careers or additional study in the STEM disciplines.

The report also includes research findings showing what makes for effective STEM education and programs:

- Capitalize on students' interests and experiences;
- Identify and build on what students know; and
- Provide experiences to actively engage students in STEM-related practices and sustain their interest.

The *Framework for K–12 Science Education* provides a vision for K–12 science education in which technology and engineering are integrated in students' learning and in which "students, over multiple years, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields" (NRC, 2012, pp. 1–2). Research in the area has identified a number of beneficial impacts that an integrated approach can have on learning. Students master the individual facts of science content knowledge better when they have a purpose for learning the material. Connections among science, technology, engineering, and mathematics are particularly important for raising achievement as students approach middle school (Russo, Hecht, Burghardt, Hacker, & Saxman, 2011).

Real-world contexts for STEM learning are also essential. Tapping knowledge to analyze and propose solutions for problems in society requires both that students apply higher-order thinking skills to this knowledge, and also that the knowledge be thoroughly grounded in a framework of scientific thinking within the students' own minds. The practice of discussing the scientific aspects of societal issues and attempting to solve problems with science gives students experience in applying science process skills. Finally, this emphasis on the human side of science and real-world problems can improve students' interest and motivation (Mid-Continent Research for Education and Learning [McREL], 2010).

Advancing Engineering Education at K–12: Benefits and Best Practices

The elementary level is an ideal time for introducing children to engineering concepts and principles and meshes well with activities and materials already found in primary classrooms (Bybee, 2011; NRC, 2007 & 2012). "Engineering has the distinct advantage in the elementary school of being something students enjoy as it incorporates hands-on and creative work. Our efforts to bring engineering to the classroom are grounded in constructionist philosophy which puts forth that people learn better when they are working with materials that allow them to design and build artifacts that are meaningful to them" (Rogers & Portsmore, 2004, p. 17).

Prior to 2012, science education standards referenced engineering and technology, but they were presented as applied science, separate from its "core content" science—and thus frequently overlooked in schools; the *Framework* and NGSS give equal status to engineering and technology among the traditional sciences (biology, chemistry, physics, and Earth and space science) and include them throughout the K–12 span (Sneider, 2012).

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

Katehi and colleagues (2009) cite multiple potential benefits of including engineering in K–12 schools:

- Improved learning and achievement in science and mathematics, with effects potentially more significant for underrepresented minority groups;
- Increased awareness of engineering and the work of engineers;
- Understanding of and ability to engage in engineering design;
- Interest in pursuing engineering as a career; and
- Increased technological literacy.

Giving students a strong foundation in engineering design provides skills they need to help solve society's challenges. Since engineering involves students working together in teams, design challenges foster collaboration while the open-ended nature of engineering design encourages creativity and engagement (Cunningham & Lachappelle, 2011). "Implementing the NGSS will better prepare high school graduates for the rigors of college and careers. In turn, employers will be able to hire workers with strong science-based skills—not only in specific content areas, but also with skills such as critical thinking and inquiry-based problem solving" (NGSS Lead States, 2013, Introduction, p. 1).

Sneider (2015) also sees increased prominence of engineering instruction at the elementary level as a possible remedy against the disconcerting trend consistently documented in the research literature of declining interest in science amongst most populations of middle school students. Promising findings suggest that girls and minority ethnic groups are more inclined to respond positively to certain fields within engineering, such as medical and environmental engineering, that have relevance and direct application to people's lives (Cunningham & Lachappelle, 2011; Sneider, 2015).

Katehi and colleagues (2009) encourage an approach to teaching K–12 engineering that emphasizes design process, problem-solving, open-ended tasks, and collaboration, as well as integration across the STEM areas to support interdisciplinary conceptual understandings. Additionally, engineering instruction should promote engineering "habits of mind," including systems thinking, creativity, optimism, collaboration, communication, and ethical considerations.

Coding in K–12 Science Education

Technology is, of course, pervasive in present day life. Technology-based tools for learning, including digital systems and software, are vital to 21st-century education, including science instruction. But it is important that students learn more than how to use technology to serve their personal, educational, and professional needs. *The Next Generation Science Standards* call for students to gain insight and understanding of how science, engineering, and technology drive each other forward and continuously change as the consequent impacts upon each other and new needs emerge from society and the environment (NGSS Lead States, 2013). As described by the National Research Council (2012):

> [W]e broadly use the term "technology" to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants. (pp. 11–12)

Within the field of science education, there has also been, in recent years, an increased focus on computing and computational thinking, including programming and coding, within K–12 classrooms (Huerta, 2015; Israel et al., 2015).

One aspect of the value of treating technology and computing as its own field of study lies in the critical need within the 21st-century workplace for technological knowledge and a high level of technical skill across a wide range of jobs (Bybee, 2013; NGSS Lead States, 2013, Appendix C). Bybee (2013) points out that it is important that students understand how technologies have advanced science (e.g., through such inventions as the microscope and Hubble Telescope) as well as how societal needs have driven technological advancement (e.g., computers and smart phones).

There are multiple benefits of including computing, programming, and computational thinking within K–12 instruction, including:

- Building higher-order thinking skills (Heese, 2014; Israel et al., 2015; Kafai & Burke, 2014);
- Increasing collaborative problem solving (Heese, 2014; Kafai & Burke, 2014);
- Expanding equity for underserved populations of students, including girls, students from minority backgrounds, and students with disabilities (Huerta, 2015; Israel et al., 2015);
- Fostering positive attitudes about computer science and computer science skills (Baytak & Land, 2011; Lambert & Guiffre, 2009); and
- Creating real-world applied contexts for teaching mathematics, algorithmic problem solving, and collaborative inquiry (Fessakis, Gouli, & Mavroudi, 2013; Jona, Wilensky, Trouille, Horn, Orton, Weintrop, & Beheshti, 2014).

Learning to code in particular comes with multiple benefits to students, including building problem-solving and higher-order thinking skills and increasing accessibility of computer literacy to traditionally underserved populations such as girls, students from minority backgrounds, and students with disabilities (Heggart, 2014; Huerta, 2015; Israel et al., 2015). According to Huerta (2015), by promoting code literacy, schools could make education more equitable, offer inclusion for students with autism spectrum disorder, improve STEM proficiency, and—because code is programming language—build neuroplasticity associated with multilingual education.

Israel and colleagues (2015) call for schools to utilize a balanced approach to teaching computing that combines explicit instruction with open-inquiry activities. Students' frustrations with unfamiliar computational tasks can be reduced via explicit instruction when each step is explained concisely and monitored until students have mastered the step. Then, allowing students ample opportunities to develop and practice skills that have been taught—including within cooperative, collaborative contexts—is essential.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

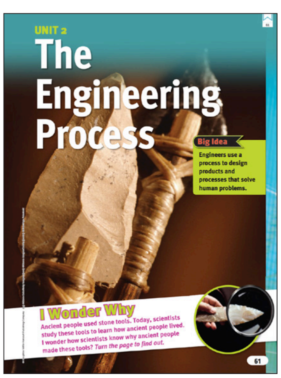
In industry and research, science, technology, engineering, and mathematics are interconnected; in education, these subjects should be taught as they are practiced in real-life contexts in which the world's issues and economies depend upon them. As explained within *A Framework for K–12 Science Education:*

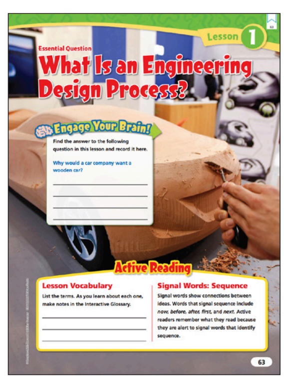
> The fields of science and engineering are mutually supportive. New technologies expand the reach of science, allowing the study of realms previously inaccessible to investigation; scientists depend on the work of engineers to produce the instruments and computational tools they need to conduct research. Engineers in turn depend on the work of scientists to understand how different technologies work so they can be improved; scientific discoveries are exploited to create new technologies in the first place. Scientists and engineers often work together in teams, especially in new fields, such as nanotechnology or synthetic biology that blur the lines between science and engineering. Students should come to understand these interactions and at increasing levels of sophistication as they mature. Their appreciation of the interface of science, engineering, and society should give them deeper insights into local, national, and global issues. (NRC, 2012, p. 204)

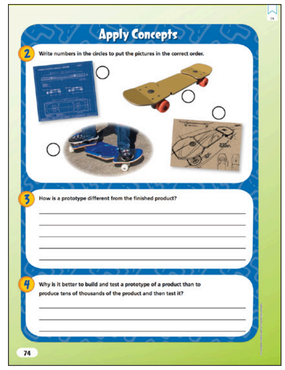
FROM RESEARCH TO PRACTICE

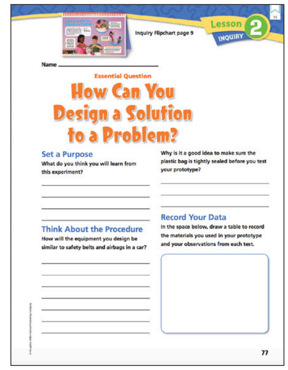
ScienceFusion places an emphasis on technology and engineering throughout. STEM is not treated as an ancillary concern, but instead is integrated within the entire program.

Each level of *ScienceFusion* includes a unit devoted to engineering that is framed around **Big Ideas** and **Essential Questions** to elicit conceptual development and deep thinking about key aspects of engineering, including design, problem solving, and the application of technology within the field.

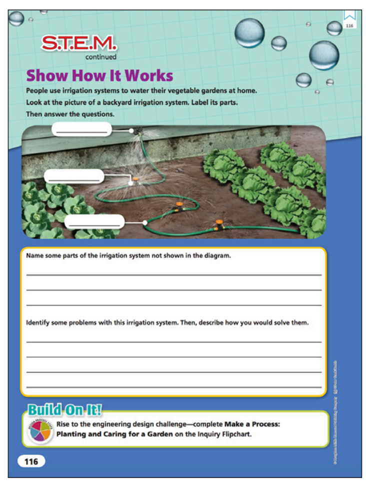






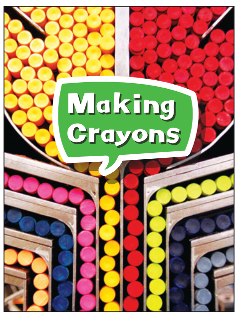


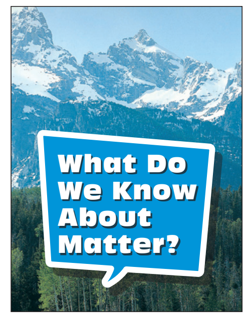
The program also includes periodic STEM tasks that have students work across these related skill areas to build knowledge as well as integrate processes and solve problems. These activities simulate the work of professionals in the STEM fields.



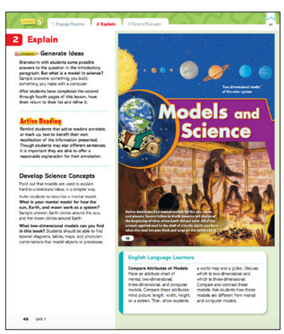
FROM RESEARCH TO PRACTICE *(CONTINUED)*

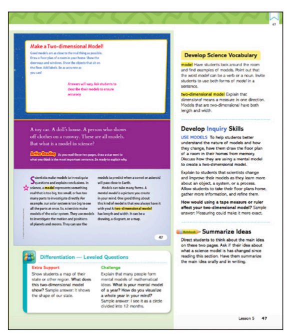
ScienceFusion also features **Science & Engineering Leveled Reader**s to help students engage with the engineering process through a non-fiction literary approach. Thirty or more readers per grade are provided with the program, allowing for teachers to meet each student's needs—whether a student is having difficulty with reading or science, working at grade level, or seeking enrichment. **Science & Engineering Leveled Readers** are available in print and digital formats. Teacher resource materials include guided reading and development strategies and both English and Spanish are supported.

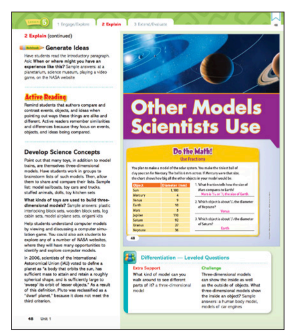


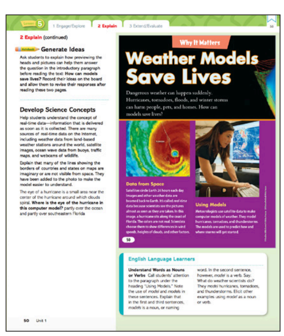


The program also develops students' awareness of the kinds of work scientists and engineers do. Modeling is one such activity professionals in the STEM field conduct and rely on. *ScienceFusion* has students consider and build models, and then engage with them in multiple ways to aid their understanding of science, technology, engineering, and mathematics.

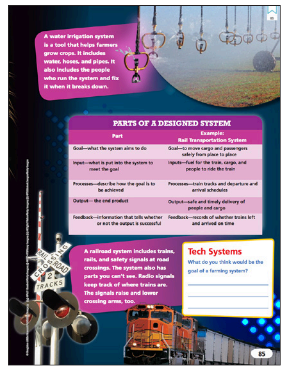








Technology is essential within *ScienceFusion*, both as digital components and program content so students learn how to use as well as understand technology and its role within science specifically and society broadly.



Computer coding is an important 21st-century skill set. A new spiraled curriculum on **Technology and Coding** has been added, with a single lesson section for each of Grades 1–8 along with a **Technology and Engineering** section at Kindergarten. Teacher-led online coding practice activities, using MIT's Scratch and Scratch Jr. open-source block programming, are also available at K–8.

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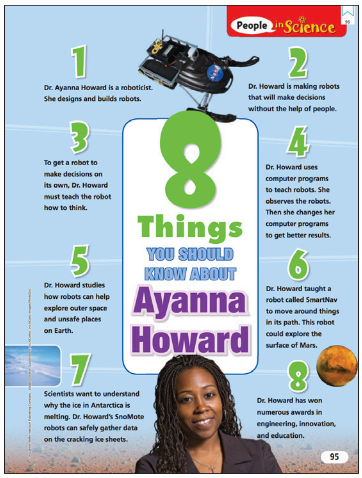
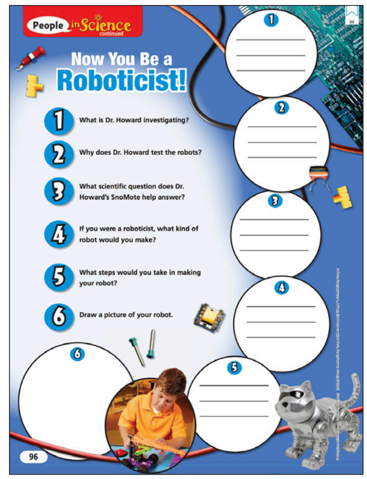
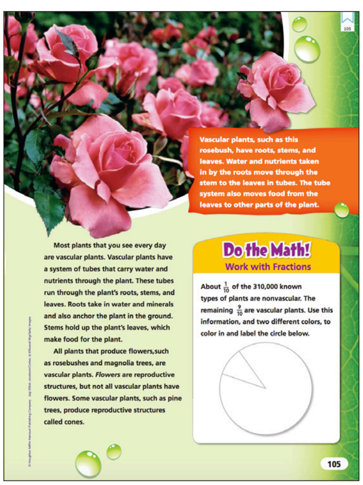
FROM RESEARCH TO PRACTICE *(CONTINUED)*

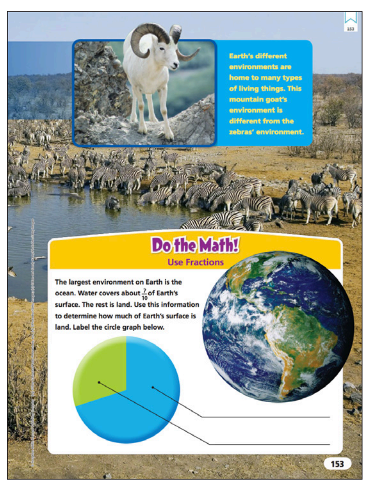
ScienceFusion also teaches students about careers in the STEM fields and accomplished professionals within them. This helps students consider their own potential paths and places doing science-related jobs, expanding their knowledge of opportunities available to them and inspiring them to pursue STEM training and work.

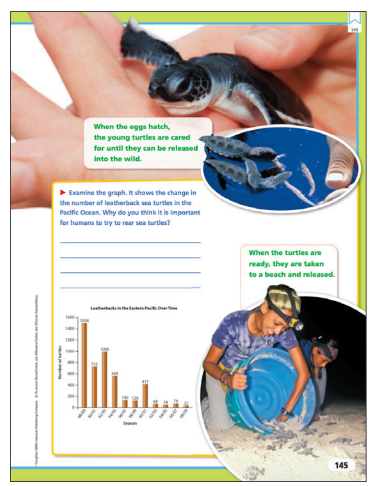




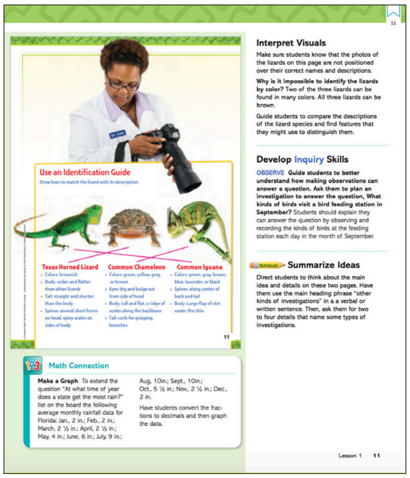
Activities requiring and supporting math skills are interwoven throughout the program's wide range of science content in Student Editions.

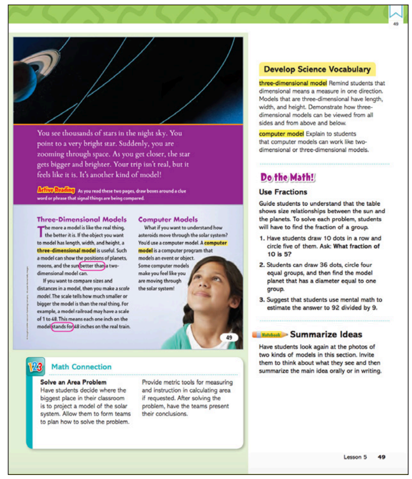


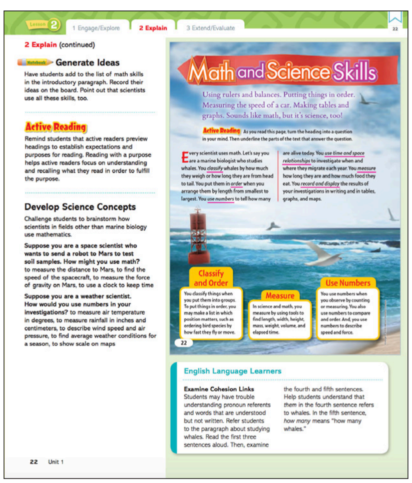


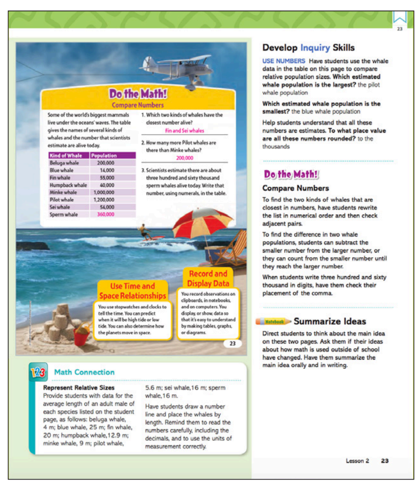


Additional opportunities for helping students make mathematical connections are provided in the *ScienceFusion* Teacher Edition. Also included for teachers is support in building students' conceptual understandings of science as part of integrated instruction in math and science skills.









STRAND 2:
THREE-DIMENSIONAL LEARNING

None of the dimensions can be used in isolation; they work together so that students can build deeper understanding as they grapple with making sense of phenomena or finding solutions to problems. As a result, learners can figure out more complex phenomena or design solutions to more perplexing problems . . . Scientists and engineers use the skills involved in three-dimensional learning throughout their careers. They talk about and engage in making sense of phenomena, and to do so, they simultaneously use SEPs, DCIs, and CCCs to discover and make connections among the science ideas related to their current understanding.

(Krajcik, 2015a, p. 6)

DEFINING THE STRAND

Among advances shared by the Framework, the *Next Generation Science Standards**, and a number of recently published state standards that are alternatives to NGSS is the three-dimensional approach to the teaching and learning of science. Such standards consist of these three dimensions: Science and Engineering Practices, Disciplinary Core Ideas (content), and Crosscutting Concepts. Previously, most state and district standards express these dimensions as distinct entities, leading to their separation in both instruction and assessment. Though innovative within K–12 education, the integration of rigorous content and application reflects how science and engineering is practiced in the real world—and is how experts across related fields advocate for how science should be taught to better prepare students for college and careers (NRC, 2007 & 2012; NGSS Lead States, 2013).

As Krajcik & Merritt (2012) explain:

> By focusing on big ideas blended with practices and crosscutting elements over time, the Framework and *Next Generation Science Standards* strive to avoid shallow coverage of a large number of topics and allow more time for students to explore and examine ideas in greater depth and use those ideas to understand phenomena they encounter in their lives. (p. 65)

Following are overarching ideas about the three-dimensional approach and how it represents a new way of teaching science, per the NGSS Lead States (2013):

- Science and Engineering Practices and Crosscutting Concepts are designed to be taught in context. Science and engineering are integrated into science education by raising engineering design to the same status as scientific inquiry in science classroom instruction at all levels and by emphasizing the core ideas of engineering design and technology applications.
- The NGSS also focus on a smaller set of Disciplinary Core Ideas (DCI) that students should know by the time they graduate from high school, allowing for a deeper understanding and application of content.

Aligning with a core tenet of the *Next Generation Science Standards* and many of the newer non-NGSS state standards, *ScienceFusion* features an integrated approach to the three dimensions of science instruction: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas—instruction and assessment should include more than one dimension at all times, rather than treating them in isolation. *ScienceFusion* allows students to enjoy learning science and engage with its processes, think deeply about and generate enduring understandings of science, and build problem-solving skills.

RESEARCH THAT GUIDED THE DEVELOPMENT OF SCIENCEFUSION

Citing a wide body of research, the National Research Council's 2007 report *Taking Science to School* made the case that the learning of science cannot be separated from the doing of science. Taking this charge further, *A Framework for K–12 Science Education* (NRC, 2012), which served as a foundation for the *Next Generation Science Standards* (NGSS Lead States, 2013) and many other state standards, outlines a vision for a three-dimensional approach to instruction determined to be necessary in order to provide students with high-quality science education for the 21st century. The three dimensions include Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas; integration of these dimensions gives students a context for the content of science, as well as a firmer grasp on understanding how scientific knowledge is acquired and built and how the sciences are connected through concepts that have universal meaning across disciplines (Bybee, 2013; NGSS Lead States, 2013).

According to Krajcik and Merritt (2012), science education in the United States has historically been impaired by efforts to present too many ideas too superficially, often leaving students both disconnected in their understandings and unable to solve problems and explain phenomena in their everyday lives. State science standards have traditionally represented practices and core ideas as separate entities. Science education researchers have reported that, within classrooms, these two dimensions are at best taught independently from one another, or the practices may go untaught entirely. This finding is troubling on several levels. First, as often inappropriately dealt with in some school settings, practices alone become science activities, and content alone devolves into mere memorization—and both are devoid of invaluable context. Second, separation of ideas from their application is not useful or practical, given that, in the real world, science and engineering are always a combination of content and practice. The three-dimensional approach to science instruction marks an innovation. It is through the integration of dimensions in *A Framework for K–12 Science Education* and NGSS that science begins to make sense and allows students to apply the material (NRC, 2015 & 2012; NGSS Lead States, 2013).

