Using the ScienceFusion Program:
A Research Based Approach
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Introduction

The purpose of this document is to demonstrate clearly and explicitly the scientific research base upon which the *Houghton Mifflin Harcourt ScienceFusion* program is built. Five major research strands underpin the program: Writing to Learn, Vocabulary, Scaffolding, Metacognition, and Engaging in Inquiry. These strands identify the key components of science instruction identified by recent research.

To help readers make the connections between the research strands and the *Houghton Mifflin Harcourt ScienceFusion* program, the following sections are used 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 Houghton Mifflin Harcourt 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 *Houghton Mifflin Harcourt ScienceFusion* program.

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

A complete bibliography of all works cited is provided at the end of this document.
Strand 1: Writing to Learn

…writing in science is essential to developing scientific literacy — an understanding of how to read science, how to write science and the content of science itself. (Wellington & Osborne, 2001, p. 81).

Defining the Strand

For most students, writing is a fundamental part of school. Nearly all students are asked to engage in some sort of writing on a daily basis, and the writing they do is typically used to determine whether or not they know or understand something they have been taught. Producing pieces of writing in order to demonstrate skills, knowledge, and understanding is a common and valuable purpose for classroom writing. There is another purpose for writing in the classroom, however, that is equally as important – writing to learn.

Regardless of the content area, 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. Research has shown that learners become more engaged in the learning process when they are asked to explain and reflect on their thinking processes (Surbeck, 1994; Good & Whang, 1999; Hettich, 1976). The act of writing can help students shape and clarify their learning.

While expressive writing can promote personal understanding across content areas, in science classes, as students become familiar with traditional ways of representing scientific inquiry and findings, they can think like scientists. In the same ways that scientists communicate and represent ideas, students can use these same methods to clarify and consolidate their own understandings. Language is not just a way to describe concepts. It is a way for students to create conceptual structures of scientific thinking. For this reason, formal scientific writing is an important form of communication in science classes.

Writing to learn can take other forms as well. Taking notes, or making annotations while reading, is another strategy that effective readers do to think about and retain new concepts encountered while reading content-area texts. In this way, active readers make texts their own, and better understand and recall concepts in reading. Notebooking in science has also been shown to be particularly effective. Here, students record data, facts, and procedures, as well as predictions, conclusions, and reflections. By integrating their facts and their 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).
Research that Guided the Development of the Houghton Mifflin Harcourt ScienceFusion program

Writing to Improve Scientific Thinking and Understanding

"In conclusion, this general review of writing for learning science in schools indicates that researchers in this field are generally agreed that writing is a necessary and valuable epistemological tool for learning." (Prain, 2006, p. 195).

“Across the studies, there is clear evidence that activities involving writing (any of the many sorts of writing we studied) lead to better learning than activities involving reading and studying only.” (Langer & Applebee, 1987, p. 135).

In an analysis of NAEP results, Braun et al. determined that students writing long answers to science tests and assignments were associated higher average scores—an estimated NAEP score gain of 5.9 scale points: “…instructional strategies for which increasing frequency was associated with higher average scores [included students] writing long answers to science tests and assignments.” (Braun et al., 2009, p. 4).

In “a study that examined the cumulative effects of students’ learning of science, and perceptions of the role of writing in learning, when the students engaged in multiple writing tasks with planned strategy support…Results from the quantitative component indicated that multiple, non-conventional writing had a significant benefit in helping students learn.…” (Hand, Hohenshell, & Prain, 2007, p. 343).

Improved logic and conceptual understanding were attributed to increased opportunities for students to write about science, in a study conducted by Fellows (1994). Requiring students to write numerous explanations of different scientific concepts resulted in posttest written explanations that included more scientifically accurate language and better expressions of abstract ideas than did explanations produced after previous instruction that did not include as much writing (Fellows, 1994).

In a study of students who were taught using a heuristic designed to support their writing about laboratory activities, Keys, Hand, Prain, and Collins (1999) found that the use of the heuristic and the act of writing provided students with the opportunity to construct scientific knowledge. “The writing data indicated that students actively generated meaning…and made well-reasoned links….Student writing also exhibited evidence of metacognitive thinking, as the writers reflected on the sources of their knowledge, the degree of certainty of their knowledge, and how their knowledge had changed over time.” (Keys et al., 1999, p. 1081).

In a secondary analysis of six previous studies on examining the benefits of writing-to-learn strategies in science teaching and learning, “the results indicated that using writing-to-learn strategies was advantageous for students compared to those students working with more traditional science writing approaches. Using diversified types of writing enabled students in treatment groups to score significantly better on conceptual questions and total test scores than those in comparison groups.” (Gunel, Hand, & Prain, 2007, p. 615).
In an examination of the effects of teaching scientific communication skills, Spektor-Levy, Eylon, and Scherz (2009) found that students who experienced performance tasks, which required them to learn and practice applying concepts through activities that focused on oral and written communication, “achieved scores similar to those who experienced only a structured instruction in skills.” They concluded that the positive effect of these performance tasks on achievement may be the result of the positive effects of formative assessment; in preparing and doing the performance tasks, students experienced meaningful, substantial gains in their learning. When these types