The integrative format represents yet another innovation, as it is intended that teaching and testing recognize all three dimensions, not only the Disciplinary Core Ideas (Bybee, 2013). This expectation stems from a Framework specification that each description of student expectations must combine a relevant Science and Engineering Practice with a Disciplinary Core Idea and Crosscutting Concept, appropriate for the designated grade level:

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

> In the future, science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. They will be assessed together, showing students not only "know" science concepts; but also, students can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design. (NGSS Lead States, 2013, Appendix F, p. 1)

Dimension 1: Science and Engineering Practices

Within *A Framework for K–12 Science Education*, Dimension 1 describes the major practices that scientists employ as they investigate and develop models and theories about the world, as well as the key set of engineering practices that engineers use as they design and build systems. The National Research Council uses the term "practices" (instead of, for example, "skills") to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice (NRC, 2012).

The perception that science is comprised of a set of practices has emerged from work across multiple fields over the past six decades that has shown that theory development, reasoning, and testing are part of a large ensemble of activities across networks of participants and institutions, with specialized ways of working, communicating, using instruments, and so on (NRC, 2012). The more recent shift to practice-based instruction within K–12 science education also stems from research on learning and instruction (Bybee, 2011; NRC, 2007 & 2012). In addressing the question "Why Practices?" the *Framework* explains:

> Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview. (NRC, 2012, p. 42)

Additional benefits of the "actual doing of science or engineering" through involvement in practices as cited within the Framework include helping students ask better questions and improve how they define problems (Bybee, 2011), as well as piquing and capturing students' interests and motivating students' continued study of science (NRC, 2012).

The eight practices of science and engineering derived from those that professionals engage in—and that the *Framework* identifies as essential for all students to learn—are:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;

6. Constructing explanations (for science) and designing solutions (for engineering);
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information (NRC, 2012).

The Science and Engineering Practices identified in the *Framework* and the NGSS elaborate on what it means to conceive and carry out authentic scientific inquiry and engineering design; engagement in these practices helps students understand how scientific knowledge develops as well as fosters an appreciation of the wide range of approaches and activities used by professional scientists and engineers (NRC, 2012; NGSS Lead States, 2013).

Science and Engineering Practices have an important place along the entirety of the K–12 spectrum, including the elementary years. Even young children engage with such practices in their observation and problem solving during play, in nature, and with toys such as blocks—and such activities provide great opportunities for deeper, more focused learning (Bybee, 2011; NRC, 2007 & 2012). Indeed, the first guiding principle cited in the *Framework* is that "Children are Born Investigators" (p. 24). "Planning and carrying out investigations should be standard experiences in K–12 classrooms. Across the grades students develop deeper and richer understandings and abilities as they conduct different types of investigations, use different technologies to collect data, give greater attention to the types of variables, and clarify the scientific and/or engineering contexts for investigations" (Bybee, 2011, p. 36).

It is essential to note that the Science and Engineering Practices constitute neither teaching strategies nor activities; they are instead indicators of achievement as well as important learning goals in their own right. To that end, the overarching 3D architecture of the *Framework* and NGSS also ensure the practices are not treated as afterthoughts but are integral to all aspects of learning, from planning to instruction to assessment (Bybee, 2013; NGSS Lead States, 2013).

Dimension 2: Crosscutting Concepts

The seven Crosscutting Concepts cited and described within the Frameworks bridge disciplinary boundaries across all domains of science and have explanatory value and application throughout much of science and engineering (NGSS Lead States, 2013; NRC, 2012). These include:

1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

3. Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4. Systems and system models. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

6. Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

The Crosscutting Concepts within the *Framework* echo many of the unifying concepts and processes in the National Science Education Standards, the common themes in the Benchmarks for Science Literacy, and the unifying concepts in the Science College Board Standards for College Success. They also provide one way of linking across the domains referred to in the Core Disciplinary Ideas (Duschl, 2012; NGSS Lead States, 2013; NRC, 2012). As noted by Duschl (2012), the *Framework* emphasizes that science learning must be coordinated around such generative conceptual ideas and scientific practices. "The Crosscutting Concepts are best thought of as the learning goals for science literacy" (p. 60).

The following guiding principles provide additional insight into the Crosscutting Concepts within standards (NGSS Lead States, 2013, Appendix G):

- Crosscutting concepts can help students better understand core ideas in science and engineering.
- Crosscutting concepts can help students better understand science and engineering practices.
- Repetition in different contexts will be necessary to build familiarity.
- Crosscutting concepts should grow in complexity and sophistication across the grades.
- Repetition alone is not sufficient.
- Crosscutting concepts can provide a common vocabulary for science and engineering.
- Crosscutting concepts should not be assessed separately from practices or core ideas.
- Crosscutting concepts are for all students.
- Inclusion of Nature of Science and Engineering Concepts.

From the *Framework*:

> Although crosscutting concepts are fundamental to an understanding of science and engineering, students have often been

> expected to build such knowledge without any explicit instructional support. Hence the purpose of highlighting them as Dimension 2 of the framework is to elevate their role in the development of standards, curricula, instruction, and assessments. These concepts should become common and familiar touchstones across the disciplines and grade levels. Explicit reference to the concepts, as well as their emergence in multiple disciplinary contexts, can help students develop a cumulative, coherent, and usable understanding of science and engineering. (NRC, 2012, p. 83)

The *Framework* recommends Crosscutting Concepts be embedded in the science curriculum beginning in the earliest years of schooling. The progression of Crosscutting Concepts across the grades demonstrates the increasing complexity suggested by the *Framework*. The grade band description of the progression of Crosscutting Concepts is representative, not fixed or required; concepts may be introduced or reinforced according to the development, experiences, and understandings of the students within a class or school (Duschl, 2012).

According to Pruitt (2015), "Crosscutting concepts are still the hardest dimension to implement but also incredibly powerful. This dimension helps students connect what they learn to the world around them in a meaningful way. It's hard, but clear instruction about how crosscutting concepts fit with the other dimensions will change science education" (p. 19).

Dimension 3: Disciplinary Core Ideas

Scientific knowledge available to people has expanded continually over the past century, and such a pace will likely only increase; this makes it impossible to teach all the ideas related to a given discipline in exhaustive detail during the K–12 years. Also, given the abundance of information available virtually in this current information age, an important role of science is not to attempt to teach "all the facts" but instead to prepare students with sufficient core knowledge, so that they can later acquire additional information successfully. An education focused on a limited set of ideas and practices in science and engineering enables students to evaluate and select reliable sources of scientific information and allow citizens to continue their building of such knowledge well beyond their K–12 school years as lifelong learners and users of scientific information—and perhaps even as producers of new findings in the sciences (NRC, 2012).

Embodying the philosophy above, the *Framework* identifies a set of Disciplinary Core Ideas for K–12 science education. These core ideas within the *Framework* and NGSS are grouped into four domains:

- Life sciences;
- Physical sciences;
- Earth and space sciences; and
- Engineering, technology and application of sciences.

As pointed out by Sneider (2012), a fundamental, monumental shift in the core ideas presented within the *Framework* (NRC, 2012) is making

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

engineering and technology among them, rather than separate from the core science content cited in prior standards documents or identified traditionally as types of "applied science."

The *Framework* describes the progression of Disciplinary Core Ideas in the grade band endpoints, but stresses that, as with the other dimensions of science learning, the progressions are provided by way of suggestion; these should be viewed as flexible and overlapping, and instruction should integrate the Disciplinary Core Ideas with Practices and Crosscutting Concepts.

In teaching Disciplinary Core Ideas, it is important to continue to focus on the application of concepts in real world contexts as part of that effort, as Sneider (2012) explains:

> No matter how carefully new curriculum materials are designed, however, some additional time will be needed for students to apply what they are learning to the real world. Today's science curriculum is so packed that it is difficult to imagine how to add yet another set of ideas on top of what we have now . . . [T]he challenge will be how to make the difficult choices about what can safely be left out of the curriculum, so that we can do a better job of teaching core ideas and helping our students understand why they are important and how to apply them to real problems. (p. 51)

Teaching Science in Three Dimensions

> Science teaching and learning in the United States are at a pivotal point. *A Framework for K–12 Science Education*, the *Next Generation Science Standards*, and many state science standards shift science educators' focus from simply teaching science ideas to helping students figure out phenomena and design solutions to problems. This emphasis on figuring out is new, provocative, and exciting, and it represents a revolution in how we teach science at all grade levels. (Krajcik, 2015a, p. 50)

It is crucial to recognize that such standards are goals that reflect what a student should know and be able to do in science. They do not dictate the manner or methods by which the standards are taught. How teachers help students meet those goals is intentionally flexible. Curricular and instructional decision-making rests with states, districts, schools, and educators. The fuller architecture seen in newer standards when compared to traditional ones is intended to minimize the intensive process of "unpacking" that has historically accompanied standards implementation, while not dictating or limiting curriculum and instructional choices (NGSS Lead States, 2013).

According to Duschl (2012), a key message from the *Framework* is that there are important interconnections among Crosscutting Concepts and Disciplinary Core Ideas and that students' understandings of concepts should be reinforced by repeated use in the context of instruction. "The coordination of the three Dimensions reinforces the importance of not separating the doing from the knowing" (p. 39).

In its *Guide to Implementing the Next Generation Science Standards* (2015), the National Research Council clarifies that science instruction should not refer to "the information that a teacher delivers to students; rather, we mean the set of activities and experiences that teachers organize in their classroom in order for students to learn what is expected of them" (p. 24).

In translating such standards into instruction and assessment, Bybee (2013) recommends that educators view the Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas within standards as a sequence of lessons (rather than as single lessons) and use them to guide planning and testing from a longer range perspective and with an integrative approach that combines and overlaps the three dimensions within a given potential activity.

Krajcik (2015a) recommends educators begin the process of implementing of the three-dimensional approach by identifying engaging phenomena or problems. From there, it is important to note the questions students are asking about the phenomena, especially ones that can be explored over a sustained period of time, and ones for which students can ask and explore sub-questions. "Engaging students in three-dimensional learning isn't an item on a checklist; it is an orientation one takes to science teaching, and it should be used every day. Three-dimensional learning involves establishing a culture of figuring out phenomena or designs to problems" (p. 50).

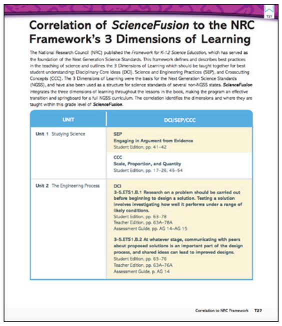
Experts concede that the transition to a three-dimensional approach will be challenging for educators and will take time (Bybee, 2011 & 2013; NRC, 2015; O'Day, 2016). "3-D Learning is hard. We do not help teachers or students by pretending it's not" (Pruitt, 2015, p. 19). However, Krajcik (2015a) stresses that:

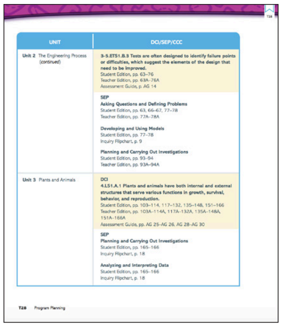
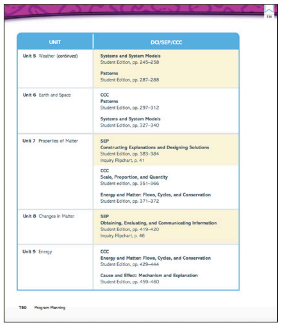
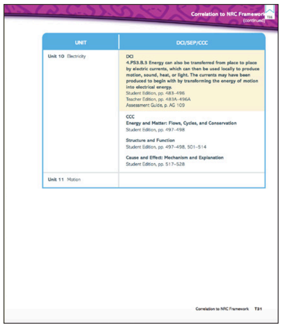
> persisting in this endeavor has its advantages. First, all students will develop deeper knowledge of the three dimensions, which will allow them to apply their knowledge to new and more challenging areas. Second, as all students engage in figuring out phenomena or solutions to problems, they will also develop problem-solving, critical-thinking, communication, and self-management skills. Third, and perhaps most importantly, three-dimensional learning will help foster all students' sense of curiosity and wonder in science. (p. 52)

FROM RESEARCH TO PRACTICE

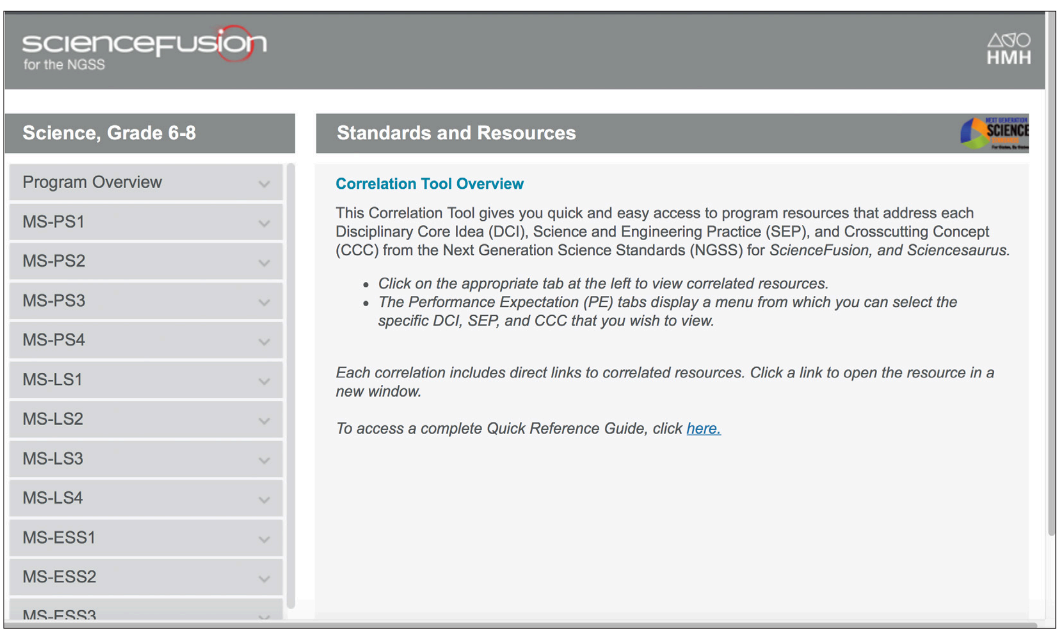
ScienceFusion supports the three-dimensional learning called for by many newer state standards. The program incorporates Disciplinary Core Ideas, Crosscutting Concepts, and Science and Engineering Practices into its content and can serve as the foundation for an NGSS curriculum.

To facilitate the transition to a NGSS curriculum, *ScienceFusion* provides correlations to the three dimensions in its Teacher Editions and online materials.



The Correlation Tool within online teacher materials provides quick and easy access to resources that address DCI, SEP, and CCC from the NGSS for *ScienceFusion* and *ScienceSaurus*®.



STRAND 3:
WRITING TO LEARN

Engaging students in talking and writing scientific explanations across different science content areas can help all students achieve greater success in science as well as develop a deeper understanding of explanations and arguments that they encounter in their daily lives.

(McNeill & Krajcik, 2012, p. 39)

DEFINING THE STRAND

Communication is a fundamental practice of science (NRC, 2012) and meaning-making experiences are essential to effective science instruction (McNeill & Martin, 2011). General literacy skills of reading, writing, and speaking are part of science literacy across K–12 (Pearson, Moje, & Greenleaf, 2010; Wellington & Osborne, 2001).

Research has long established that writing plays a vital role within effective science instruction and aids improvement in specific science skills. "[W] riting in science is essential to developing scientific literacy—how to read science, how to write science and the content of science itself" (Wellington & Osborne, 2001, p. 81). The more opportunities students have to write during science instruction, the more they learn (Hand, Hohenshell, & Prain, 2007).

Therefore, students need regular opportunities to consider and apply those terms in meaningful writing activities. As stated within the Framework, "[f]rom the very start of their science education, students should be asked to engage in the communication of science, especially regarding the investigations they are conducting and the observations they are making" (NRC, 2012, p. 77).

The writing-based strategies of notation and annotation while reading aid comprehension and recall of information as well as improve reading speed and accuracy (Sherer, Gomez, Herman, Gomez, White, & Williams, 2008).

Notetaking and annotation correlate with increased achievement in science specifically (Waldman & Crippen, 2009). Marcarelli (2010) and Klentschy (2008, 2005) recommend notebooking throughout the phases of science instruction as it forms a framework that allows students to be more metacognitive and generate increased meaning during questioning, investigation, data collection, and peer collaboration.

In *ScienceFusion*, students write on a regular basis. The interactive write-in format of the program's Student Edition requires students to write to demonstrate understanding and to practice and apply concepts. The *ScienceFusion* program was designed to have students perform the tasks that real scientists complete on a daily basis. Notebooking and annotating student texts are essential elements of the program that encourage active reading and application of concepts.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

Writing Aids Learning

Across content areas, the very act of writing can help students to process new information, make sense of complex ideas, and connect to their prior knowledge and experiences (Knipper & Duggan, 2006). According to Vygotsky (1962), such cognitive functions as analyzing and synthesizing develop more fully through writing engagement. Lance and Lance (2006), who use the term "exploratory writing" to refer to writing that has as its goal idea investigation and discovery, contend that such writing encourages students to make sense of new ideas for which they do not yet have a solid understanding.

Taking notes, or making annotations while reading, is a strategy that effective readers do to think about and retain new concepts encountered while reading. When students annotate a text while reading, they add notes, highlight or underline to identify important ideas, mark examples, or call attention to specific words, lines, or passages. "Annotation is the written result of the mental process of comprehension that occurs as the reader absorbs the material on the page" (Spatt, 1983, p.163). In this way, active readers make texts their own and better understand and recall concepts in reading.

According to Zywica and Gomez (2008), annotation helps students become more active and engaged readers. Notetaking has been shown to improve students' writing (Buczynski & Fontichiaro, 2009) and to improve their thinking, literacy skills, and collaboration (Gilbert & Kotelman, 2005; Sherer et al., 2008). According to Sherer and colleagues (2008), the strategy of annotation can help students not only comprehend and recall information, but also read more quickly and accurately because they will know how to identify the most important information while reading.

Writing Boosts Science Achievement

Within science instruction specifically, research has demonstrated that the more opportunities students have to write, the more students learn (Hand, et al., 2007). These effects are enhanced when students complete writing tasks with the purpose of learning (Gunel, Hand, & Prain, 2007). Waldman and Crippen (2009) found that strategies such as taking notes and annotating correlate with increased achievement. Braun, Coley, Jia, and Trapani (2009) reported that when science students had increased writing opportunities, they had significantly higher test scores than students who did not engage in writing activities. Prain (2006) concluded from a review of writing for learning research in science that "researchers in this field are generally agreed that writing is a necessary and valuable epistemological tool for learning" (p. 195).

Marcarelli (2010) recommends the incorporation of notebooking at all phases of science instruction; it is where students should respond to the initial overarching question, explore ideas to form hypotheses, record data during investigative labs and collaboration with peers, construct meaning out of collected information, and reflect on discussions and results. She further points out that science notebooking supports the kind of instruction Donovan and Bransford call for in *How Students Learn: Science in the Classroom* (NRC, 2005), which should:

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

- Elicit and address students' prior conception of scientific phenomena;
- Help students develop deep understandings of science subject matter and of scientific inquiry; and
- Help students monitor and assume control of their own learning—in other words, be metacognitive in their approach toward science.

Klentschy (2008, 2005) recommends that science notebooks include the following components; each has unique value and not all will be used in conjunction with every unit of instruction, but collectively they form a framework that aids students in making sense of what they investigate:

- Question, problem, purpose;
- Prediction;
- Planning;
- Observations, data, charts, graphs, and drawings;
- Claims and evidence;
- Conclusions; and
- Reflection: next steps and new questions.

Notebooking in science has been shown to be particularly effective in empowering students and supporting learning. Further, as Klentschy (2005) concluded, studies conducted to examine the impact of a program of instruction using notebooks on students' achievement "revealed positive results—particularly that providing a 'voice' for students through their science notebooks has led to increased student achievement in science and in reading and writing as well" (p.27). Multiple benefits of science notebooking have been reported in the research literature. Notebooking allows students to take control of their learning while processing information and engaging in self-reflection (Waldman & Crippen, 2009). As a place to integrate facts and students' thought processes, a science notebook becomes "a central place where language, data, and experience work together to form meaning for the student" (Klentschy, 2005, p. 24).

Interactive science notebooks foster in students identification of preexisting ideas, enrichment and refinement of their understandings, and reflection on learning (Marcarelli, 2010). They also encourage active learning and opportunities for students to pursue their own interests (Hargrove & Nesbit, 2003; Gilbert & Kotelman, 2005). Finally, notebooks enhance literacy generally, providing abundant opportunity for students to develop writing skills in science and beyond (Gilbert & Kotelman, 2005; Young, 2003) and to develop voice in the process of constructing meaning from their experiences with science (Klentschy & Molina-De La Torre, 2004). When students use an interactive notebook, they engage in writing practice, thereby improving their ability to write coherently (Buczynski & Fontichiaro, 2009). All of this encourages connections to the Common Core State Standards for English Language Arts, as called for by the *Frameworks* (NRC, 2012).

Science notebooks also reveal students' thought processes and thinking about concepts and skills; these in turn can provide teachers with vital insights into individual students' learning as well tools for formative assessment (Buczynski & Fontichiaro, 2009; Hargrove & Nesbit, 2003; Marcarelli, 2010). Science notebooking, then, yields improved thinking and teaching (Gilbert & Kotelman, 2005). As Hargrove and Nesbit (2003) point out:

> While standardized tests provide information about what students know and can do at the end of instruction (usually at the end of the school year), there is an immediate need to regularly monitor student progress so as to influence best instructional practices. Science notebooks provide this form of rich assessment data. Not only do students learn about themselves as scientists, teachers are informed about what and how students learn, and the efficacy of their instructional practices. These kinds of data allow the teacher to tailor instruction to what students really need. (p. 3)

Notebooks help teachers differentiate instruction and meet the needs of all learners

(Amaral, Garrison, & Klentschy, 2002; Gilbert & Kotelman, 2005). Notebooks are particularly beneficial to English language learners and students with special needs. "The notebook provides a safe place to practice writing and express prior knowledge and newly acquired language" and can also be used as evidence to inform meetings and devise intervention strategies with specialists and other professionals supporting particular populations of students (Marcarelli, 2010, p. 4).

Finally, science notebooks involve students in authentic scientific processes, such as recording observations and data, conducting research, collaborating with peers, and analyzing results—allowing students to engage in science as professionals in related fields do (Hargrove & Nesbit, 2003; Marcarelli, 2010; Young, 2003).

Notebooks can also provide additional support of effective instructional practices when students use them to go beyond notetaking, to develop narrative statements and non-verbal representations (e.g., drawings and diagrams) of their observations and understandings (Hargrove & Nesbit, 2003; Marcarelli, 2010; Marzano, Pickering, & Pollock, 2001).

"Writing can be a solitary cognitive act of producing meaning for oneself, and writing can be a social act of producing meaning through negotiation with others. The very symbols that are used to express ideas, the manner in which the symbols are arranged, and the ways those symbols are interpreted by the writer and reader are socially, culturally, and historically bound. These aspects of writing cannot be ignored. But we also cannot ignore that there is a mind/brain that stores, manipulates, and uses the symbols for oneself or makes them available for others to use" (Hacker, Keener, & Kircher, 2009, p. 170).

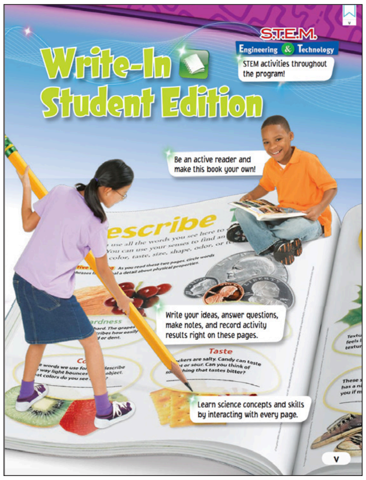
FROM RESEARCH TO PRACTICE

ScienceFusion provides students with numerous opportunities to write about and reflect on newly learned content and on the processes they used to make sense of new scientific concepts. The *ScienceFusion* Write-In Student Edition allows students to take notes, draw sketches, and record data on the pages of their textbook, as a form of notebooking. Throughout the program, students are asked to write in response to prompts that ask them to engage in various types of thinking and reflection.

FROM RESEARCH TO PRACTICE (CONTINUED)

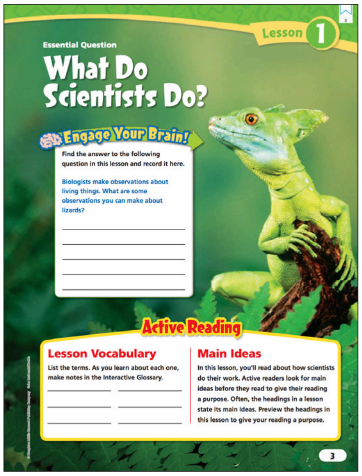
Writing to Improve Scientific Thinking and Understanding in *ScienceFusion*

The Write-In Student Edition in *ScienceFusion* promotes a student-centered, interactive approach in which students are regularly writing to improve their scientific thinking and understanding. Writing is incorporated into each science lesson, and students use writing to learn science concepts, vocabulary, and inquiry skills.



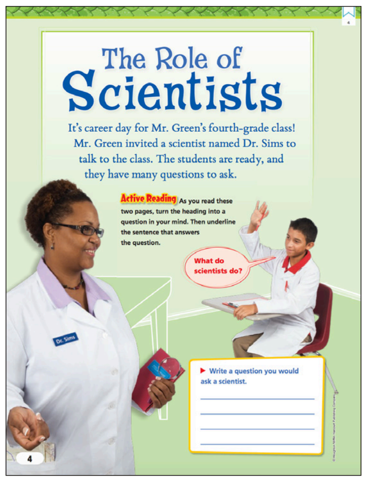
Before Reading

The **Engage Your Brain!** pre-reading feature in the print edition activates students' prior knowledge on a topic, provides an informal pre-assessment of students' knowledge, encourages students to consider concepts related to those that will be discussed within the lesson, and provides a space for students to record their responses on write-on lines or within graphic organizers.



During Reading

Other regular prompts, including the **Active Reading** prompts throughout each lesson, remind students to use writing to reflect on their learning and improve their scientific thinking and understanding.

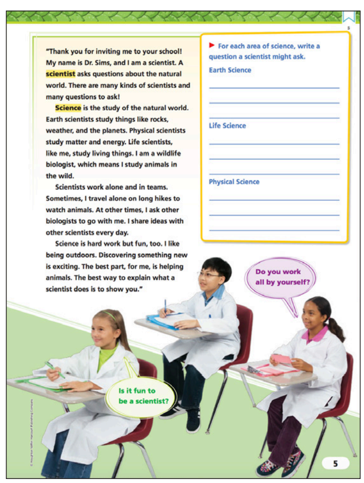

The Role of Scientists

It's career day for Mr. Green's fourth-grade class! Mr. Green invited a scientist named Dr. Sims to talk to the class. The students are ready, and they have many questions to ask.

Active Reading As you read these two pages, turn the heading into a question in your mind. Then underline the sentence that answers the question.

▶ Write a question you would ask a scientist.

4


"Thank you for inviting me to your school! My name is Dr. Sims, and I am a scientist. A scientist asks questions about the natural world. There are many kinds of scientists and many questions to ask!

Science is the study of the natural world. Earth scientists study things like rocks, weather, and the planets. Physical scientists study matter and energy. Life scientists, like me, study living things. I am a wildlife biologist, which means I study animals in the wild.

Scientists work alone and in teams. Sometimes, I travel alone on long hikes to watch animals. At other times, I ask other biologists to go with me. I share ideas with other scientists every day.

Science is hard work but fun, too. I like being outdoors. Discovering something new is exciting. The best part, for me, is helping animals. The best way to explain what a scientist does is to show you."

▶ For each area of science, write a question a scientist might ask.

Earth Science

Life Science

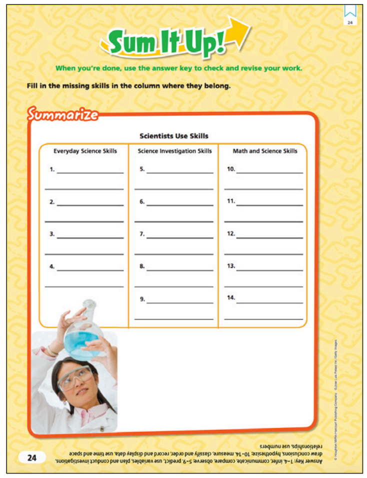
Physical Science

5

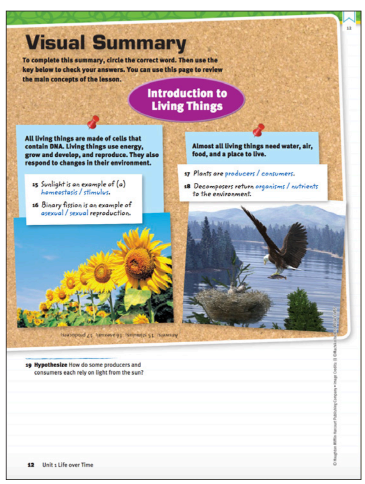
FROM RESEARCH TO PRACTICE *(CONTINUED)*

After Reading

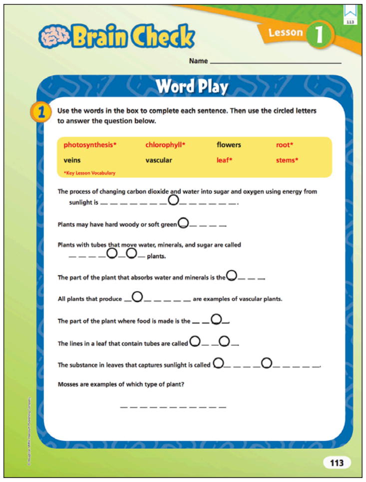
For students in Grades K through 5, the **Sum It Up!** feature after each lesson offers further opportunities for students to write to demonstrate and reflect upon their understanding.

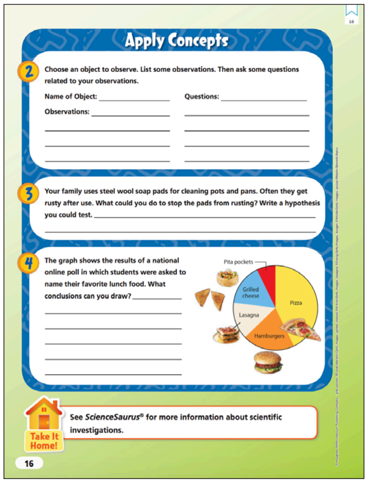


For students in Grades 6 through 8, the **Visual Summary** at the end of each lesson provides an opportunity for students to visually review the contents of the lesson and write about the key ideas from the reading.

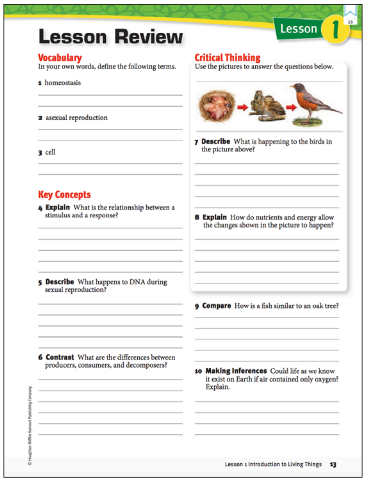


For students in Grades K through 5, regular **Brain Checks** provide additional prompts to elicit student writing and thinking, such as in the **Apply Concepts** section, in which students apply what they have learned.





For students in Grades 6 through 8, the **Lesson Review** provides an opportunity for students to consider **Vocabulary, Key Concepts,** and **Critical Thinking** questions related to the lesson's topic.

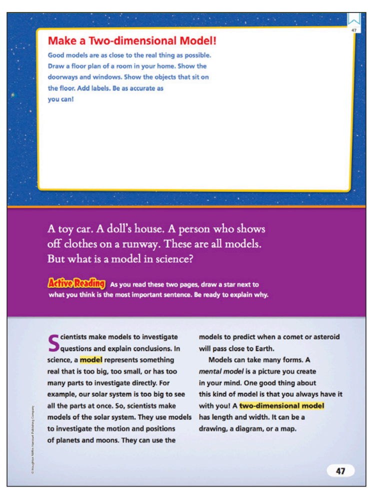


In the **Unit Review**, students again have the chance to write about what they have learned. Students in Grades K through 5 answer **Apply Inquiry** and **Review the Big Idea** questions to think about what they have learned and apply it in a new context, while students in Grades 6 through 8 make connections between ideas in the lessons and answer questions on **Vocabulary, Key Concepts,** and **Critical Thinking.**

FROM RESEARCH TO PRACTICE *(CONTINUED)*

Writing in Scientific Genres in *ScienceFusion*

In *ScienceFusion* students learn to think like scientists by engaging in the work of scientists. By writing about experiments, students learn the scientific process and the language of science. Creating and writing within graphic representations alongside reading and writing also is imitative of the work of scientists and aids learning of scientific concepts.

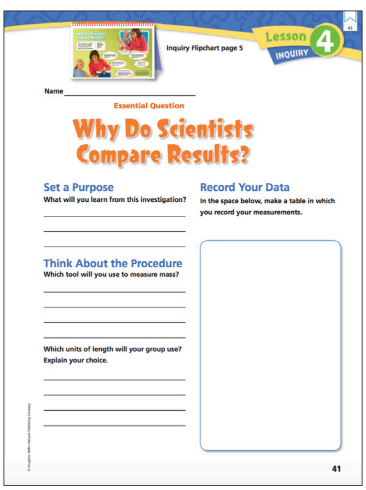


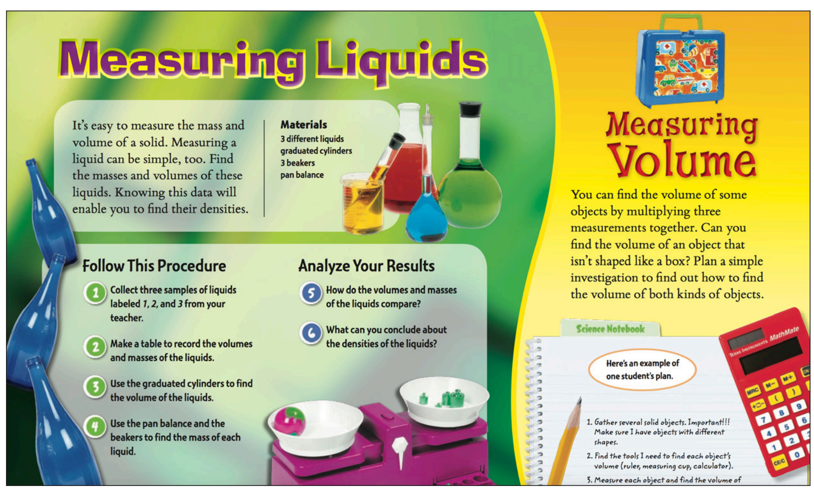
ScienceFusion contains a rich and varied lab program, which includes activities that address a variety of proficiency levels through varied amounts of instructional support—directed, guided, and independent— and curricular needs, including time availability and materials.

Throughout levels K through 5, students write in a structured way about their inquiry-based learning activities. The structure followed in the **Lesson Inquiry** sections in the Write-In Student Edition and in the **Inquiry Flipchart** encourages students to engage in the scientific process.

The responses that they write require that they:

- **Set a Purpose** for their investigation;
- **Think About the Procedure** they will use;
- **Record Your Data** from observations;
- **Draw Conclusions** about the data; and
- **Analyze and Extend** their thinking about the findings of the investigation.

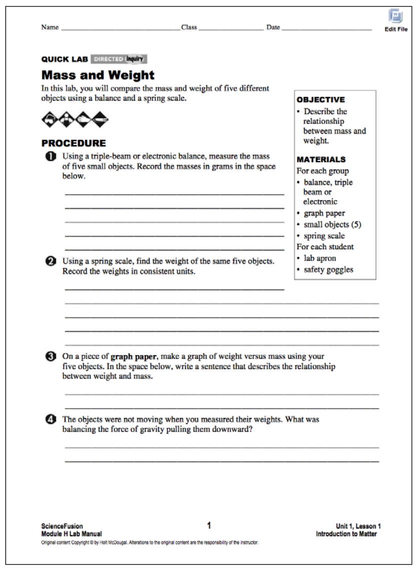




FROM RESEARCH TO PRACTICE *(CONTINUED)*

In Grades 6 through 8, students respond in writing when they complete activities throughout the Student Edition and in the Lab Manuals:

- Quick Labs
- Exploration Labs
- Field Labs
- S.T.E.M. Labs



Name ______________ Class ______________ Date ______________

Edit File

QUICK LAB DIRECTED Inquiry

Mass and Weight

In this lab, you will compare the mass and weight of five different objects using a balance and a spring scale.

OBJECTIVE
- Describe the relationship between mass and weight.

MATERIALS

For each group
- balance, triple beam or electronic
- graph paper
- small objects (5)
- spring scale

For each student
- lab apron
- safety goggles

PROCEDURE

1. Using a triple-beam or electronic balance, measure the mass of five small objects. Record the masses in grams in the space below.
2. Using a spring scale, find the weight of the same five objects. Record the weights in consistent units.
3. On a piece of **graph paper**, make a graph of weight versus mass using your five objects. In the space below, write a sentence that describes the relationship between weight and mass.
4. The objects were not moving when you measured their weights. What was balancing the force of gravity pulling them downward?

ScienceFusion
Module H Lab Manual

1

Unit 1, Lesson 1
Introduction to Matter

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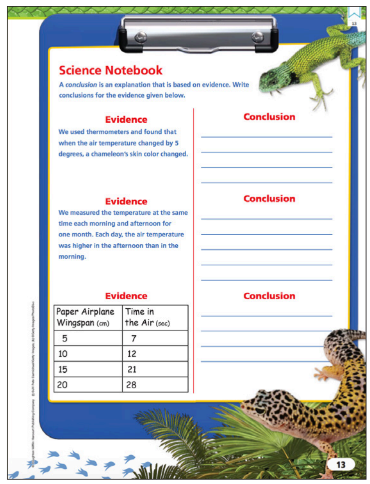
Students respond to questions about their procedures, their observations, conclusions, and analyses of their findings.

In addition, in the Teacher Resources Science Toolkit for the middle grades, teachers are provided with resources (including guidelines, templates, transparencies, and models) to support instruction in Writing in the Sciences, including producing scientific writing such as:

- **Writing a Lab Report**
- **Maintaining a Science Notebook**
- **Taking Research Notes**
- **Conducting Interviews and Surveys**
- **Planning a Research Report**
- **Drafting a Research Report**
- **Revising a Research Report**
- **Documenting Sources**
- **Writing for Displays: Labels, Captions, Summaries**

Annotating and Notebooking to Reflect on and Remember Scientific Concepts in *ScienceFusion*

Notebooking and annotation are built into the format and structure of *ScienceFusion*. The write-in textbook design of *ScienceFusion* provides students with opportunities to take notes, make sketches, and record data right in their textbooks. Students notebook to record data, consider the meanings of vocabulary terms, list facts, make predictions, draw conclusions, and reflect.



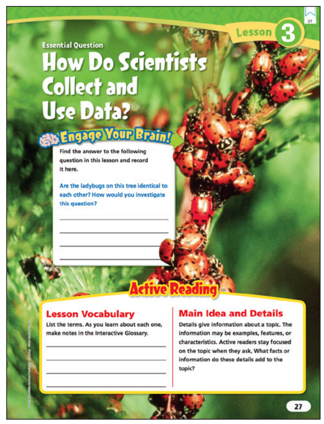
Each lesson opens with an **Essential Question**—such as "What Are the Oceans Like?", "What Objects Are Part of the Solar System?", or "What Are the Building Blocks of Organisms?"

FROM RESEARCH TO PRACTICE *(CONTINUED)*

In Grades K through 5, students are prompted to consider these **Essential Questions** as they work through the Student Edition; students are reminded: "Before you begin each lesson, be sure to write your thoughts about the Essential Questions." In the higher grades, students are prompted to make sure they are ready to discuss their responses to the **Essential Question** after the end of the lesson.

As students learn new content-area vocabulary, the program's **Lesson Vocabulary** features remind students to make notes about terms in the **Interactive Glossary**.

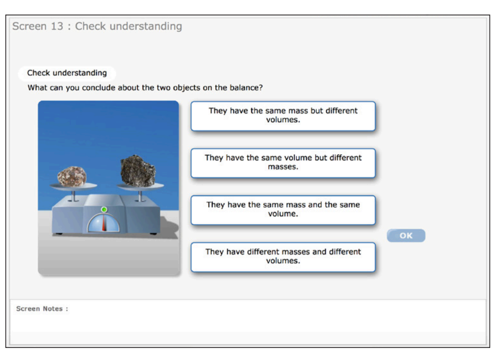
To encourage students to think about and retain main ideas, the program's **Active Reading** feature encourages students to read actively and make notes.



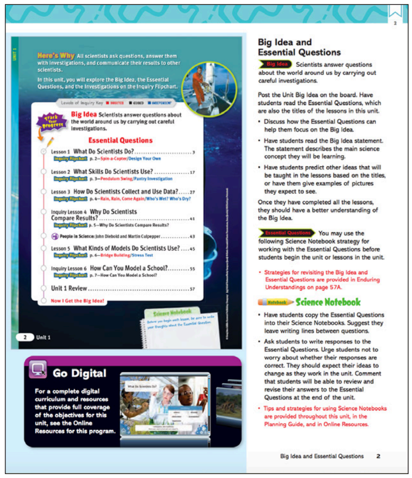
For students in the higher grades, blank pages are included in the consumable Write-In Student Edition as a space for students to keep their own notes about what they have learned.

The digital components of the program utilize the power of technology to offer students the ability to highlight and take notes as they move through the text.

Throughout the print and digital components of the program, interactive notebooking serves as an informal assessment opportunity for teachers to make sure students are understanding important ideas and concepts, and as a self-assessment opportunity to build students' awareness of their own understanding.



In addition, the Teacher Edition for the program includes Science Notebooking strategies focusing on vocabulary, inquiry, and assessment.



UNIT 1

Here's Why All scientists ask questions, answer them with investigations, and communicate their results to other scientists.

In this unit, you will explore the Big Idea, the Essential Questions, and the Investigations on the Inquiry Flipchart.

Levels of Inquiry Key ■ DIRECTED ■ GUIDED ■ INDEPENDENT

Track Your Progress

Big Idea Scientists answer questions about the world around us by carrying out careful investigations.

Essential Questions

Lesson 1 What Do Scientists Do? 3
Inquiry Flipchart p. 2—Spin-a-Copter/Design Your Own

Lesson 2 What Skills Do Scientists Use? 17
Inquiry Flipchart p. 3—Pendulum Swing/Pantry Investigation

Lesson 3 How Do Scientists Collect and Use Data? 27
Inquiry Flipchart p. 4—Rain, Rain, Come Again/Who's Wet? Who's Dry?

Inquiry Lesson 4 Why Do Scientists Compare Results? 41
Inquiry Flipchart p. 5—Why Do Scientists Compare Results?

People in Science: John Diebold and Martin Culpepper 43

Lesson 5 What Kinds of Models Do Scientists Use? 45
Inquiry Flipchart p. 6—Bridge Building/Stress Test

Inquiry Lesson 6 How Can You Model a School? 55
Inquiry Flipchart p. 7—How Can You Model a School?

Unit 1 Review 57

Now I Get the Big Idea!

Science Notebook
Before you begin each lesson, be sure to write your thoughts about the Essential Question.

2 Unit 1

Go Digital

For a complete digital curriculum and resources that provide full coverage of the objectives for this unit, see the Online Resources for this program.

2

Big Idea and Essential Questions

Big Idea Scientists answer questions about the world around us by carrying out careful investigations.

Post the Unit Big Idea on the board. Have students read the Essential Questions, which are also the titles of the lessons in this unit.

- Discuss how the Essential Questions can help them focus on the Big Idea.
- Have students read the Big Idea statement. The statement describes the main science concept they will be learning.
- Have students predict other ideas that will be taught in the lessons based on the titles, or have them give examples of pictures they expect to see.

Once they have completed all the lessons, they should have a better understanding of the Big Idea.

Essential Questions You may use the following Science Notebook strategy for working with the Essential Questions before students begin the unit or lessons in the unit.

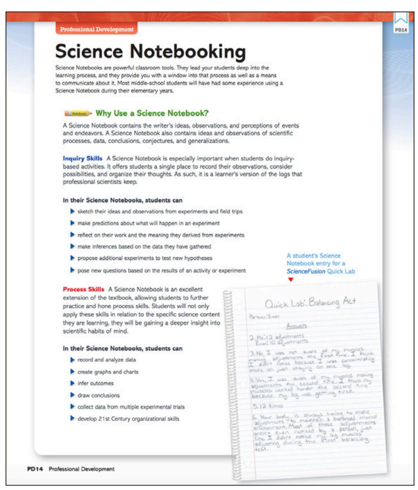
- Strategies for revisiting the Big Idea and Essential Questions are provided in Enduring Understandings on page 57A.

Notebook **Science Notebook**

- Have students copy the Essential Questions into their Science Notebooks. Suggest they leave writing lines between questions.
- Ask students to write responses to the Essential Questions. Urge students not to worry about whether their responses are correct. They should expect their ideas to change as they work in the unit. Comment that students will be able to review and revise their answers to the Essential Questions at the end of the unit.
- Tips and strategies for using Science Notebooks are provided throughout this unit, in the Planning Guide, and in Online Resources.

Big Idea and Essential Questions 2

Finally, as part of its Professional Development Support for teachers, the ScienceFusion program includes professional development on Science Notebooking and strategies and tips for using and grading the Write-In Student Edition.



PD14

Professional Development

Science Notebooking

Science Notebooks are powerful classroom tools. They lead your students deep into the learning process, and they provide you with a window into that process as well as a means to communicate about it. Most middle-school students will have had some experience using a Science Notebook during their elementary years.

Notebook **Why Use a Science Notebook?**

A Science Notebook contains the writer's ideas, observations, and perceptions of events and endeavors. A Science Notebook also contains ideas and observations of scientific processes, data, conclusions, conjectures, and generalizations.

Inquiry Skills A Science Notebook is especially important when students do inquiry-based activities. It offers students a single place to record their observations, consider possibilities, and organize their thoughts. As such, it is a learner's version of the logs that professional scientists keep.

In their Science Notebooks, students can

- sketch their ideas and observations from experiments and field trips
- make predictions about what will happen in an experiment
- reflect on their work and the meaning they derived from experiments
- make inferences based on the data they have gathered
- propose additional experiments to test new hypotheses
- pose new questions based on the results of an activity or experiment

Process Skills A Science Notebook is an excellent extension of the textbook, allowing students to further practice and hone process skills. Students will not only apply these skills in relation to the specific science content they are learning, they will be gaining a deeper insight into scientific habits of mind.

In their Science Notebooks, students can

- record and analyze data
- create graphs and charts
- infer outcomes
- draw conclusions
- collect data from multiple experimental trials
- develop 21st Century organizational skills

A student's Science Notebook entry for a *ScienceFusion* Quick Lab

Quick Lab: Balancing Act

Partner: Evan

Answers

2. Me: 12 adjustments
Evan: 10 adjustments

3. No, I was not aware of my muscles making adjustments the first time. I think I didn't notice because I was concentrating more on just staying on one leg.

4. Yes, I was aware of my muscles making adjustments the second time. I think my muscles worked harder the second time because my leg was getting tired.

5. 12 times

6. Your body is always having to make adjustments to maintain a balanced internal environment. Most of these adjustments aren't even noticed by a person, just like I didn't notice my leg muscles adjusting during the first balancing test.

PD14 Professional Development

STRAND 4: VOCABULARY

To provide quality science learning, classroom teachers must understand the vocabulary demands placed on students and students' beliefs about teaching and learning that are important for their development of knowledge.

(Brown & Concannon, 2014, p. 204)

DEFINING THE STRAND

Broadly defined, vocabulary is knowledge of words and word meanings. Yet, vocabulary does not solely consist of knowing words and their meanings; vocabulary development is a building process in which connections between new and old words are made and background knowledge and meaningful context impact comprehension (Brown & Concannon, 2014; Snow, Griffin, & Burns, 2005). As Stahl states, "Vocabulary knowledge is knowledge; the knowledge of a word not only implies a definition, but also implies how that word fits into the world" (Stahl, 2005).

Vocabulary knowledge is fundamental to learning across the content areas in school and throughout life. Marzano (2004) claims vocabulary development is an effective intervention for improving general academic achievement. In order to comprehend what is taught or encountered, students must have access to the meanings of words so that they can understand what is being said or written. Because most of students' success in school and beyond depends upon their ability to read and write while showing understanding, there is a need to offer instruction that equips students with the skills and strategies necessary for lifelong vocabulary development. Research shows that "By giving students explicit instruction in vocabulary, teachers help them learn the meaning of new words and strengthen their independent skills of constructing the meaning of text" (Kamil, Borman, Dole, Kral, Salinger, & Torgesen, 2008, p. 11).

Vocabulary instruction in the science classroom is particularly crucial because in this area, new words are often more complex or refer to complex concepts and may have specific meanings that may be different from or more precise than their everyday meanings in other contexts (Fisher & Blachowicz, 2013; Michaels, Shouse, & Schweingruber, 2008). Research has yielded findings indicating instructional strategies that are particularly effective at boosting vocabulary knowledge in the content areas and in science in particular (Armbruster & Nagy, 1992; Bintz, 2011; Brown & Concannon, 2014; Fisher & Blachowicz, 2013).

ScienceFusion was designed to introduce students to the vocabulary necessary to thrive in science. Throughout the program, students are presented with vocabulary terms relevant to the science concepts and skills they are learning. The vocabulary is previewed before reading and reinforced during and after through teacher instruction and student practice and review. Vocabulary strategies are demonstrated by teachers so students can decipher the meaning of unknown words they encounter while reading. Vocabulary development is furthered and connections to related terms are maximized by the use of multiple graphic organizers and other dynamic presentations in the *ScienceFusion* Write-In Student Edition and digital resources.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

The Importance of Vocabulary Development within Science

Vocabulary consists of "the words we must know to communicate effectively: words in speaking (expressive vocabulary) and words in listening (receptive vocabulary)" (Neuman & Dwyer, 2009, p. 385). Researchers have long documented that vocabulary development should be an instructional aim for literacy and across content areas (Bintz, 2011; Harmon, Wood, & Kiser, 2009; National Institute of Child Health and Human Development, 2000).

The development of academic vocabulary in particular—terms and concepts commonly used within and across specific content areas—has been identified as vital to academic performance and an important intervention for at-risk students (Blachowicz, Fisher, Ogle, & Watts-Taffe, 2013; Marzano, 2004; National Institute of Child Health and Human Development, 2000).

Knowledge of key words and conceptual vocabulary in science instruction specifically is essential to learning in this domain. Science includes specialized language that can be challenging to students as so much of it is dense, complex, outside of familiar contexts, and/or refers to unfamiliar concepts (Fisher & Blachowicz, 2013). A weak understanding of vocabulary and vocabulary acquisition strategies will seriously hinder students' ability to read and comprehend science textbooks (Harmon & Hedrick, 2005). This is an issue because science instruction, especially as students approach and enter the middle school level, is frequently dependent upon textbook use (Brown & Concannon, 2014). "[S]cience texts have a high degree of lexical density . . . marked by the number of content words embedded in clauses, by the total number of content words, or through the percentage of content words in relation to the total number of words" (Fang, 2004, in Shanahan & Shanahan, 2008, p. 52). These content words are technical terms, which must be deeply learned in order to learn the science behind them. Thus, teachers need to be sure they support students reading of science books with robust instruction in the vocabulary students will encounter in their science instruction.

Research-Based Best Practices for Vocabulary Building in Science

Research has found various instructional practices effective for boosting vocabulary development; there is no single best strategy, so a multi-pronged approach is recommended (Bintz, 2011; Blachowicz, et al., 2013).

In a discussion of the distinctions between vocabulary in literature and in content-area reading, Armbruster and Nagy (1992) point out the inherent connection of vocabulary terms with concepts. If students cannot demonstrate knowledge of a particular word, this may be an indication that they failed to grasp the meaning of an entire lesson. This is complicated by the fact that new vocabulary in a lesson is often interrelated, but these concepts are not associated with known words. If students do not understand the meaning of one word, they may not truly comprehend other new words presented during a lesson. Therefore, these researchers suggested that science students receive robust vocabulary instruction using several approaches, including semantic mapping that represents how concepts are interrelated.

Fisher and Blachowicz (2013) echo fellow researchers in urging science teachers to incorporate visual representations to enhance students' learning of new vocabulary: "students learn by doing" (p. 4); constructing graphs and charts and sorting words by their relationships and whether or not individual students knew individual words into semantic maps, word clouds, and other representations were both determined to be effective methods. Harmon and Hedrick (2005) also emphasize that graphic organizers are effective tools in teaching and learning vocabulary in the content areas.

Research reinforces a widely held understanding that students must repeatedly experience vocabulary in different contexts in order for learning to occur (Fisher & Blachowicz, 2013; Harmon & Hedrick, 2005).

Discussion is another strategy that can help students tie scientific vocabulary with their conceptual understandings of science. "Discussion and direct student involvement also appear to be important components in science vocabulary instruction" (Harmon & Hedrick, 2005, p. 273).

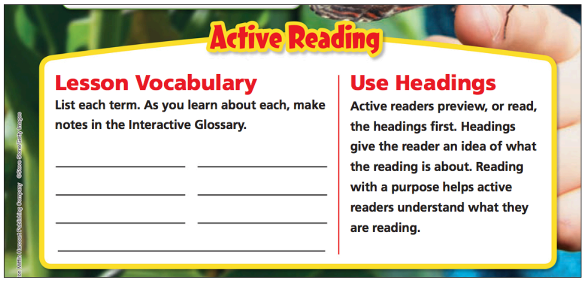
FROM RESEARCH TO PRACTICE

ScienceFusion was designed to introduce students to the vocabulary necessary to learn in science. Throughout the program, students are presented with vocabulary terms relevant to the science concepts and skills they are learning. The vocabulary is previewed before reading and reinforced during and after through teacher instruction and student practice and review.

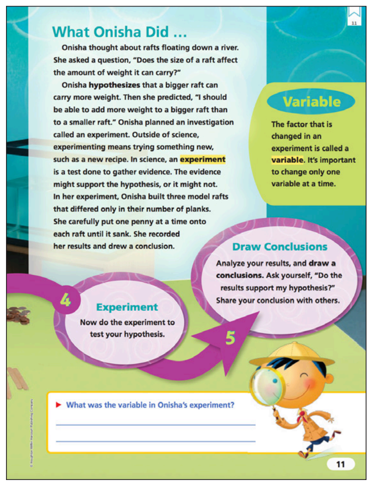
Vocabulary to Comprehend Science Topics in ScienceFusion

Throughout *ScienceFusion*, attention is paid to developing students' scientific vocabulary.

To align with the findings of research that shows that pre-reading activities which focus on vocabulary significantly improve comprehension, *ScienceFusion* begins each lesson with attention to vocabulary. Each lesson opens with **Lesson Vocabulary** (K–5) or **Vocabulary Terms** (6–8), in which students list the terms from the lesson and make notes in their **Interactive Glossaries**, review the terms, make sketches, or write definitions to help them learn these key words.



The words selected for focus are scientific, technical terms, which will help students develop a specialized vocabulary for learning in science. These words appear in bold highlights in the text and are clearly defined by the context around them so that students develop this understanding of science words while they actively read the text.



To reinforce the vocabulary after reading, in the K through 5 Student Editions, students complete **Brain Check Word Play** activities that appear after students read a section of text. In Grades 6 through 8, students review **Vocabulary** as part of the **Lesson Review**. At the end of each unit, vocabulary again is a focus in the **Unit Review**, in which students complete a **Vocabulary Review**.

The program's **Interactive Glossary**—which includes either visuals or video and audio—helps students make the new terms part of their own vocabularies.

FROM RESEARCH TO PRACTICE (CONTINUED)

ScienceFusion also includes **Vocabulary Cards** for students and teachers as well as **Extra Support for Vocabulary and Science Concepts** to reinforce learning and provide practice.

Name ________________________________

Extra Support for Vocabulary and Concepts

What Is Science?

Science Concepts

Read the Ideas more than once. Do your best to remember them.

1. An investigation is a procedure used to find answers to questions about nature.
2. An investigation may involve observing, comparing, and testing.
3. Scientists look for evidence, or information, as they investigate a question.
4. Scientists draw conclusions from the results of their investigations.
5. A conclusion must be supported by evidence; an opinion need not be supported by evidence.
6. An inference is an idea based on an observation.
7. A person's opinion should not affect how the person carries out an investigation.

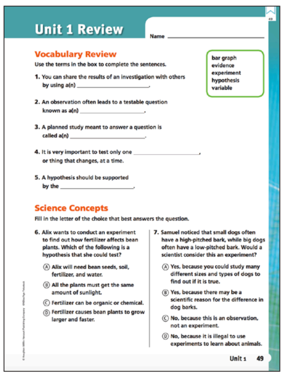
Developing skills with word analysis helps students acquire additional content-area vocabulary. Instruction on word parts is included to support students in learning new words—and more deeply understanding the content-area vocabulary in each lesson. The **Teacher Resources** include resources for **Building Science Vocabulary**, such as these examples from middle school Module A:

- **Context Clues: Restatement**
- **Context Clues: Examples**
- **Context Clues: Comparison or Contrast**
- **Analogies**
- **Prefixes**
- **Suffixes**
- **Word Roots**
- **Greek Word Roots**
- **Latin Word Roots**

Vocabulary to Connect Scientific Concepts and Terminology in *ScienceFusion*

As noted in the research section of this report, understanding concepts in science requires an understanding of vocabulary and vice versa. Vocabulary in ScienceFusion is not presented as a separate focus of study, but instead it is integrated into the comprehension and application activities throughout the program.

Throughout all levels of *ScienceFusion*, students engage in activities—and teachers are provided with additional suggestions—for **Previewing Vocabulary** and **Reinforcing Vocabulary**. Whether before, during, or after reading, vocabulary is always clearly connected with the relevant scientific concepts.



Unit 1 Review

Name ______________

Vocabulary Review

Use the terms in the box to complete the sentences.

bar graph
evidence
experiment
hypothesis
variable

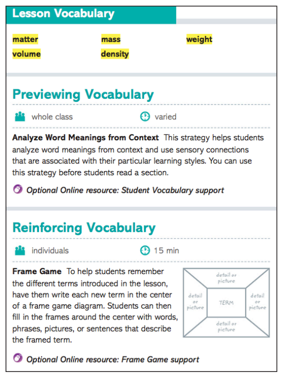
1. You can share the results of an investigation with others by using a(n) ______________.
2. An observation often leads to a testable question known as a(n) ______________.
3. A planned study meant to answer a question is called a(n) ______________.
4. It is very important to test only one ______________, or thing that changes, at a time.
5. A hypothesis should be supported by the ______________.

Science Concepts

Fill in the letter of the choice that best answers the question.

6. Alix wants to conduct an experiment to find out how fertilizer affects bean plants. Which of the following is a hypothesis that she could test?
   - Ⓐ Alix will need bean seeds, soil, fertilizer, and water.
   - Ⓑ All the plants must get the same amount of sunlight.
   - Ⓒ Fertilizer can be organic or chemical.
   - Ⓓ Fertilizer causes bean plants to grow larger and faster.
7. Samuel noticed that small dogs often have a high-pitched bark, while big dogs often have a low-pitched bark. Would a scientist consider this an experiment?
   - Ⓐ Yes, because you could study many different sizes and types of dogs to find out if it is true.
   - Ⓑ Yes, because there may be a scientific reason for the difference in dog barks.
   - Ⓒ No, because this is an observation, not an experiment.
   - Ⓓ No, because it is illegal to use experiments to learn about animals.

Unit 1 49



Lesson Vocabulary

matter mass weight
volume density

Previewing Vocabulary

whole class varied

Analyze Word Meanings from Context This strategy helps students analyze word meanings from context and use sensory connections that are associated with their particular learning styles. You can use this strategy before students read a section.

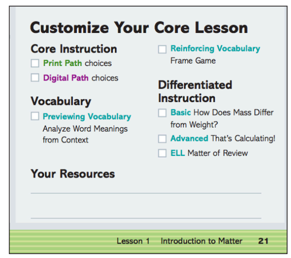
Optional Online resource: Student Vocabulary support

Reinforcing Vocabulary

individuals 15 min

Frame Game To help students remember the different terms introduced in the lesson, have them write each new term in the center of a frame game diagram. Students can then fill in the frames around the center with words, phrases, pictures, or sentences that describe the framed term.

Optional Online resource: Frame Game support



Customize Your Core Lesson

Core Instruction
- ☐ Print Path choices
- ☐ Digital Path choices

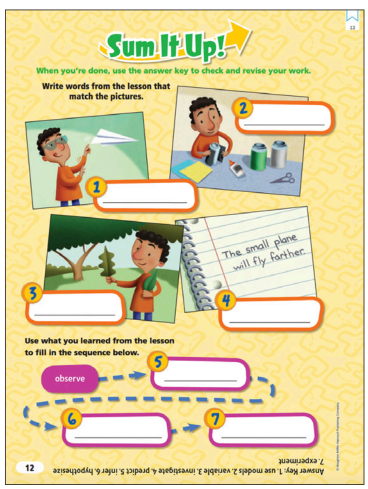
Vocabulary
- ☐ Previewing Vocabulary Analyze Word Meanings from Context
- ☐ Reinforcing Vocabulary Frame Game

Differentiated Instruction
- ☐ Basic How Does Mass Differ from Weight?
- ☐ Advanced That's Calculating!
- ☐ ELL Matter of Review

Your Resources

Lesson 1 Introduction to Matter 21

In Grades K through 5, the **Sum It Up!** activities that appear at the end of each lesson focus on students making connections between the scientific concepts studied and the terminology learned. These activities might involve such tasks as students matching terms or images with the related definitions, or correcting provided definitions to make them accurate, or completing a summary of the lesson with appropriate terms.



FROM RESEARCH TO PRACTICE *(CONTINUED)*

In Grades 6 through 8, the **Lesson Review** provides an opportunity for students to connect terms and concepts when responding to the **Vocabulary, Key Concepts,** and **Critical Thinking** prompts.

The words selected for focus in each lesson are essential to a deep understanding of the concepts; the program's focus is on using the terms as a guide to conceptual learning, rather than encouraging rote memorization of definitions. Students are presented with questions before, during, and after reading, which are designed to help them think more fully about the scientific terms and the concepts they describe and use the terms in applying their new understandings.

When students complete the hands-on inquiry activities in the **Lab Manual** (Grades 6–8) and in the **Inquiry Flipchart** (Grades K–5) they must understand the lesson's vocabulary in order to complete the activity—and in order to write about their processes and findings. In addition, the Teacher Edition for the program includes strategies for helping students build and develop science concepts and vocabulary in every lesson.

STRAND 5: SCAFFOLDING

To create a successful science classroom, teachers need to modify and adapt curriculum materials so as to design instruction that is appropriate for a particular group of students at a particular time. Making these kinds of modifications to achieve effective instruction requires knowledge of science, knowledge of how students learn science, and knowledge of how to plan effective instruction.

(National Research Council, 2007, p. 344)

DEFINING THE STRAND

A Framework for K–12 Science Education calls for rigorous standards for all students as well as accounting for diversity and equality in teaching all students (NRC, 2012). To successfully implement many of the newer sets of state standards, teachers must transform their classrooms from places where they communicate information about science to students into places where they work together with students, actively and collaboratively, to construct scientific explanations, argue from evidence and develop models to understand the natural world, while at every step engaging in the same practices as professional scientists and engineers (Krist & Reiser, 2014).

"Learners face many obstacles in learning science as practice, and they require support in order to engage in it productively" (NRC, 2007, p. 271). Teachers must meet the wide-ranging needs of all students within their classrooms. A typical classroom may include students who struggle with the rigorous science content, as well as reading, writing, and math skills. A typical classroom may also include advanced students ready for additional challenges, English language learners, and below-level students in need of support. To accommodate the needs of each of these students, "teachers need to understand how students think, what they are capable of doing, and what they could reasonably be expected to do under supportive instructional conditions, and how to make science more accessible and relevant to them" (NRC, 2007, p. 345).

Connecting instruction to students' interests and experiences as well as to the diverse backgrounds that students bring to a classroom is particularly important for broadening participation in science (NRC, 2012).

ScienceFusion was designed to provide students with ample guidance as they learn scientific concepts and skills. Lessons are presented within a graduated approach and models are included so teachers can demonstrate concepts and skills to students. Throughout the program, scaffolds help students solidify what they know in order to build on that foundation. Teachers have available to them a variety of print, digital, and inquiry instructional opportunities to customize instruction to meet each student's specific needs. *ScienceFusion* also provides suggestions for removing these types of scaffolds as students become more advanced in their learning and skills.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

Addressing Challenging Content

> Successful application of science and engineering practices (e.g., constructing explanations, engaging in argument from evidence) and understanding of how crosscutting concepts (e.g., patterns, structure, and function) play out across a range of disciplinary core ideas (e.g., structure and properties of matter, earth materials and systems) will demand increased cognitive expectations of all students. Making such connections has typically been expected only of "advanced", "gifted", or "honors" students. At the same time, the NGSS make it clear that these increased expectations apply to those students who have traditionally struggled to demonstrate mastery even in the previous generation of less cognitively demanding standards. (NGSS Lead States, 2013, Appendix D, p. 1)

To effectively build students' understanding in science, teachers need to start with what students know—what foundations they have, as well as what misconceptions and knowledge gaps exist. Engaging in science discourse and practice is commonly difficult for students, particularly at the K–8 level, because they lack experience in these activities; without explicit instruction and support in such ways of doing, knowing, and talking science, students may not find science relevant, and may even reject it outright (NRC, 2000; Krajcik, Blumenfeld, Marx, Bass, & Fredericks, 1998; Lee & Fradd, 1998; McNeill, Lizotte, Krajcik, & Marx, 2006).

The Importance of Scaffolding

At each level of scientific study, students are expected to build and expand on their understanding of science concepts and inquiry. Often learning a concept requires guidance in order to maintain and build on the knowledge that is acquired. When that concept is the foundation for another concept, it is necessary to ensure that the transition between concepts is carefully supported. According to Michaels, Shouse, and Schweingruber (2008) "research indicates that one of the best ways for students to learn the core concepts of science is to learn successively more sophisticated ways of thinking about these ideas. . ." (p. 63). Scaffolding is an effective educational technique that involves providing support to students as they learn, and gradually decreasing the amount of support provided until students are completing tasks independently. In scaffolding, students receive support as they reach competence and continue to develop on their own—building on what they have learned. Vygotsky defined scaffolding as the "role of teachers and others in supporting the learner's development and providing support structures to get to that next stage or level" (Raymond, 2000, p. 176).

Scaffolding of instruction optimizes students' long-term recall and later application of science material. As a result of these benefits, the National Research Council (2007) stated that scaffolding of instruction is vital to ". . .help students examine, scrutinize, and critically appraise their understanding of key scientific concepts" (p. 277).

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

Scaffolding has been found to have a positive effect on science achievement, leading to higher scores on assessments of scientific skills and understanding among students who received scaffolding when compared to students who did not receive instruction using a scaffolded approach (McNeill, et al., 2006). Further, Zydney (2010) found that when using technology-based learning environments, scaffolds lead to greater student learning than when such supports were not presented to students.

When scaffolding instruction, the types of scaffolds can vary but should consistently provide adequate support as needed. Scaffolds can be effective in many forms, including but not limited to, activating prior knowledge, modeling, questioning, or using cues or tools (Stone, 1998). In science, educators who seek to achieve improvement in their students' understanding of science concepts must employ scaffolding to take students from their point of understanding and support them in developing new conceptual understandings. In science, three broad types of conceptual change commonly occur in the classroom. Teachers may need to elaborate on preexisting concepts (such as deepening an understanding of anatomical features and how they relate to animal behaviors). They may need to restructure a network of concepts (such as restructuring students' understanding of "air as nothing" to understand air and matter). Or, educators may need to help students achieve new levels of explanation (such as in helping students understand atomic-molecular theory) (Michaels et al., 2008, p. 42–43).

Scaffolding to Deepen Scientific Understanding and Inquiry

The proper sequence of scaffolding experiences is necessary for students to build a true comprehension of new concepts and ideas (Kesidou & Roseman, 2002) and scaffolding of instruction has been found to have a positive effect on science achievement, leading to higher scores on assessments of scientific skills and understanding among students who received scaffolding when compared to students who did not receive instruction using a scaffolded approach (Mastropieri, Scruggs, Norland, Berkeley, McDuffie, Halloran Tornquist, & Connors, 2006; McNeill, Lizotte, Krajcik, & Marx, 2006). Further, Zydney (2010) found that when using technology-based learning environments, scaffolds lead to greater student learning than when such supports were not presented to students. Scaffolding has also been found to bolster learning that occurs during science inquiry. In a series of experiments, Scruggs and colleagues (1994, 1995) looked at the impact of highly structured inquiry methods and concluded that students who were coached to derive their own explanations and elaborate on their own reasoning recalled information more fully and consistently than did students who were in an explicitly taught, direct instruction group (Scruggs, Mastropieri, & Sullivan, 1994; Sullivan, Mastropieri, & Scruggs, 1995).

Scaffolding to Address Previously Held Ideas and Misconceptions

Unfortunately, students hold many misconceptions regarding science, and teachers need to know what misconceptions and knowledge gaps exist before allowing students to continue working independently (Armbruster & Nagy, 1992) because, if their initial understanding is not engaged, students may fail to grasp new concepts and information that are taught, or they may learn for the purpose of a test but revert to their preconceptions outside the classroom (NRC, 2000). Kesidou and Roseman (2002) found that "curriculum materials that alert teachers to their students' likely misconceptions, suggest strategies for identifying and dealing with them, and incorporate appropriate strategies to take account of students' ideas greatly enhance teachers' effectiveness in promoting student understanding . . ." (p. 532).

Thus, scaffolding of instruction is important during instruction and during remediation and relearning activities to counter students' misconceptions and ensure students have the proper foundation to move forward in their science education. Scaffolding of instruction optimizes students' long-term recall and later application of science material; as a result of these benefits, the National Research Council (2007) claims that scaffolding of instruction is vital.

Scaffolding to Build Confidence and Independence

Research has long documented the connection between a student's sense of confidence and self-efficacy for learning and his or her learning and achievement. Students who believe they can learn persist in learning, are engaged in learning, and subsequently learn more than peers who are less confident in their abilities. As a result, building students' confidence in learning is an important element of effective instruction. Scaffolding is one way to accomplish this goal. As Hyde (2006) states, "Scaffolding does not necessarily make the problem easier, and the teacher does not do the work for students or show them how to do it. It enables the person to do it" (p. 28).

This empowerment gives students confidence in their ability and allows them to take on increasingly more challenging material and assignments as they demonstrate success completing previous tasks. Scaffolding allows teachers to remain cognizant of students' progress and to offer the right amount of support to students so they can, ultimately, become independent learners. Larkin (2001) found from interviewing and observing teachers who scaffolded instruction that their students became more independent learners and concluded that "scaffolding principles and techniques can guide teachers to assist students in any grade level to become more independent learners" (p. 34). Scaffolding yields greater science achievement, leading to higher scores on assessments of scientific skills and understanding among students who received scaffolding than those who did not receive instruction using a scaffolded approach (McNeill, et al., 2006).

FROM RESEARCH TO PRACTICE

The *ScienceFusion* program was designed to provide students with ample guidance as they learn scientific concepts and skills. The opportunity for teachers to use the print path or digital path with the inquiry strand or to combine the paths into instruction customized for particular students and learning contexts means that instruction can be tailored to meet students' needs.

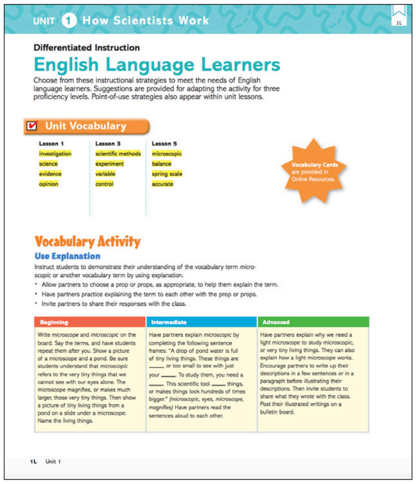
Scaffolding to Deepen Scientific Understanding and Inquiry in ScienceFusion

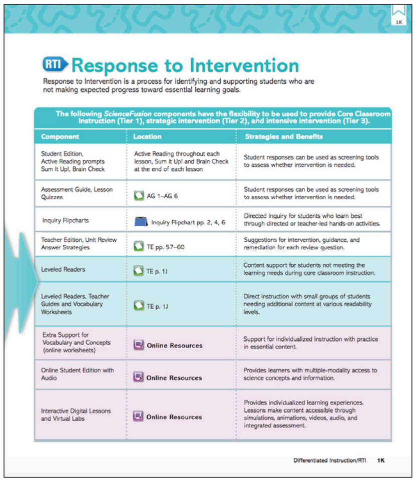
Throughout the ScienceFusion program, scaffolds exist to help students solidify what they know in order to build on it.

Scaffolds are in place to help students review and reflect on concepts before moving on. The unique write-in format of the Student Edition and the interactive nature of the technology components of the program provide a framework that teaches students to reflect on what they know and check comprehension before continuing. This scaffold allows for students to show what they know or reflect on what they have not quite mastered yet—and the responsibility for learning to shift to students.

In the program's Teacher Edition, suggestions are provided for teachers to assess students' prerequisite and prior knowledge, such as in the module's section on **Opening Your Lesson**, which provides guidance on important **Prerequisite Knowledge** for the lesson and suggested questions for **Accessing Prior Knowledge**.

The Teacher's Edition supports teachers in providing resources for their diverse needs of their students.



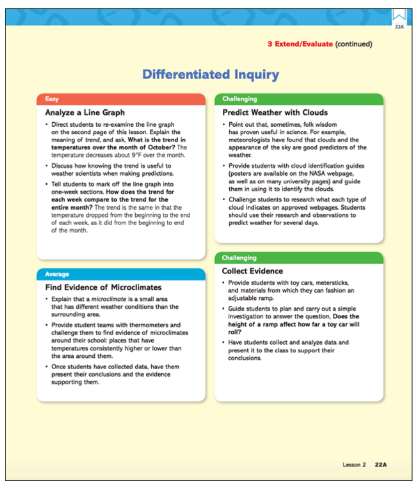


Structured inquiry is another strength of program. *ScienceFusion's* structured set of guiding questions for students to describe their processes for inquiry and their findings scaffolds students' learning of the scientific process.

To support teachers in effectively providing scaffolding in the classroom, inquiry levels are provided for every lab of ScienceFusion:

- Guided Inquiry develops inquiry skills within a supportive environment.
- Directed Inquiry introduces inquiry skills within a structured framework.
- Independent Inquiry deepens inquiry skills with student-driven questions and procedures.

In this way, students can move from a more guided and directed inquiry process to a more independent one as they build confidence and capacity in engaging in the scientific process. Indeed, the multiple and varied components of the program facilitate scaffolding for teachers by providing clear options with varying levels of support and student independence. As teachers plan instruction for units, **Options for Instruction** pages show print, labs, and digital options for each lesson. The **Differentiated Instruction** page provides resources for meeting the needs of all students. As teachers plan for lessons, the program suggests **Probing Questions**, which can serve as scaffolds to build students' inquiry skills. Suggestions for **Discussion** are provided to scaffold students' extended learning.



22A

3 Extend/Evaluate (continued)

Differentiated Inquiry

Easy

Analyze a Line Graph

- Direct students to re-examine the line graph on the second page of this lesson. Explain the meaning of *trend*, and ask, **What is the trend in temperatures over the month of October?** The temperature decreases about 9°F over the month.
- Discuss how knowing the trend is useful to weather scientists when making predictions.
- Tell students to mark off the line graph into one-week sections. **How does the trend for each week compare to the trend for the entire month?** The trend is the same in that the temperature dropped from the beginning to the end of each week, as it did from the beginning to end of the month.

Average

Find Evidence of Microclimates

- Explain that a *microclimate* is a small area that has different weather conditions than the surrounding area.
- Provide student teams with thermometers and challenge them to find evidence of microclimates around their school: places that have temperatures consistently higher or lower than the area around them.
- Once students have collected data, have them present their conclusions and the evidence supporting them.

Challenging

Predict Weather with Clouds

- Point out that, sometimes, folk wisdom has proven useful in science. For example, meteorologists have found that clouds and the appearance of the sky are good predictors of the weather.
- Provide students with cloud identification guides (posters are available on the NASA webpage, as well as on many university pages) and guide them in using it to identify the clouds.
- Challenge students to research what each type of cloud indicates on approved webpages. Students should use their research and observations to predict weather for several days.

Challenging

Collect Evidence

- Provide students with toy cars, metersticks, and materials from which they can fashion an adjustable ramp.
- Guide students to plan and carry out a simple investigation to answer the question, **Does the height of a ramp affect how far a toy car will roll?**
- Have students collect and analyze data and present it to the class to support their conclusions.

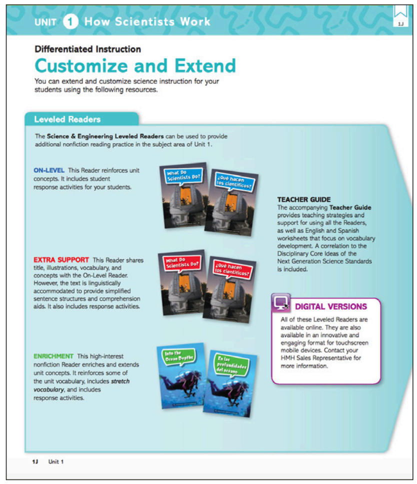
Lesson 2 **22A**

In addition, each Grade K–5 features a STEM unit that focuses on a scaffolded approach to building engineering and design skills. Then, students are given the opportunity to practice those skills in each subsequent unit. In the middle school grades, students' learning of the scientific process is scaffolded through the structured inquiry opportunities in the Lab Manual through:

- **Quick Labs**
- **Exploration Labs**
- **Field Labs**
- **S.T.E.M. Labs**

FROM RESEARCH TO PRACTICE *(CONTINUED)*

Science & Engineering Leveled Readers provide practice in nonfiction reading at each student's proficiency level – below level, on level, and above level.


UNIT 1 How Scientists Work

1J

Differentiated Instruction

Customize and Extend

You can extend and customize science instruction for your students using the following resources.

Leveled Readers

The **Science & Engineering Leveled Readers** can be used to provide additional nonfiction reading practice in the subject area of Unit 1.

ON-LEVEL This Reader reinforces unit concepts. It includes student response activities for your students.

EXTRA SUPPORT This Reader shares title, illustrations, vocabulary, and concepts with the On-Level Reader. However, the text is linguistically accommodated to provide simplified sentence structures and comprehension aids. It also includes response activities.

ENRICHMENT This high-interest nonfiction Reader enriches and extends unit concepts. It reinforces some of the unit vocabulary, includes ***stretch vocabulary***, and includes response activities.

TEACHER GUIDE

The accompanying **Teacher Guide** provides teaching strategies and support for using all the Readers, as well as English and Spanish worksheets that focus on vocabulary development. A correlation to the Disciplinary Core Ideas of the Next Generation Science Standards is included.

DIGITAL VERSIONS

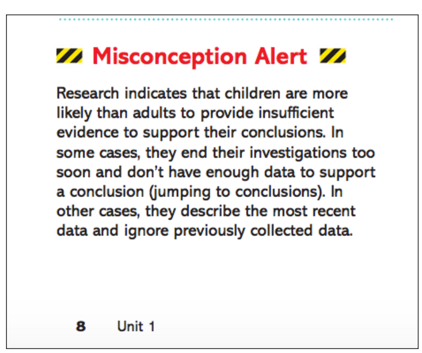
All of these Leveled Readers are available online. They are also available in an innovative and engaging format for touchscreen mobile devices. Contact your HMH Sales Representative for more information.

1J Unit 1

Scaffolding to Address Previously Held Ideas and Misconceptions in ScienceFusion

To effectively build students' understandings in science, teachers need to know what misconceptions and knowledge gaps exist. The program aligns with research that finds that curricular materials that identify possible misconceptions and suggest strategies to address these misconceptions enhance instructional effectiveness (Kesidou & Roseman, 2002).

To support teachers in providing scaffolded instruction to challenge students' previously held misconceptions, the program's Unit Planning Support for teachers includes built-in professional development for addressing possible misconceptions, as in the Content Refresher pages that include Common Misconceptions. At the lesson level, the program's Lesson Level Support includes guidelines for measuring students' Preconceptions and Assessing Prior Knowledge. Misconception Alerts and Learning Alerts address possible student misconceptions.


Misconception Alert

Research indicates that children are more likely than adults to provide insufficient evidence to support their conclusions. In some cases, they end their investigations too soon and don't have enough data to support a conclusion (jumping to conclusions). In other cases, they describe the most recent data and ignore previously collected data.

8 Unit 1

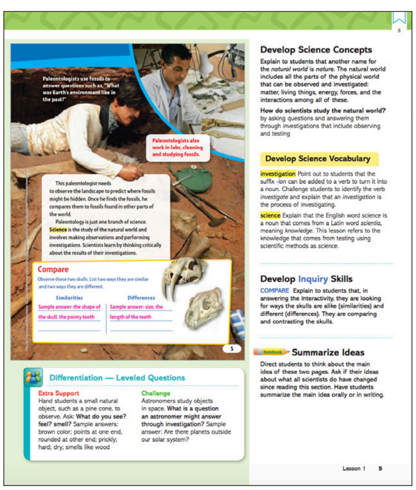
Research suggests that students who have misconceptions about science topics may seek to integrate new knowledge into their existing understandings without actively challenging their misconceptions. The program's regular opportunities to engage in inquiry-based learning (through such features as the **Inquiry Flipchart** and **Lab Manual** activities) mean that students are forced to confront any misconceptions—and revise their schema accordingly.

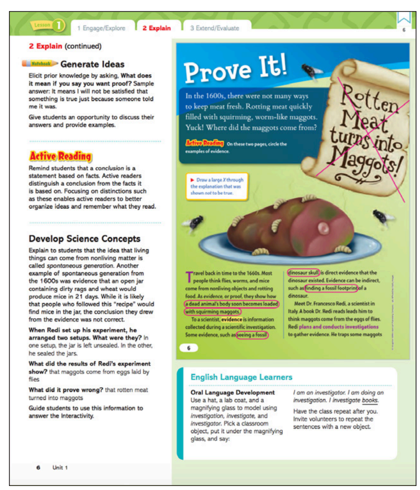
Scaffolding to Build Confidence and Independence in ScienceFusion

Research has long documented the connection between a student's sense of confidence and self-efficacy.

In ScienceFusion, scaffolded inquiry opportunities are provided regularly, giving students the opportunity to investigate topics relevant to the world around them. Offering students these kinds of meaningful contexts to apply their knowledge and engage in the work of scientists builds their confidence as they come to realize that they are not passive recipients of information, but are active investigators.

The program's activities consistently scaffold a progression of student learning—from opportunities for students to engage and explore new concepts, to explaining new concepts, to extending and evaluating new understandings. This kind of structured support for learning and predictable patterns for instruction builds students' confidence in their ability to succeed.

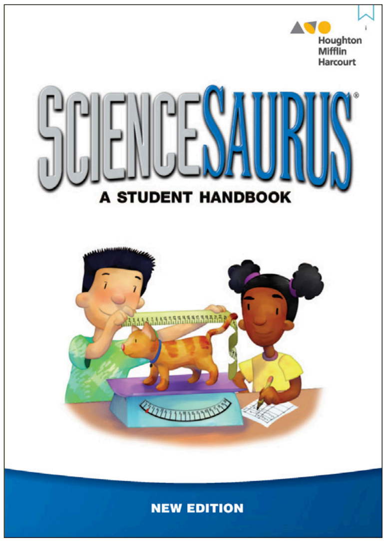




FROM RESEARCH TO PRACTICE *(CONTINUED)*

Experiencing academic success builds students' confidence in the classroom. *ScienceFusion's* **Multi-modal Learning** ensures that each student's individual learning style can be met. Every lesson is designed to be accessed in multiple ways—print, digital, or hands-on. The program also incorporates activities that involve visual, kinesthetic, and verbal modes of learning and responding.

Additional scaffolding to guide K–5 students through inquiry is provided via the program's *ScienceSaurus* reference manual resource.



STRAND 6: METACOGNITION

The instructional techniques that have been shown to be effective in producing conceptual understanding of new science content all have a strong metacognitive component.

(National Research Council, 2007, p. 112)

DEFINING THE STRAND

Understood broadly as thinking about thinking, metacognition has been defined more specifically as "the ability to monitor one's current level of understanding and decide when it is not adequate" (NRC, 2000, p. 47). The National Research Council's 2000 publication *How People Learn* stressed the importance of fostering metacognition to allow students to take control of their own learning and monitor their own progress. Studies have determined that there is a significant correlation between metacognition and academic achievement and that training in the use of metacognitive skills increases achievement; researchers have also discovered relationships between metacognition and study habits and attitudes (Ozsoy, Memis, & Temur, 2009).

Scientific knowledge develops and changes over time; therefore, students of science must understand that knowledge can be revised based on new evidence and that reflection is an essential aspect of scientific thinking. The ability to reflect on, or be metacognitive about, learning is essential for success in science (Michaels, et al., 2008). Further, when a metacognitive component is added to the learning process, providing opportunities for students and teachers to talk through and about their scientific thinking idea formation and status of their conceptions, students show a greater permanent restructuring of their understandings of content (Blank, 2000).

The instruction Donovan and Bransford call for in *How Students Learn: Science in the Classroom* (NRC, 2005) helps students monitor and assume control of their own learning—

in other words, be metacognitive in their approach toward science.

Carefully crafted and profound essential questions are vital for both inquiry and metacognition (Bennett, 2015; Lazar, 2011). Indeed, a critical inquiry approach calls for a question-based approach to teaching that fosters engaged learning, rich understandings of the self and others, and an empowered sense of citizenship (Beach, Thein, Webb, 2016).

ScienceFusion provides students with numerous opportunities to think about their thinking while learning new scientific concepts and engaging in scientific inquiry. Students are asked to respond to prompts that engage in planning, monitoring, and reflecting. Students' progress is evaluated via periodic assessments, which additionally provide students insight into their own learning. Such reflection can be performed using a variety of written and visual formats. The diverse metacognitive exercises in *ScienceFusion* allow students a better perspective of their strengths and weaknesses, yielding greater learning and critical thinking.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

The National Research Council's *How People Learn* (2000) cited the importance of educators fostering metacognition to allow students to take control of their own learning and monitor their own progress. Studies show that the use of metacognitive strategies increases learning (Ozsoy, Memis, & Temur, 2009) and that supporting thinking strategies is useful (Scruggs & Tolfa, 1985).

Some basic metacognitive strategies include connecting new information to that previously learned; selecting thinking strategies purposefully; and planning, monitoring, and evaluating thinking processes (Dirkes, 1988). Conscious regulation and control of cognitive activity are also recognized as major components of metacognition (Harris, Graham, Brindle, & Sandmel, 2009).

Helping students become more metacognitive about their own thinking and learning is closely tied to teaching practices that emphasize self-assessment, and providing support for self-assessment is an important component of effective teaching (NRC, 2005).

Metacognition to Develop Scientific Reasoning and Produce Conceptual Change

Science is a process of asking questions and testing hypotheses through experimentation and study. This empirical process can be difficult for students. According the National Research Council (2005), the results of previous research investigating metacognition apply not only to students' understanding of science text, but also to their appropriate use of the scientific method.

Reflection is an essential part of scientific thinking. Because scientific knowledge develops and changes over time, students of science must understand that knowledge can be revised based on new evidence. The ability to reflect on, or be metacognitive about, their learning is essential for students to become proficient in science. "When students understand the nature and development of scientific knowledge, they know that science entails searching for core explanations and the connections between them" (Michaels, et al., 2008, p. 20). This can include giving students opportunities to test their ideas by building things and seeing whether they work and performing experiments that seek to falsify hypotheses (NRC, 2005, p 12). It is therefore important to focus students' attention on how tasks are accomplished. Emphasizing content and process goals will help students connect processes and outcomes, learning, and achievement.

By teaching students both how to conduct scientific research and guiding them to reflect on this process, teachers support students in learning how to perform research while also building other critical thinking and analytic skills. "Adding a reflective component to learning not only speeds up the time it takes to learn, but also makes it possible to learn things that one might never figure out through trial and error . . ." (NRC, 2007, pp. 4–14). Thus, when students engage in metacognitive activities, they make new connections that may not have been possible if the teachers used other instructional approaches. For example, when in the course of science instruction, teachers and students were provided with opportunities to talk through and about their idea formation and the status of their conceptions—when the addition of this

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

metacognitive component is included—students showed a greater permanent restructuring of their understandings of content (Blank, 2000).

"[I]nstructional techniques that have been shown to be effective in producing conceptual understanding of new science content all have a strong metacognitive component" (NRC, 2007, 4-14). This benefit leads to improved student performance and is why researchers have found that instruction that includes a specific metacognitive component is more effective than instruction that does not include such a component (Pogrow, 1999; White, & Frederiksen, 1998). In fact, Georghiades (2006) suggested that metacognition is associated with a more durable, long-term understanding of scientific concepts because such strategies increase students' awareness of what they know, making them better prepared to apply this knowledge in future readings and new contexts and assignments.

Question-Based Learning Enhances Metacognition and Inquiry

The process of inquiry-based and metacognitive learning begins with carefully crafted and profound questions (Bennett, 2015; Lazar, 2011). Indeed, a critical inquiry approach calls for a question-based approach to teaching that fosters engaged learning, rich understandings of the self and others, and an empowered sense of citizenship (Beach, et al., 2016). According to McTighe and Wiggins (2013), a good essential question is open-ended, without a single, final, and correct answer; is thought provoking and intellectually engaging, often sparking discussion and debate; and requires higher-order thinking, such as analysis, inference, evaluation, prediction. Also, it cannot be effectively answered by recall alone; points toward important, transferable ideas within (and sometimes across) disciplines; raises additional questions and sparks further inquiry; requires support and justification, not just an answer; and recurs over time—that is, the question can and should be revisited again and again—in a revisionist, reflective process that similar to the scientific process itself.

FROM RESEARCH TO PRACTICE

ScienceFusion provides students with numerous opportunities to think about their thinking and learning while acquiring new scientific concepts and engaging in scientific inquiry.

Developing Metacognition in *ScienceFusion*

The overarching structure of *ScienceFusion* is built around a model that facilitates students in building their own understandings of new ideas. The program follows the **5E Instructional Model**. The 5E Instructional Model is a well-researched and widely used approach backed by a significant research base attesting to its effectiveness (Bybee, 2015; Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook, & Landes, 2006). The model itself grew out of established principles in the field of education as well as proven use of the constructivist learning cycle approach. In the 5E model, students follow a sequence of learning:

- **Engage:** Students make connections between past and present learning experiences and engage in activities and encounter prompts designed to pique their interest in the topic and measure their understanding.
- **Explore:** Students actively learn through inquiry-based experiences and build their own understanding through direct involvement with the topic.
- **Explain:** Students communicate what they have learned so far and figure out what it means.
- **Extend:** Students apply new concepts they have learned in a different context.
- **Evaluate:** Students and teachers assess the students' level of learning.

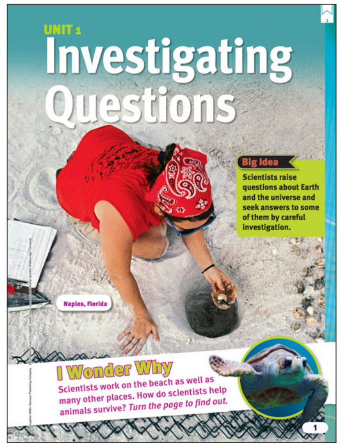
Within each grade level, *ScienceFusion* follows a clear structure that gives students a framework in which they can think about their own thinking and learning in science.

Each unit of the program is organized by a **Big Idea**, a broad, powerful concept that connects scientific facts and events.

For example, in Grade 3, some of these **Big Ideas** include:

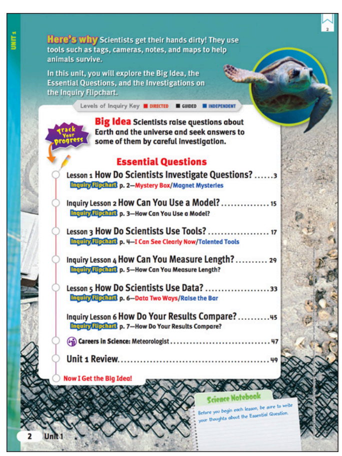
- Investigating Questions—**Big Idea**: *Scientists raise questions about Earth and the universe and seek answers to some of them by careful investigation.* (Unit 1)
- The Engineering Process—**Big Idea**: *Technology is all around us. The design process is used to develop new types of technology to meet people's needs.* (Unit 2)
- Plants and Animals—**Big Idea**: *All living things go through a cycle of growth. Living things have adaptations that help them survive in their environments.* (Unit 3)
- Ecosystems and Interactions—**Big Idea**: *All the living, once-living, and nonliving things interact in an ecosystem. All living things need energy to survive and grow.* (Unit 4)
- Changes to Earth's Surface—**Big Idea**: *Processes on Earth can change Earth's landforms. Some of these changes happen slowly, while others happen quickly.* (Unit 5)

FROM RESEARCH TO PRACTICE *(CONTINUED)*



Within these **Big Ideas**, each segment is organized around **Essential Questions**. Each **Essential Question** identifies the conceptual focus of the lesson—and gives students a sense of direction and purpose for their learning. For example, in Grade 3, Unit 1, the **Big Idea** ("Scientists raise questions about Earth and the universe and seek answers to some of them by careful investigation.") is followed by six **Essential Questions**:

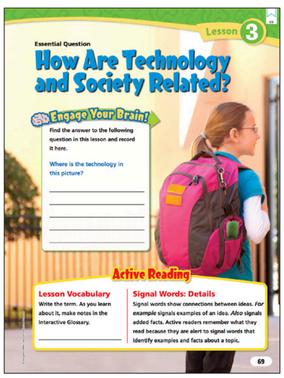
- How Do Scientists Investigate Questions? (Lesson 1)
- How Can You Use a Model? (Lesson 2)
- How Do Scientists Use Tools? (Lesson 3)
- How Can You Measure Length? (Lesson 4)
- How Do Scientists Use Data? (Lesson 5)
- How Do Your Results Compare? (Lesson 6)



These **Big Ideas** and **Essential Questions** ensure that students have a clear framework for their learning and that their learning is purposeful.

Within these overarching organizing structures, throughout the program students are directed to respond to prompts that ask them to engage in monitoring and reflection on their own learning and understanding.

The program's **Active Reading** prompts and think-along activities encourage students to think about their comprehension and check on their understanding of key ideas all along their progression through individual lessons. By asking for these kinds of on-going checks, students take the responsibility for their own learning.


Lesson 3

Essential Question

How Are Technology and Society Related?

Engage Your Brain!

Find the answer to the following question in this lesson and record it here.

Where is the technology in this picture?

Active Reading

Lesson Vocabulary

Write the term. As you learn about it, make notes in the Interactive Glossary.

Signal Words: Details

Signal words show connections between ideas. *For example* signals examples of an idea. *Also* signals added facts. Active readers remember what they read because they are alert to signal words that identify examples and facts about a topic.

69


Technology

What is technology? Look at this train station. Nearly everything you see is an example of technology.

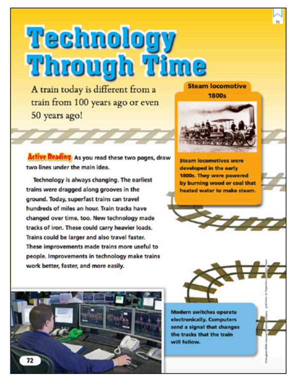
Active Reading As you read these two pages, circle two clue words or phrases that signal a detail such as an example or an added fact.

Technology is anything that people make or do that changes the natural world. Technology meets people's wants or needs. Technology is not just computers and cell phones. Think about the things in a train station. They all have a purpose. The technology in a train station helps people travel easily. Can you imagine how different the world would be without technology?

Suitcase

A suitcase contains a traveler's needs. For example, it can carry clothing, shoes, pajamas, a hairbrush, a toothbrush, and toothpaste. All of these items are examples of technology.

70


Technology Through Time

A train today is different from a train from 100 years ago or even 50 years ago!

Steam locomotive 1800s

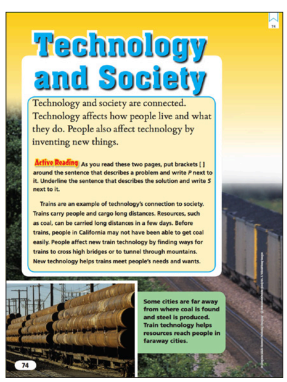
Steam locomotives were developed in the early 1800s. They were powered by burning wood or coal that heated water to make steam.

Active Reading As you read these two pages, draw two lines under the main idea.

Technology is always changing. The earliest trains were dragged along grooves in the ground. Today, superfast trains can travel hundreds of miles an hour. Train tracks have changed over time, too. New technology made tracks of iron. These could carry heavier loads. Trains could be larger and also travel faster. These improvements made trains more useful to people. Improvements in technology make trains work better, faster, and more easily.

Modern switches operate electronically. Computers send a signal that changes the tracks that the train will follow.

72


Technology and Society

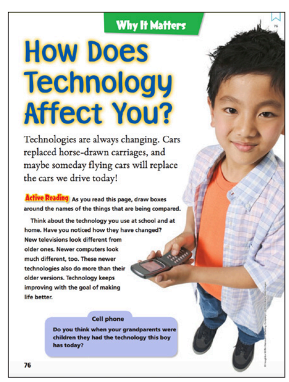
Technology and society are connected. Technology affects how people live and what they do. People also affect technology by inventing new things.

Active Reading As you read these two pages, put brackets [ ] around the sentence that describes a problem and write *P* next to it. Underline the sentence that describes the solution and write *S* next to it.

Trains are an example of technology's connection to society. Trains carry people and cargo long distances. Resources, such as coal, can be carried long distances in a few days. Before trains, people in California may not have been able to get coal easily. People affect new train technology by finding ways for trains to cross high bridges or to tunnel through mountains. New technology helps trains meet people's needs and wants.

Some cities are far away from where coal is found and steel is produced. Train technology helps resources reach people in faraway cities.

74


Why It Matters

How Does Technology Affect You?

Technologies are always changing. Cars replaced horse-drawn carriages, and maybe someday flying cars will replace the cars we drive today!

Active Reading As you read this page, draw boxes around the names of the things that are being compared.

Think about the technology you use at school and at home. Have you noticed how they have changed? New televisions look different from older ones. Newer computers look much different, too. These newer technologies also do more than their older versions. Technology keeps improving with the goal of making life better.

Cell phone

Do you think when your grandparents were children they had the technology this boy has today?

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And, finally, regular and ongoing opportunities for assessment—in the form of the program's **Lesson Quizzes, Unit Tests, Performance Assessments, Cumulative (or End-of-Module) Tests, Alternative Assessments,** and **Student Self-Assessments**—encourage students to monitor their own progress and maintain an awareness of their own understandings.

STRAND 7:
ENGAGING IN INQUIRY

". . .[T]here is a growing body of evidence that indicates a strong relationship between inquiry-based science instruction and improved achievement not only in science, but also in reading, language arts, and mathematics."

(Klentschy & Molina-De La Torre, 2004, p. 352)

DEFINING THE STRAND

Behind reform efforts such as those that drove *A Framework for K–12 Science Education* and newer state standards is an essential belief that science proficiency involves more than an understanding of key concepts—rather, science is learned through doing (Krajcik, McNeill, & Reiser, 2008; NRC, 2007). "[O]ur expectation is that students will themselves engage in the [range of cognitive, social, and physical] practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices themselves" (NRC, 2012, p. 30).

A Framework for K–12 Science Education (NRC, 2012) calls for engaging students directly in scientific practices—the kinds of activities that actual scientists and engineers do—in ways that integrate both inquiry and design. It is recommended that these activities be viewed within three spheres:

- Investigation: ask questions, observe, experiment, measure, collect data, test solutions;
- Construction of explanations/solutions: reason, imagine, calculate, predict, develop theories, and models; and
- Evaluation: argue, critique, and analyze.

Science instruction characterized by these hands-on activities and engaging in the activities for the purpose of having students explore and explain real-world, meaningful phenomena and problems is the approach that best aligns with three-dimensional learning (Krajcik, 2015b).

An activity-driven approach to science instruction benefits students in myriad ways, within science and beyond. When students are actively engaged in the process of observing, reasoning, and making connections through experimentation and hands-on study, they acquire necessary skills and ways of thinking (Stewart, Cartier, & Passmore, 2005). The process of inquiry-based learning begins with **carefully crafted and profound questions** (Bennett, 2015; Lazar, 2011). Indeed, **a critical inquiry approach calls for question-based approach to teaching that fosters engaged learning, rich understandings of the self and others, and an empowered sense of citizenship** (Beach, et al., 2016).

ScienceFusion features ongoing opportunities for students to observe and engage in scientific inquiry. Investigation and inquiry activities using both traditional, hands-on experiences and cutting-edge, digital virtual labs are included throughout. The program provides specific suggestions for instruction that will scaffold and support student learning. Asking probing questions to get students to consider alternative explanations for their findings or to predict what might happen if they were to modify certain aspects of their experimental conditions helps students reflect on their thinking and build strong inquiry skills.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

In science, students learn by doing. "For students to develop the abilities that characterize science as inquiry, they must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations" (NRC, 1996, p. 173). *A Framework for K–12 Science Education* builds on this foundation. The National Science Education Standards (NRC, 1996), the National Research Council (NRC, 1996, 2005, 2007), and the National Science Foundation (NSF, 2000) all concur that science educators must support students' natural, interactive inquiries and engage them in meaningful, authentic investigative processes. "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge" (NRC, 2012, p. 27).

The first guiding principle cited in the *Framework* is that "children are born investigators" (NRC, 2012, p. 24). However, the report *Taking Science to School: Learning and Teaching Science in Grades K–8* (NRC, 2007) revealed intriguing research findings regarding the relationship young children have to science and engineering. Many preschoolers, as a result of their direct experiences with the physical environment, have sophisticated ways of thinking about the world and of understanding and influencing that world around them. Though they may lack deep knowledge and extensive experience, children of all backgrounds and socio-economic levels have a much greater capacity to reason in complex and subtle ways than had previously been assumed. The report as well as findings from other researchers suggests that as early as kindergarten, students are able to engage in meaningful, authentic scientific and engineering practices—and educators would serve their development best by building on students' existing knowledge and refining prior conceptions (National Science Teachers Association, 2014; NRC, 2007 & 2012).

In 2007's *Taking Science to School: Learning and Teaching Science in Grades K–8*, the NRC also argues that students who are proficient in science are those who are able to:

1. Know, use, and interpret scientific explanations of the natural world;
2. Generate and evaluate scientific evidence and explanations;
3. Understand the nature and development of scientific knowledge; and
4. Participate productively in scientific practices and discourses.

Duschl, Scheweingruber, and Shouse urge students' active participation in productive scientific practices and discourse (NRC, 2007). Michaels, Shouse, and Schweingruber (2008) contend that, for students to truly understand science, they must engage in the same activities that real scientists perform on a daily basis: ". . . there is compelling evidence that when classrooms function to support real scientific practice, students' understandings of science can flourish" (p. 127).

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

Inquiry-Based Learning to Improve Understanding

Helping students engage in authentic investigative practices, particularly in collaborative formats that entail seeking evidence and reasons for the ideas or knowledge claims they draw, allows students to develop deeper understandings of content (Krajcik & Blumenfeld, 2006) and fosters a view of science away from a static set of facts toward recognizing science as a constructive, social process (McNeill & Krajcik, 2008). Among the eight science and engineering practices outlined within the *Next Generation Science Standards* (NGSS Lead States, 2013) is Practice 3: Planning and Carrying Out Investigations. This practice draws directly from *A Framework for K–12 Science Education:*

> Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions. (NRC, 2012, p. 61)

Inquiry-based instruction is vital to understanding science and engineering because such teaching emphasizes the "process" of these disciplines. Researchers have found that students acquire the skills necessary to investigate when they are actively engaged in observing, reasoning, and making connections through experimentation and hands-on study (Stewart et al., 2005). Michaels and colleagues (2008) contend that for students to truly understand science and engineering they must engage in the same activities that real scientists and engineers perform on a daily basis. Drawing on the work of his own and other researchers and collaborators, Krajcik has long advocated for situating science learning within in-depth, hands-on, activity-driven investigations of meaningful, real-world problems that seek answers to driving questions and entail skills essential to science—chiefly observation, explanation, modeling, argumentation, and engineering design (Krajcik & Blumenfeld, 2006; Krajcik, et al., 2008).

Other researchers also have found that inquiry-based instruction leads to greater science achievement and improved academic outcomes. Inquiry learning has been found to support greater understanding of science vocabulary (Carlisle, Fleming, & Gudbrandsen, 2000), understanding and application of new science concepts, laws, and models to new situations (White & Frederiksen, 1998), and improved metacognitive thinking (Kipnis & Hofstein, 2008). When students learn new concepts through inquiry instruction, they are more likely to remember this information in the long-term. For instance, Bay, Staver, Tanis, and Hale (1992) demonstrated that, while students in an inquiry group and direct instruction group performed equally well on a posttest administered immediately after intervention, students who completed the inquiry task demonstrated better performance on a measure administered two weeks later, suggesting that active learning can lead to more durable, longer-term knowledge of science. Further, analysis of standardized test scores reveals that students who reported experiencing more hands-on inquiry lessons during their science instruction perform significantly better on measures of end-of-year science achievement than students not exposed to these inquiry activities (Stohr-Hunt, 1996).

The process of inquiry-based learning begins with carefully crafted and profound questions (Bennett, 2015; Lazar, 2011). Indeed, a critical inquiry approach calls for a question-based approach to teaching that fosters engaged learning, rich understandings of the self and others, and an empowered sense of citizenship (Beach, et al., 2016).

Inquiry-Based Learning to Meet the Needs of All Students

Inquiry-based learning empowers students. As Kuhn, Black, Keselman, and Kaplan (2000) argue, students who engage in inquiry will "come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own" (p. 496). This type of empowerment is important for helping all students achieve. Inquiry-based learning in many forms has been shown to increase the achievement of all students. In a study of NAEP results, Braun and colleagues (2009) found that modeling and science demonstrations by teachers led to increased achievement: for the instructional strategy of teachers doing a science demonstration across all racial/ethnic and school disadvantage groups, scores were lowest in the "never or hardly ever" category and highest in the category of "one or two times a week"; for all levels of school disadvantage, African American students were less likely to be exposed to the optimal use of this strategy.

Thus, schools may make progress in closing the achievement gap by focusing on this type of strategy (Braun, et al., 2009, p. 4). Beneficial effects of inquiry lessons are an important tool in closing achievement gaps in science, and, therefore, inquiry-based learning should be introduced early in children's science education (White & Frederiksen, 1998).

FROM RESEARCH TO PRACTICE

ScienceFusion provides students with numerous opportunities to observe and engage in scientific inquiry. In ScienceFusion, students engage in the practices of scientists and engineers; they learn by doing. The program's **eLearning Curriculum, Write-In Student Edition,** and **Leveled Labs** (via the **Inquiry Flipcharts** and the **Lab Manual**) work together to provide students with continuous, meaningful interactions with science.

Inquiry-Based Learning to Improve Understanding in ScienceFusion

The *ScienceFusion* program provides numerous print and digital resources designed to engage students in inquiry-based learning. Throughout the program—in the print path, hands-on inquiry activities, and the digital path—students are engaged in numerous opportunities for scientific inquiry.

FROM RESEARCH TO PRACTICE *(CONTINUED)*

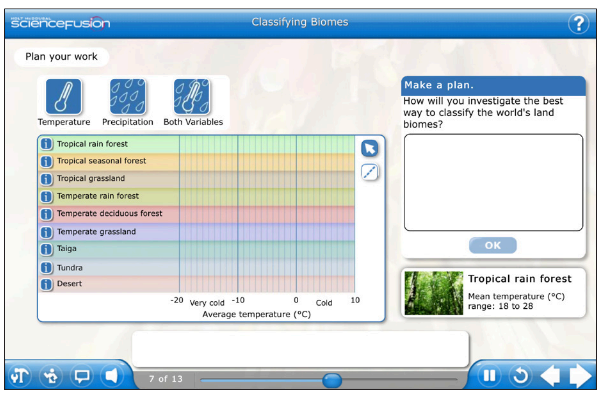
Overview of Inquiry-Based Learning Resources in *ScienceFusion*	
K-5: PRINT PATH	**6-8: PRINT PATH**
• S.T.E.M. Activities • Inquiry Flipcharts/Lesson Inquiry	• S.T.E.M. Activities • Lab Manual - Quick Labs - Exploration Labs - Field Labs - S.T.E.M. Labs
K-5: DIGITAL PATH	**6-8: DIGITAL PATH**
• Virtual Labs • Video-Based Projects • Inquiry Support (Grades 1-5, Teacher Resources)	• Virtual Labs • Video-Based Projects

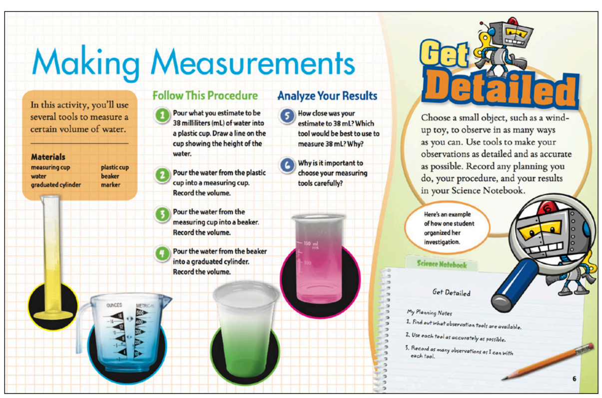
Labs and Activities. The print-based path of the program provides students with inquiry lessons, embedded with prompts that encourage students to engage in the scientific process, setting a purpose for their investigations, planning their procedures, recording their data, drawing conclusions, and generating further questions.

The *ScienceFusion* **Lab Program** facilitates students' construction of understanding through inquiry and application. Three distinct levels of inquiry—directed (or structured) inquiry, guided inquiry, and independent (or open) inquiry—offer varying amounts of guidance to help teachers scaffold and differentiate student inquiry according to learners' needs.

- **Lab Manual.** In Grades 6 through 8, each ScienceFusion module comes with its own lab manual. Each unit includes multiple **Quick Labs** in every lesson and four additional labs that require one or more class periods to complete—**Exploration, Field**, and **STEM** labs.
- **Inquiry Flipcharts.** For Grades K–5, these provide students with additional opportunities to explore scientific and engineering concepts further and to continue to engage in the thinking and practices of scientists. The **Inquiry Flipcharts** deliver three levels of hands-on inquiry—directed, guided, and independent.
- **Digital Virtual Labs.** Taking advantage of the benefits of instruction via computer, the program provides online virtual lab experiences for students.
- **Video-Based Projects.** Inquiry-based projects are available online, along with teacher and student resources to support them. Each project consists of a video, teacher support pages, and student activity worksheets.

ScienceFusion's holistic approach to inquiry-based learning connects what students learn in a hands-on setting to the content and skills learned in the write-in textbook and the digital lessons. As they engage in inquiry activities throughout the program, students are faced with probing questions to consider alternative explanations for their findings or to predict what might happen if they were to modify certain aspects of their experimental conditions.

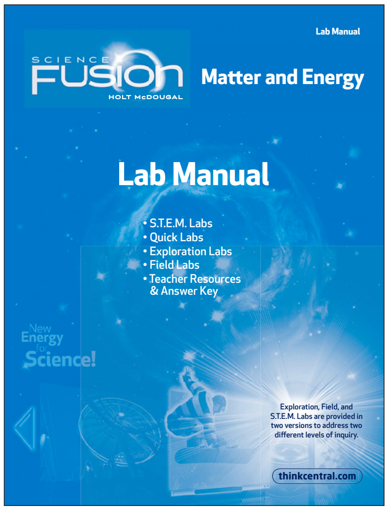


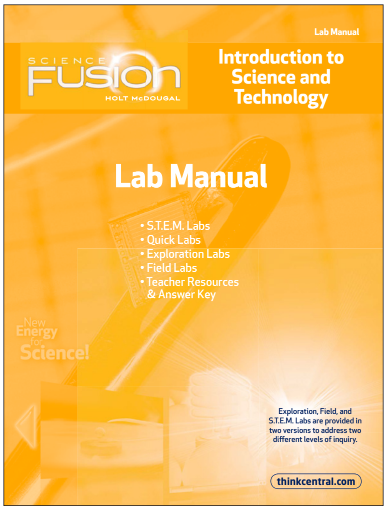


FROM RESEARCH TO PRACTICE *(CONTINUED)*

Inquiry-Based Learning to Meet the Needs of All Students in *ScienceFusion*

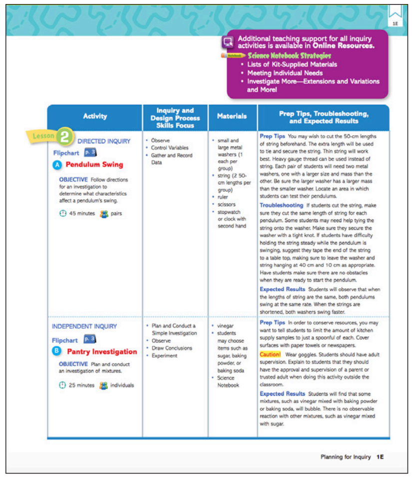
ScienceFusion supports all learners through its inquiry-based learning activities. The unique design of the program—with two parallel paths, the **Print Path** and the **Digital Path**, with the **Inquiry** strand woven closely into each—allows for teachers to customize their combination of print, digital, and inquiry to best meet their students' needs. Throughout all paths of *ScienceFusion*, students learn by doing. Every page, every lab, and every activity provides an opportunity for students to ask questions, think critically, and make informed decisions. Throughout, students must inquire, think, predict, analyze, and apply.





In addition, the flipcharts are designed so that they can be placed on a table so that students can work as lab partners or in collaborative groups, supporting varied grouping arrangements that can help meet the needs of all students.

All along the way, the *ScienceFusion* Teacher Edition provides guidance in how to most effectively integrate inquiry into students' learning of science and engineering via program content and features and instructional support.



1E

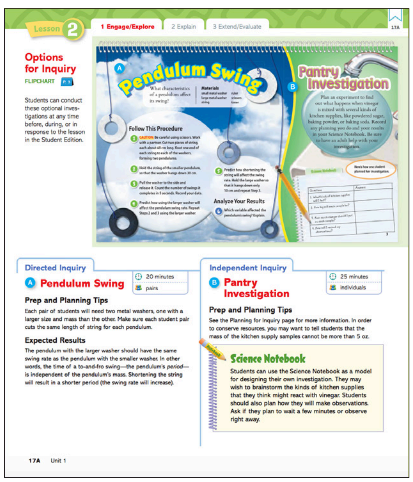
Additional teaching support for all inquiry activities is available in **Online Resources.**

Science Notebook Strategies

- Lists of Kit-Supplied Materials
- Meeting Individual Needs
- Investigate More—Extensions and Variations and More!

Activity	Inquiry and Design Process Skills Focus	Materials	Prep Tips, Troubleshooting, and Expected Results
Lesson 2 DIRECTED INQUIRY Flipchart p. 3 **A Pendulum Swing** OBJECTIVE Follow directions for an investigation to determine what characteristics affect a pendulum's swing. 45 minutes pairs	• Observe • Control Variables • Gather and Record Data	• small and large metal washers (1 each per group) • string (2 50-cm lengths per group) • ruler • scissors • stopwatch or clock with second hand	**Prep Tips** You may wish to cut the 50-cm lengths of string beforehand. The extra length will be used to tie and secure the string. Thin string will work best. Heavy gauge thread can be used instead of string. Each pair of students will need two metal washers, one with a larger size and mass than the other. Be sure the larger washer has a larger mass than the smaller washer. Locate an area in which students can test their pendulums. **Troubleshooting** If students cut the string, make sure they cut the same length of string for each pendulum. Some students may need help tying the string onto the washer. Make sure they secure the washer with a tight knot. If students have difficulty holding the string steady while the pendulum is swinging, suggest they tape the end of the string to a table top, making sure to leave the washer and string hanging at 40 cm and 10 cm as appropriate. Have students make sure there are no obstacles when they are ready to start the pendulum. **Expected Results** Students will observe that when the lengths of string are the same, both pendulums swing at the same rate. When the strings are shortened, both washers swing faster.
INDEPENDENT INQUIRY Flipchart p. 3 **B Pantry Investigation** OBJECTIVE Plan and conduct an investigation of mixtures. 25 minutes individuals	• Plan and Conduct a Simple Investigation • Observe • Draw Conclusions • Experiment	• vinegar • students may choose items such as sugar, baking powder, or baking soda • Science Notebook	**Prep Tips** In order to conserve resources, you may want to tell students to limit the amount of kitchen supply samples to just a spoonful of each. Cover surfaces with paper towels or newspapers. **Caution!** Wear goggles. Students should have adult supervision. Explain to students that they should have the approval and supervision of a parent or trusted adult when doing this activity outside the classroom. **Expected Results** Students will find that some mixtures, such as vinegar mixed with baking powder or baking soda, will bubble. There is no observable reaction with other mixtures, such as vinegar mixed with sugar.

Planning for Inquiry 1E



Lesson 2 | 1 Engage/Explore | 2 Explain | 3 Extend/Evaluate | 17A

Options for Inquiry

FLIPCHART p. 3

Students can conduct these optional investigations at any time before, during, or in response to the lesson in the Student Edition.

Directed Inquiry

A Pendulum Swing

20 minutes · pairs

Prep and Planning Tips

Each pair of students will need two metal washers, one with a larger size and mass than the other. Make sure each student pair cuts the same length of string for each pendulum.

Expected Results

The pendulum with the larger washer should have the same swing rate as the pendulum with the smaller washer. In other words, the time of a to-and-fro swing—the pendulum's *period*—is independent of the pendulum's mass. Shortening the string will result in a shorter period (the swing rate will increase).

Independent Inquiry

B Pantry Investigation

25 minutes · individuals

Prep and Planning Tips

See the Planning for Inquiry page for more information. In order to conserve resources, you may want to tell students that the mass of the kitchen supply samples cannot be more than 5 oz.

Science Notebook

Students can use the Science Notebook as a model for designing their own investigation. They may wish to brainstorm the kinds of kitchen supplies that they think might react with vinegar. Students should also plan how they will make observations. Ask if they plan to wait a few minutes or observe right away.

17A Unit 1

STRAND 8: ADVANTAGES OF BLENDED LEARNING/MULTIMEDIA FOR TEACHING SCIENCE

. . .a variety of technological applications can be used to enhance science learning, promote reflection, and build communities of learning . . .The diverse technologies then serve as integral tools that enhance teaching and learning beyond what traditional methods allow.

(Dani & Koenig, 2008, pp. 209–210)

DEFINING THE STRAND

Research has long attested to the effectiveness of technology and digital tools to facilitate student learning and increase achievement in the classroom (e.g., North Central Regional Educational Laboratory, 2003; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011; Teh & Fraser, 1995; U.S. Department of Education, 2010; Waxman, Lin, & Michko, 2003) and that computer-generated multimedia environments are particularly beneficial as they provide rich, varied instruction that is engaging and advances student thinking (Goldman-Segall, 1998; Mayer 2001, 2005 & 2013).

Digital learning is transforming education (Delgado, Wardlow, McKnight, & O'Malley, 2015; Johnson, Becker, Estrada, & Freeman, 2015; Modern Teacher, 2016). According to a report on emerging technology trends, blended learning approaches, which integrate digital or web-based learning into a conventional classroom setting, are on the rise in schools (Johnson, et al., 2015).

Concluding meta-analyses of online learning studies in the literature for the U.S. Department of Education (2010), Means and colleagues found that instruction combining online and face-to-face elements—blended learning—was associated with a larger advantage.

This finding is all the more exciting given the U.S. Department of Education's report that technology-intensive instruction can make education more equitable by closing the digital use divide and making transformative learning opportunities available to all students (2016):

> Technology can be a powerful tool for transforming learning. It can help affirm and advance relationships between educators and students, reinvent our approaches to learning and collaboration, shrink long-standing equity and accessibility gaps, and adapt learning experiences to meet the needs of all learners. (p. 1)

To promote scientific literacy and to prepare students for the demands of the 21st century, experts advocate the thoughtful and effective integration of digital technologies in science instruction (National Research Council, 1996, 2005, 2007). Computers support the active, inquiry-based learning that is essential in the science classroom; "there is compelling evidence that when classrooms function to support real scientific practice, students' understandings of science can flourish" (Michaels, et al., 2008, p. 127).

ScienceFusion delivers content via both print and digital formats, maximizing options for educators and optimizing student learning.

ScienceFusion harnesses the power of technology to create a digital program that enriches printed materials, provides dynamic multimedia learning environments, and allows for a more interactive experience resulting in improved understanding of science concepts. With detailed feedback and customized content, the digital approach supports and maximizes mobile learning. It also allows students to engage in inquiry processes similar to those of working scientists.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

Learning involves many systems and processes in the human body, particularly the brain and central nervous system, which together comprise the cognitive network. Piaget (1953) is credited with drawing attention to how cognitive systems function within children and performed some of the pioneering research examining the extent and limitations of children's cognition. Building on this research, modern cognitive theory is often the center of research endeavors in education. According to this "science of learning", a learner's knowledge is maintained in networks of interconnected ideas and concepts and acquiring new knowledge is a function of perceptual abilities, attention, motivation, prior knowledge, and attributes of the material being taught (Sweller, 2005).

Biology contributes to the functioning of a student's cognition; while educators cannot change such biological factors, they do, however, have the ability to affect student learning through how instructional practices are used to create learning environments and present material. One environment for learning that has been shown to have great promise for student achievement is the multimedia environment. To understand how educators can create a multimedia environment to optimize student learning, cognitive psychologist Richard Mayer proposed his Cognitive Theory of Multimedia Learning (Mayer, 2001). Simply stated, Mayer (2001, 2005) argues that student learning is increased when students are given information using multiple presentation formats, in particular, words/audio and pictures. Because the cognitive system has different memory structures that are sensitive to these various presentation modes, students have a greater likelihood of encoding information and retaining this information when it is presented using a combination of forms of instruction (i.e., the multimedia principle). "The case for multimedia learning is based on the idea that instructional messages should be designed in light of how the human brain works" (Mayer, 2001, p. 4).

While teachers can utilize a variety of different formats to provide multimedia instruction, schools throughout the United States have increased the adoption and use of different digital and technological tools, such as computers, multimedia presentations, and high-speed internet for educational purposes (Gray & Lewis, 2009). Thus, it is appropriate that teachers harness these new tools to engage students in multimedia learning. Along with traditional lecture practices, teachers now can use video,

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

audio, and PowerPoint®, and have a host of animations, simulations, and other interactive content available via the internet. But, because all learners are sensitive to "cognitive overload" (Sweller, 2005), simply providing content using many different digital tools is no guarantee that student learning will be improved. Rather, teachers need to appropriately use the various presentation modes that are available to them to ensure student learning is optimized. ". . .[T]he goal of multimedia presentations is not only to present information, but also to provide guidance for how to process the presented information—that is, for determining what to pay attention to, how to mentally organize it, and how to relate it to prior knowledge . . . multimedia is a sense-making guide—that is, an aid to knowledge construction (Mayer, 2001, p. 15).

Multimedia design can be integrated into classrooms as part of a larger blended learning approach. Blended learning, also known as hybrid, refers to an educational environment in which teachers use digital technology in an otherwise conventional classroom context on a regular basis. Blended learning utilizes both device-driven instruction and face-to-face instruction, with the objective to maximize the advantages of each (Delgado et al., 2015). The definition of blended learning is both simple (physical + virtual learning) and complex—complex because of the myriad of design possibilities within such an approach (Garrison & Kanuka, 2004). As explained by Osguthorpe & Graham (2003):

> Those who use blended approaches base their pedagogy on the assumption that there are inherent benefits to face-to-face interaction (both among learners and between learner and instructor) as well as the understanding that there are some inherent advantages to using online methods in their teaching. Thus the aim of those using blended learning approaches is to find a harmonious balance between online access to knowledge and face-to-face human interaction. (p. 228).

Research findings supporting the use of technology to bolster learning have been extensive. As one example, a 2003 meta-analysis of 42 studies with 282 effect sizes and combined sample sizes approaching 7,000 students concluded that technology had a positive and significant effect on student outcomes (cognitive and affective) when compared with traditional instruction (North Central Regional Educational Laboratory, 2003).

In an evaluation of evidence-based practices in online learning for the United States Department of Education (2010), which included a review and meta-analyses of online learning studies in the literature, it was found that that students who took all or part of their classes online performed better on average than those taking the same course through traditional face-to-face instruction; instruction combining online and face-to-face elements—blended learning—was associated with a larger advantage relative to purely face-to-face instruction than purely online: "Blended instruction has been more effective, providing a rationale for the effort required to design and implement blended approaches" (p. xviii).

Perhaps in part because blended learning teaches students through mediums and modes that engage them and fit with their daily practices and experiences, students were found to have very positive views on their experiences with blended learning (Uğur, Akkoyunlu, & Kurbanoğlu, 2011). According to the findings of Public Impact, “blended learning that combines digital instruction with live, accountable teachers holds unique promise to improve student outcomes dramatically” (2013, p. 1). Blended learning opportunities expand the possibility of growth for all students while affording historically disadvantaged students greater equity of access to high-quality education, in the form of both enhanced, instructionally effective content and more personalized learning (Molnar, 2014).

> The growth of online learning in brick-and-mortar schools carries with it a bigger opportunity that has not existed in the past with education technology, which has been treated as an add-on to the current education system and conventional classroom structure. Online learning has the potential to be a disruptive force that will transform the factory-like, monolithic structure that has dominated America’s schools into a new model that is student-centric, highly personalized for each learner, and more productive, as it delivers dramatically better results at the same or lower cost (Horn & Staker, 2011, p. 2).

Multimedia and Blended Learning Can Meet the Needs of All Learners

The research is clear: technology in the classroom can support learning for all students, including average and below-average learners (Becker, 1986) as well as those who are from disadvantaged backgrounds, holding promise to close achievement gaps (Public Impact, 2013; Molnar, 2014). Technology is increasingly being used in the United States to personalize learning and give students more choice over what and how they learn and at what pace; this will better prepare students to organize and direct their learning in their lives even after formal schooling (USDOE, 2016).

Students struggling to grasp scientific concepts can benefit from computer-based learning environments with the largest effects on student learning occurring when the content material is complex; in fact, the more complex the material that is being taught, the greater the benefit of technology use (Holzinger, Kickmeier-Rust, & Albert, 2008). Huppert, Lomask, and Lazarowitz, (2002) also reported that using computers for low-performing science students enhances their ability to understand science concepts and reason like scientists by mastering skills such as measurement, interpreting data, and designing an experiment.

Mayer’s (2001) research on multimedia learning supports these findings—that all students, including low-performing learners, benefit particularly from well-designed multimedia learning environments. In fact, Mayer and his colleagues (1995) compared the impact of multimedia instruction with that of text-only instruction. Knowledge retention was significantly greater among those students categorized as “low-knowledge” learners (Mayer, Steinhoff, Bower, & Mars, 1995). Adherence to the principles of effective multimedia design are most essential for low-knowledge and high-spatial learners. For these students, the impact of effective design is greater than for those who have high prior knowledge or low spatial abilities (Mayer & Moreno, 1998). Computers can assist in meeting the individual needs of students with special needs by embedding supports that can be used as needed by students. These scaffolds can take many forms, such as activating prior knowledge, modeling, questioning, or providing cues or tools for students (Stone, 1998).

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

Other student populations that traditionally underperform in science can significantly improve their science skills by using computer technology. Researchers have shown that the achievement gap between boys and girls in science can be made smaller by computer-based instruction, with these effects attributable to girls' ability to learn material at their own pace and in a non-competitive situation (Huppert, Lomask, & Lazarowitz, 2002). Further, Braun and colleagues (2009) found that, in comparison to those who are not, students from minority backgrounds are significantly less likely to report being exposed to active learning experiences, which have been found to be associated with improved student achievement, including modeling demonstrations via digital or online virtual laboratory. These researchers argue that the achievement gap between minority and white students could be decreased by increasing the occurrence of these educational multimedia learning environments within minority student science classrooms.

Digital learning is enhanced when students are given more control over their interaction with media (USDOE, 2010; Patrick & Powell, 2009). Blended learning allows for a personalized learning experience for students (Imbriale, 2013; Tucker, 2012), allowing them to drive the path and pace of their own learning (Public Impact, 2013). Digital learning tools can provide more flexibility and support for individual students by modifying content and complexity (USDOE 2016). Additionally, advances in software technology have increased adaptive learning and improved feedback (USDOE, 2016). "Technology can enable personalized learning or experiences that are more engaging and relevant" (USDOE, 2016, p. 10).

According to Horn and Staker (2011), a blended learning approach specifically offers a more consistent and personalized pedagogy that helps each child feel and be successful at school. "Leveraging technology, blended-learning programs can let students learn at their own pace, use preferred learning modalities, and receive frequent and timely feedback on their performance for a far higher quality learning experience. As online programs capture student achievement data in real-time across the school, teachers can spend more time helping personalize learning for students" (p. 6).

Computer-based collaborative tools allow for online interactions that can create and strengthen a community of learners. Tucker (2012) found that blended learning fostered students' communication and collaboration skills. "What makes blended learning particularly effective is its ability to facilitate a community of inquiry" (Garrison & Kanuka, 2004, p. 97).

By providing a diverse array of online and other digital resources, technology supports learning drawn from real-world challenges and students' personal interests and passions while also aiding the organization of a project-based curriculum (USDOE, 2016).

Multimedia Can Support Metacognition

Multimedia environments can also support the development of metacognition. For instance, White and Frederiksen (1998) found that students taught with a multimedia curriculum which included a metacognitive component had greater student achievement when compared to students not taught with this component.

One method to improve metacognitive reasoning is to scaffold instruction. Scaffolding is an educational technique that involves providing support to students as they learn, and gradually decreasing the amount of support provided until students are completing tasks independently. McNamara and Shapiro (2005) demonstrated the value of using digital agents for scaffolding. They found that digital agents could serve as mentors, providing strategic think-alouds to help students make connections between previously introduced material and new concepts, and thereby improving students' ability to grasp new concepts. Likewise, Zydney (2010) reported on the value of multimedia scaffold for learning. In one study, the inclusion of an organization tool as a scaffold improved student problem-solving abilities, suggesting that students benefited from support in organizing their knowledge and presenting their findings. By scaffolding learning—making learning strategies explicit through think-alouds or providing an organizing structure for thinking about a problem—teachers support students' development of metacognition, enabling them to recognize when such strategies will be useful in future learning situations.

Digital Learning through Multimedia and Blended Approaches Increases Motivation

An increasing body of evidence supports the idea that effective technology use in the classroom increases student engagement (Tucker, 2012) and motivates students to take charge of their own learning (Horn & Staker, 2011). In their synthesis of research on improving student engagement, Taylor and Parsons (2011) found multimedia and technology use to be a key, shared element in engaging classroom environments. Chen, Lambert, and Guidry (2010) found that Web-based learning led to increased student engagement and learning outcomes in their study.

Other researchers have indicated that multimedia learning leads to increased student motivation because of the freedom of choice and self-pacing that these environments provide and the engaging and active learning that is possible within these environments (Schunk, Pintrich, & Meece, 2008). These components of multimedia learning affect student motivation, driving students to be more likely to complete science tasks. For instance, Abdoolatiff & Narod (2009) discovered that students who completed a computer-based science lab performed significantly better on a test measuring understanding of the lab and reported increased motivation and enthusiasm for the material when compared to students taught the same material using traditional approaches. Further, using computer-based instruction in the science classroom is related to other motivational aspects, including increased value placed on the subject, students' improved perceptions of their abilities, increased student self-confidence, and overall enjoyment (Ke, 2008).

Other researchers have indicated that multimedia learning leads to increased student motivation because of the student control these environments allow, and the engagement in active learning (Schunk, et al., 2008). In comparing the performance of students who completed a computer-based science lab to that of students taught the same material in a traditional learning environment, Abdoolatiff and Narod (2009) discovered that students in the former group understood the material better and reported greater interest and motivation to learn. Positive effects—across content areas and with students of different ages—have been found specifically for technology environments that employ game-based learning (Henderson, Klemes, & Eshet, 2000).

The use of technology can positively impact student engagement and motivation in the science classroom specifically. Ke (2008) found computer-based instruction in the science classroom correlated to increased student self-confidence and overall enjoyment. Reinking (2001) looked at the connection between multimedia learning and increased engagement, and found four main reasons for the effectiveness of multimedia learning environments:

- the interactive nature of the medium;
- the ability to embed supportive scaffolds, and accessibility of environments;
- the concrete, game-like nature of the medium; and
- the social learning aspects of computer-assisted learning.

Students Learn Better with Integrated Visuals and Models

"For hundreds of years the primary vehicle for instruction has been words, such as lectures or textbooks. Advances in computer and communication technologies now allow instructors to supplement verbal modes of instruction with visual modes of instruction, including dazzling graphics that students can interact with. Research on multimedia learning provides encouraging evidence that under appropriate circumstances, students learn better from words and pictures than from words alone . . ." (Mayer, 2013, p. 396).

As Mayer states in his seminal work, *Multimedia Learning* (2001), "the case for multimedia rests in the premise that learners can better understand an explanation when it is presented in words and pictures than when it is presented in words alone" (p. 1). Visuals and multimedia learning can be effectively presented via technology, as well as through paper-based materials. An effective textbook may employ pictures, charts, figures, and graphic organizers. An effective computer-based learning environment may present students with animations, video clips, and interactive simulations.

Research has consistently supported the use of visuals in instruction. Mayer (2001) found through multiple studies that students learn better when presented information both visually and verbally, so that they can access information through different modes. Marzano and colleagues (2001) identified nonlinguistic representations as one of the nine most effective instructional strategies that teachers can use in the classroom. As Clark and Feldon (2005) concluded from their review of research in multimedia learning, properly utilizing this principle when designing instructional environments and curriculum can have great educational benefits as well as reduce the time it takes students to learn new concepts.

While pairing pictures and words is more beneficial than either approach, other researchers have found that learning is increased when visual content includes animations. For instance, Rieber (1990) examined the effects of three levels of visual elaboration—no graphics, static graphics, and animated graphics—and found that the most effective approach for teaching challenging material was the combination of text and animated graphics. Other researchers have indicated that computer-based visualizations and simulations are particularly helpful for students with low content knowledge and are most effective when scaffolds are built into these programs to guide students toward understanding the complex relationships (Cifuentes & Hsieh, 2004; NRC, 2007).

Computer-based visual instruction is particularly helpful in the sciences, a content area in which modeling plays a crucial role to students' understanding. Students who might otherwise face challenges in visualizing phenomena and objects can harness the power of technology to aid in these visualizations. A committee convened by the National Research Council to develop *A Framework for K–12 Science Education* (2012) emphasized the importance of visuals and modeling, and students becoming adept at constructing drawings or diagrams to represent phenomena with models, evaluate given models, and make and employ simulations using tools and technology.

Simulations are learning environments that imitate a real-life process or situation, and which allow learners to test effects of their hypotheses on intended outcomes (Merchant, Goetz, Kenney-Kennicutt, Kwok, Cifuentes, & Davis, 2012). Virtual worlds are open-ended environments in which users design and create their own objects and may contain the illusions of a 3-D space, digital representation of learners in the form of an avatars, and the ability to communicate with other participants. "Technology can help learning move beyond the classroom and take advantage of learning opportunities available in museums, libraries, and other out-of-school settings" (USDOE, 2016, p. 12).

In a meta-analysis to examine overall effect and impact of instructional design principles in the content of virtual reality technology-based instruction, Merchant and colleagues (2012) found games, simulations, and virtual worlds effective in improving learning outcome gains.

Barnett and colleagues (2005) found that students who created and interacted with 3-D models showed greater learning about astronomy concepts. This computer-based modeling helps students to develop "understandings through their first-hand experience . . ." and examine "their understanding from multiple perspectives" (Barnett, Yamagata-Lynch, Keating, Barab, & Hay, 2005, pp. 351–352). Dani and Koenig (2008) observed that the dynamic nature of virtual environments provides for models and simulation of complex or abstract scientific concepts, phenomena, systems, or processes, which leads to increased active thinking, increased student engagement and student motivation, and the formation of deeper conceptual understanding. Using these animations provides students with a dynamic visual that researchers have found is associated with greater conceptual understanding of scientific concepts (Bell & Trundel, 2008). Similarly, Webb (2005) argued that technology-based learning environments in science are especially conducive to conceptual change because of the increased opportunities computers provide for visualizing through simulations.

Students Learn Better When They Are Engaged in Active Learning

Active learning is not physical behavior; active learning occurs when students' cognitive activity is the most active (Mayer, 2001). High levels of interactivity are a key feature of effective digital learning programs. As concluded by Sims, Dobbs, and Hand (2002), "[t]he capacity of computer-based technology to display combinations of media elements and respond meaningfully to user actions and manipulations has been established for many years." (p. 146). Zhang (2005) adds, "[l]ack of sufficient control over instructional content can diminish potential learning benefits" (p. 149).

Researchers point to the benefits of technology for boosting active learning: simulations, models, and digital tools "create exciting opportunities for students to create, manipulate, and interact with their own constructions, which in turn supports them in developing understandings through their first-hand experience" (Barnett et al., 2005, p. 351). In the conclusion of two experimental studies to assess effectiveness of interactive e-learning, Zhang (2005) found students in a full interactive multimedia-based e-learning environment achieved better performance and higher levels of satisfaction than those in a traditional classroom and those in a less interactive e-learning environment. "This study implies that to create effective learning, e-learning environments should provide interactive instructional content that learners can view on a personalized self-directed basis" (p. 160).

Roy and Chi (2005) cautioned that while multimedia environments have the potential to improve student learning, such learning can only occur if students are actively engaged cognitively when interacting with these technologies. When using digital technologies, students need to continually build and integrate new knowledge with their existing understanding if virtual environments are truly going to be effective.

One way to increase the active learning in digital environments is to include regular feedback, prompts, and questions (Webb, 2005). Researchers at the National Research Council concluded, after an extensive review of the existing research, that studies "show that interacting with software prompts can help students articulate their understanding as well as provide rationales for decisions that they would otherwise not make explicit" (NRC, 2007). Similarly, Aleven and Koedinger (2002) looked at the impact of self-explanation on student learning and reported that a computer-based approach of prompting students to generate self-explanations can support student learning in virtual environments, leading to significantly greater performance than when such explanations are not provided.

Students Learn Better When They Use Technology for Inquiry

According to Buczynski and Fontichiaro (2009), including technology in inquiry learning leads to students being more active learners, increases student application of science concepts, and builds cooperation skills. Use of technology-enhanced inquiry lessons is associated with greater student mastery of science. For example, Sun, Lin, and Yu (2008) revealed that students using Web-based inquiry lessons had significantly greater scores on a posttest designed to measure understanding of material presented in the lab when compared to students who completed the same lesson using traditional approaches.

Similarly, Huppert, Lomask, and Lazarowitz (2002) compared the performance of students completing computer-assisted inquiry lessons to students completing a traditional "hands-on" inquiry activity with no technology component and found that both approaches led to significant improvement, from pretest to posttest, in science knowledge, but that lower performing students performed significantly better on the posttest after using the computer-assisted lesson. The authors suggest that this result might be from the additional support and flexibility virtual labs offer students with content knowledge and skills.

Research also indicated that students who complete computer-based inquiry lessons witness a significant increase in not only science knowledge, but also application of science process, such as identifying variables and hypothesis generation (Tan, Yeo, & Lim, 2005). Evidence suggests that combining elements of hands-on activities with virtual simulations leads to greater conceptual understanding than if only hands-on experiments are performed (Zacharia, Olympiou, & Papaevripidou, 2008).

Another advantage of a technology-based environment for inquiry is the speed and simplicity with which students can engage in a virtual lab, thereby allowing them to focus more fully on the concepts learned (Webb, 2005). Also, virtual simulations provide students with the opportunity to be exposed to a wide variety of experiments they would not encounter because of costs and/or logistics. When properly designed, these inquiry lessons encourage students to apply and extend their understanding of scientific concepts and use various critical thinking methods, which lead to improved science performance on achievement tests (Dani & Koenig, 2008). Just as real scientists utilize more technology when they perform research, science students should make use of these technologies to perform experiments, conduct secondary research, and communicate with one another to foster greater understanding and application of science knowledge.

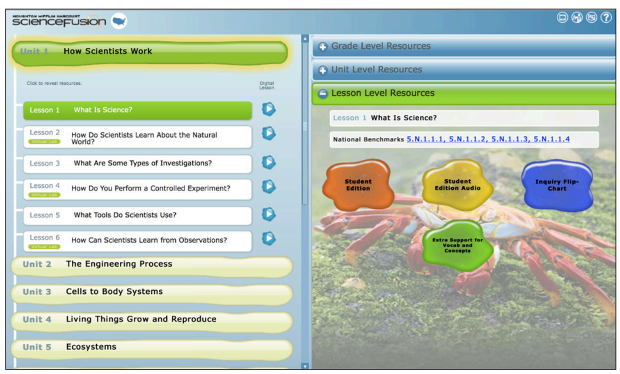
Therefore, computers can support the active, inquiry-based learning that is essential in the science classroom; "there is compelling evidence that when classrooms function to support real scientific practice, students' understandings of science can flourish" (Michaels et al., 2008, p. 127).

Working scientists use technology tools, including computer simulations, models of phenomena, and collaborative tools such as e-mail in the course of their inquiries. Similarly, these tools can help students learn to think and act like scientists. We know that students learn best by doing, particularly in science class (National Research Council, 2000; Dalton, Morocco, Tivnan, & Rawson Mead, 1997). A multimedia environment can support students as they engage in the scientific process, making predictions and posing questions, collecting evidence and recording data, thinking critically, and interpreting and communicating the results. Multimedia environments are particularly beneficial in helping students with the visualizing and modeling of scientific concepts that is essential for learning science concepts (Cifuentes & Hsieh, 2004). Multimedia and technology-based tools should not replace hands-on experiences or traditional laboratories. Instead, they can provide students with repeated exposures and varied representations, thereby deepening their learning (Huppert, et al., 2002).

FROM RESEARCH TO PRACTICE

ScienceFusion features a learner-centered focus. Technology was not used because of its capacity as technology but instead because of its capacity to help students learn science. The Digital Path was designed and planned with a strong and consistent focus on the goals for deep learning in the sciences and an understanding of how students best achieve these goals.

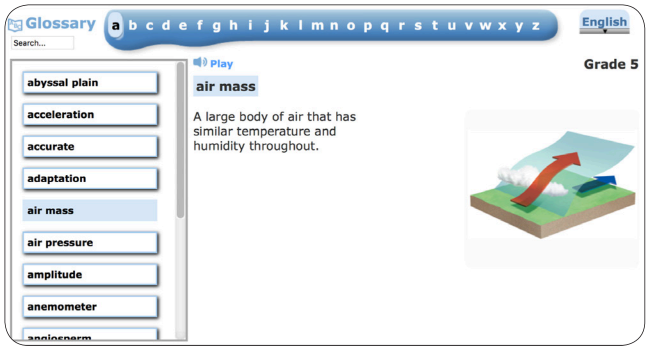
In *ScienceFusion*, students experience a **multi-modal learning environment** which fuses print, digital, and hands-on experiences. The technology components of the program allow for enhanced learning and the program allows teachers to meet the needs of students who learn best visually, kinesthetically, or verbally. Every lesson is designed to be accessed in multiple ways—print, digital, or hands-on—so that all students can be reached via their unique learning styles. Audio can accompany print to aid comprehension for students who learn best with auditory support.



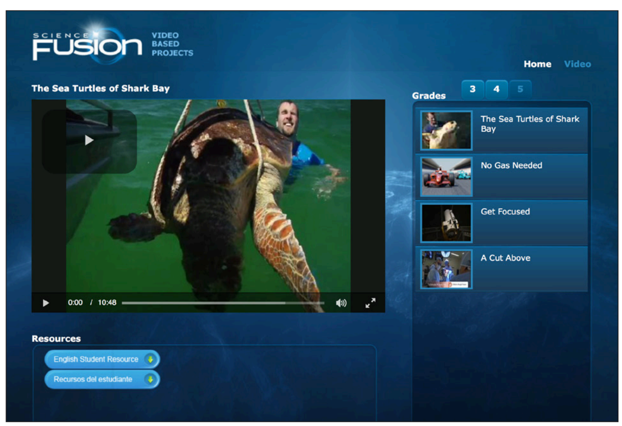
Integrated Visuals in *ScienceFusion*

In order to help students integrate new science concepts with understanding, in *ScienceFusion*, students are given numerous visuals and models to illustrate the concepts. Scaffolds and strategically inserted narration and animation help students to “see” the data and draw the correct scientific assumptions from virtual labs or online demonstrations.

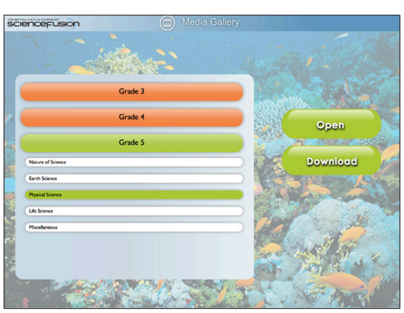
In addition, the program's **Interactive Glossary** visuals support students' learning of content-area vocabulary.

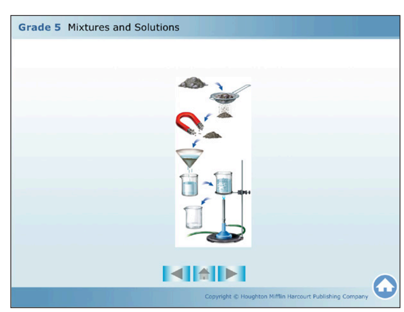


By completing the **Video-Based Projects**, students learn through an active learning environment in which visuals and animation combine with audio and text to engage students and allow for application of content-area learning.



The **Media Gallery**, a Microsoft® PowerPoint slide presentation of key images from the *Student Edition*, can be used by the teacher or students to create their own presentations.



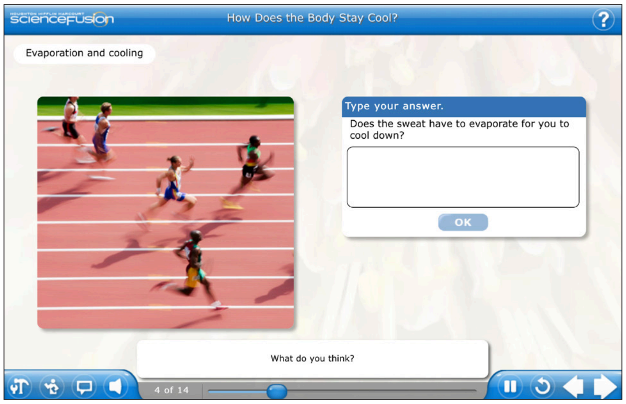


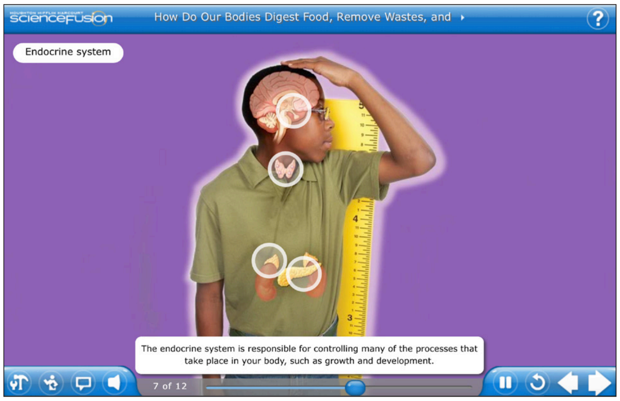
FROM RESEARCH TO PRACTICE *(CONTINUED)*

Self-Paced and Active Learning Opportunities in *ScienceFusion*

Students engage in active learning on every page and with every activity in *ScienceFusion*. Simulations, animations, videos, **Virtual Labs, Video-Based Projects,** and assessments all encourage active learning and interactivity through the digital design.

Throughout *ScienceFusion's* **Digital Interactive Lessons**, students control the pace of learning—they click through vocabulary words and images to find facts and definitions. They navigate each page to replay for review, pause to take notes, or click next to continue. Inquiry is integrated throughout the program's print and digital paths. **Virtual Labs** and activities engage students in actively applying content that they have learned.





Examples of design features and teaching and learning resources that illustrate the program's commitment to active learning include:

- **Opportunities to provide feedback, respond to prompts, or answer questions:** Throughout the lessons, students are prompted with Active Reading suggestions, provided with opportunities to click through visuals or vocabulary words to learn more information, and given chances to move ahead or review content as needed.
- **Activities to ensure active learning:** Animation in the program engages students' attention, and specific prompts and activities involve students in active learning tasks and situations. When engaged in simulated laboratory activities, students are prompted to take notes in their lab books, record observations, analyze data, and draw conclusions.
- **Online Unit Self Quizzes:** The self-assessment quizzes give students a view of their strengths and weaknesses in a given unit.
- **eTextbook:** The online Student Edition provides students anytime access to their print textbook. It is ready to use with an interactive whiteboard. Students can annotate on the screen, highlight, and underline.
- **Video-Based Projects:** These inquiry-based projects consist of a video, teacher support pages, and student activity worksheets.
- **Interactive Glossary:** The ScienceFusion Interactive Glossary provides program vocabulary and definitions with either photographic imagery or audio/video elements.
- **Student Vocabulary Cards:** The program's Student Vocabulary Cards include short activities designed to help students actively understand and retain the meanings of vocabulary terms in the Student Edition.

FROM RESEARCH TO PRACTICE *(CONTINUED)*

Inquiry-Based Digital Learning in *ScienceFusion*

The *ScienceFusion* program provides numerous resources designed to engage students in inquiry-based learning, including in the digital path. *ScienceFusion* teaches students the processes that scientists engage in when they experiment—and then provides opportunities for students to engage in digital experimentation themselves.

- **Virtual Labs:** Taking advantage of the benefits of instruction via computer, the program provides modeling and online virtual lab experiences for students. Labs are embedded with prompts that encourage students to engage in the scientific process—setting a purpose for their investigations, planning their procedures, recording their data, drawing conclusions, and generating further questions. Because of the possibility of engaging in laboratory experiences much more efficiently online than in the traditional classroom, the program provides students with several virtual laboratory experiments in less time than they would be able to complete one hands-on laboratory in the classroom.
- **Video-Based Projects:** Numerous inquiry-based projects are available online, along with teacher and student resources to support them.
- **Opportunities to apply and extend concepts.** Throughout the digital path of the program, students are given opportunities to apply and extend concepts through think-along questions and prompts. By engaging student in these kinds of ongoing checks on comprehension, the multimedia environment engages students in actively learning to think like scientists.

Other digital features expand students' learning of science, such as HMH Field Trips powered by Google® Expeditions. HMH® is among the first to develop K–8 content for Google Expeditions. Using a simple Google cardboard device and a smartphone, students are drawn into immersive 3-D virtual worlds where learning and engagement are maximized. Teachers are given flexibility in customizing these experiences for their classrooms.

STRAND 9:
PRINCIPLES OF DESIGN FOR EFFECTIVE BLENDED LEARNING/ MULTIMEDIA INSTRUCTION

The challenge for instructional designers is to apply design principles in ways that reduce extraneous processing (such as scanning between captions and the graphic), manage intrinsic processing (such as attending to relevant portions of the narration and graphic), and foster generative processing (such as mentally organizing and integrating the material).

(Mayer & Johnson, 2008, p. 385)

DEFINING THE STRAND

As Mayer discusses in his 2001 book, *Multimedia Learning*, simply using computers does not necessarily lead to increased learning. The key is to use the technology in such a way that it is consistent with how people learn; the design should be centered not around what the technological tools can do but on how the learners can best learn. When a multimedia environment is poorly designed, with extraneous information and ineffective presentation, students become overloaded cognitively and cannot process the new conceptual information (Wainwright, 1989; Sweller, 2005).

The overall coherence of an instructional message in a multimedia environment is important. In a series of studies, Mayer (2001) investigated specific ways that multimedia learning could be designed to provide robust instruction that did not result in cognitive overload. He reported that the timing and placement of the integration of visuals with text is important, as is the use of audio to allow learners to gain knowledge through multiple channels. To create an effective multimedia learning environment, Mayer (2001, 2005) offers several principles to guide the design and implementation of different educational practices in the 21st-century classroom.

ScienceFusion utilizes technology to aid students' learning of science. The program's digital components were designed according to research-based principles for effective instruction. Visuals and models were developed in multimedia formats to bolster students' understanding of complex concepts and relationships. Animations and simulations provide students with an opportunity to engage in active learning and apply and extend concepts they have learned. Virtual labs were designed to be fully interactive and provide students a rich, genuine experience to replicate the activities scientists engage in when performing research.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION*

The Modality Principle

The Modality Principle *states that students learn better from animation and narration (spoken text) than they do from animation and on-screen text. Presenting words auditorily allows students to process the "text" through their auditory/verbal channel and process the images via their visual/ pictorial channel.*

As Schnotz (2005) summarized, many researchers ". . .have shown that students learn better when pictures are presented with spoken text instead of written text" (p. 61). The improvement in student learning is most likely the result of activating two memory systems—the auditory sensory memory, via the spoken word, and the visual memory system, by presenting relevant visuals (Mayer, 2001). Comparisons of multimedia learning environments in which text is presented via narration, to on-screen, visual presentations confirm that students learn more when on-screen pictorial presentations are accompanied by auditory narration (Craig, Gholson, & Driscoll, 2002).

The Spatial and Temporal Contiguity Principles

The Spatial Contiguity Principle *asserts that students learn more when corresponding words and images are close to each other on the page or screen. When words are placed far from corresponding pictures, learners must devote mental energy to scanning and making connections between pictures and words.*

The Temporal Contiguity Principle *refers to the idea that students will learn better when related pictures and words are presented at the same time, rather than sequenced one after the other. When images and corresponding text are separated by time, particularly a longer time, learners have more difficulty building connections between the two.*

Placement and timing of presentations are both important to students' comprehension of new material in multimedia learning environments. According to Schnotz (2005), "students learn better from words and pictures than from words alone, if the words and pictures are semantically related to each other (the coherence condition) and if they are presented closely together in space or in time (the contiguity condition)" (p. 60). Although the occurrence of text and pictures in a multimedia environment should be minimized, when they are necessary, such presentations of words and pictures should occur close to one another because "if we want students to build cognitive connections between corresponding words and pictures, it is helpful to present them contiguously in time and space . . ." (Mayer, 2001, p. 112). For instance, Mayer, Steinhoff, Bower, and Mars (1995) performed a series of experiments examining the effects of text and picture placement on transfer problems of adding meaningful illustrations to support a scientific text. Their findings suggested that illustrations that were integrated with the corresponding text and contained annotations resulted in a 50% increase in solutions on transfer problems, particularly among students with less experience with the topic. The researchers concluded that "building a useful mental model of a scientific system depends on building integrative connections between verbal information selected from the text and corresponding features of images selected from the illustrations" (p. 39). Similarly, multiple studies have demonstrated that student learning is significantly improved when students view a simulation and accompanying narration at the same time, rather than experiencing the presentations separately (Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994). Thus, pictorial simulations and the relevant auditory narration should be presented at the same exact time to ensure that these two distinct memory systems are processing the information together, leading to increased encoding and retention.

The Coherence Principle

The Coherence Principle *states that students will demonstrate greater learning when irrelevant material is not included. When learners' attention is focused on extraneous material, their attention is not focused on what we want them to learn. Including extraneous material can also divert students' focus, encouraging them to make misleading connections and organize their ideas around the wrong central ideas or themes.*

Earlier work on coherence was conducted with print texts, looking at the addition of interesting, but extraneous, details and their impact on readers' comprehension. This research indicated that irrelevant details interfere with learners' ability to identify and remember the main ideas of passages (e.g., Garner, Gillingham, & White, 1989). Similarly, a series of experiments conducted by Harp and Mayer (1998) found that students who read the passages with extraneous but attractive details performed significantly worse on tests of reading comprehension than did students whose passages did not include the irrelevant information. Continued research supports these findings in a multimedia environment. Learners tend to learn less from presentations that include appealing details that are extraneous to the main idea or instructional goal of the presentation (Harp & Mayer, 1997, 1998; Mayer, Heiser, & Lonn, 2001). Appealing but extraneous illustrations have the same negative impact on comprehension and retention that similarly seductive text details do. The addition of such distracting illustrations "hurt student learning of a scientific explanation," leading the researchers to "question the overuse in science textbooks of attention-grabbing color photographs that are not directly relevant to helping the reader make sense out of the explanation in the passage" (Harp & Mayer, 1997, p. 100).

Mayer, Griffith, Jurkowitz, and Rothman (2008) looked at the impact of extraneous details on students' understanding of scientific concepts rendered through a multimedia science presentation. Specifically, this study looked at the impact of high-interest extraneous details versus low-interest extraneous details. Researchers found that high interest, but irrelevant, information was more detrimental to student learning than low interest, extraneous material because students paid more attention to the information that was interesting but not important. This engagement left them with less cognitive capacity to focus on important and relevant content. As Mayer and Moreno (1998) pointed out, while coherence is essential for maximizing learning, brevity is also important as "a shorter presentation primes the learner to select relevant information and organize it productively" (p. 5).

Similarly, irrelevant sounds and music affect student learning and understanding. In a series of experiments comparing learning from a basic version of a multimedia lesson with learning from a version with added sounds and music, Mayer (2001) determined that "students perform more poorly on verbal retention when background sounds and music are added to a multimedia explanation" (p. 126) and "adding background music and sounds resulted in poorer problem-solving transfer performance" (p. 127).

The Segmentation Principle

The Segmentation Principle *indicates that students retain more when information is presented in learner-paced units, rather than as a complete unit. Because all students have different prior experiences, the time it takes to incorporate new information into long-term memory varies for all students. Giving students control over the speed and presentation of new material increases students' ability to focus on material they are unfamiliar with and decreases time spent reviewing known content, improving overall student retention.*

Recent research has indicated that when students have control over virtual learning spaces, they are able to remember more and have significant improvement in learning when compared to the performance of students working in learning environments in which they have less control (U.S. Department of Education, 2009). As Mayer (2005) indicated, "people learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit" (p. 175). The principle suggests that the segmenting of units is important—as is learner control over the segments. That is, students should be able to control the pace of information, through a "Start/Stop" button or a "Continue" button. Researchers found that segmenting multimedia lessons using smaller parts and control features increases student retention because it places less demands on short-term memory, allowing students to make the connections between segmented material more easily than when material is presented as a whole unit (Lusk, Evans, Jeffrey, Palmer, Wikstrom, & Doolittle, 2009; Mayer & Chandler, 2001; Mayer, Dow, & Mayer, 2003). This segmenting of multimedia lessons not only provides educational benefits, but also motivates students to complete their work and improves student attitudes toward learning new material (Schunk, et al., 2008).

Guided Discovery Learning Principle

The Guided Discovery Principle *states that people learn better when guidance is provided in discovery-based multimedia environments. Providing different supports and prompts establishes a frame for learning and encourages learners to discover facts, content, and processes through their own investigations, leading to greater retention in long-term memory.*

According to de Jong (2005), scientific discovery learning is the process in which students "take the role of scientists who want to design theory-based empirical observations. Scientific discovery learning, therefore, is a complex learning method that consists of a number of specific learning processes" (p. 215). Such learning is necessary for students to understand how to employ the scientific process and make sense of experimentation and investigation in the science classroom. Computer technology provides an ultimate medium for such learning (de Jong & van Joolingen, 1998). Discovery learning is improved through several multimedia learning enhancements, including guided discovery, in which students are routinely prompted to explain their work, answer questions, and provide feedback, which results in greater retention and application (Mayer, 1987). Technology can provide more (multiple types) of prompts that aid in students' science thinking and application of scientific knowledge, including demonstrating different modalities for real-world problems, presenting necessary information and feedback, providing students an environment in which to reason and solve problems, and giving students access to supplementary resources to increase efficiency (Lajoie, Lavigne, Guerrera, & Munsie, 2001). Various studies of guided discovery learning have shown the effectiveness of different types of scaffolds on student learning. For example, de Jong & van Joolingen (1998) found that assigning exercises such as questions and activities improved application of the scientific process, while Zhang, Chen, Sun, and Reid (2004) found that activities that encouraged reflection and provided students with concrete examples during digital simulation had a positive effect on student learning. Similarly, Moreno (2004) reported that multimedia agents that provided explanatory feedback reduced students' cognitive load, allowing them to learn more and demonstrate more interest and motivation than students who did not receive explanatory feedback.

Providing students with tools and access to domain-specific resources has also been found to positively affect student scientific discovery. For instance, Rieber, Tzeng, and Tribble (2004) examined students' interactions with a computer-based science simulation and found that students provided with brief multimedia explanations of content gained significantly greater "implicit and explicit understanding of the science principles" (p. 307). Reid, Zhang, and Chen (2003) also found that providing access to the scientific knowledge base, through the form of a reference book embedded in the multimedia learning program, helped to support learners.

FROM RESEARCH TO PRACTICE

ScienceFusion was designed following the principles that research has identified are essential for learning in a multimedia environment. Throughout the K–8 program, these principles serve as the foundations for the structure of the learning environment, as evidenced by the program's effective application of the principles.

The Modality Principle in *ScienceFusion*

The use of a narrator to deliver content in *ScienceFusion* meets the design principle that Mayer (2001) has termed the modality principle. This principle suggests that because students can only take in a certain amount of information at one time in one way, or mode, multimedia environments should be designed to allow students to access information both by sight and by sound. The use of a narrator to deliver important content in the ScienceFusion program demonstrates the program's adherence to this key design principle. Students can listen to content, as they look at visuals and text on screen.

The Spatial and Temporal Contiguity Principles in *ScienceFusion*

The design of the *ScienceFusion* materials facilitates students' cognitive connections between words and images. In *ScienceFusion*, words and pictures are clearly connected. Words connected to relevant visuals keep students' attention focused on the important concepts.

Both the placement of images and text and the timing of their presentation were considered in the design of the *ScienceFusion* materials. Related pictures and words are presented at the same time so that students make connections between images and text.

The Coherence Principle in *ScienceFusion*

In *ScienceFusion*, only relevant material is included. This helps students to maintain a clear focus on relevant, important ideas.

Extraneous material is not included in the *ScienceFusion* program. Unnecessary animation and sounds are excluded—to keep students focused on the important facts and concepts. Background music, for example, is used to engage students at the very opening of the lesson but then is not repeated throughout, so that students focus on the words and visuals—not distracting tunes.

The Segmentation Principle in *ScienceFusion*

In *ScienceFusion*, units are learner-paced. The time needed to incorporate new information varies by learner. For this reason, in *ScienceFusion*, students have control over the speed and presentation of new material.

- By clicking on the page numbers at the bottom of the screen, students control the pace of the presentation.
- By clicking on the "Next" icon, students can continue to the next page.
- By clicking on the "Replay" icon, students can replay the audio.
- By clicking on the "Back" icon, students can go back to the previous page.
- By clicking on the "Pause" icon, students can pause.
- By clicking on the "Toggle Sound" icon and the "Closed Caption" icon, students can control how content is delivered—through audio or text.

The segments of lessons—where smaller units of content are delivered at one time or on a single screen— place less demand on students' short-term memory. Placing less demand on short-term memory enables greater learning and retention.

The Guided Discovery Learning Principle in *ScienceFusion*

ScienceFusion follows a discovery-based learning model. In *ScienceFusion*, students take the role of scientists—employing the scientific process while conducting experiments and investigations. The program's online labs, Video-Based Projects, and Inquiry Flip Charts invite students to learn through active investigation and discovery.

RESEARCH THAT GUIDED THE DEVELOPMENT OF *SCIENCEFUSION* (CONTINUED)

In addition, throughout the *ScienceFusion* program, students are prompted to complete activities and answer questions to demonstrate their understanding and apply the new concepts they have learned.

To facilitate students' discovery-based learning, *ScienceFusion* offers students the supports and resources they need to acquire new knowledge—including the following **Grade-Level** or **Module-Level Resources, Unit-Level Resources,** and **Lesson-Level Resources**:

- Online Student Edition
- Student Edition Audio
- People in Science
- People in Science Gallery
- Video-Based Projects for Students
- Online Unit Self Quiz
- Glossary
- Student Vocabulary Cards
- Extra Support for Vocabulary and Concepts
- Inquiry Flip Chart
- Student Handbook
- Leveled Readers 1, 2, and 3 (for Grades K–5)

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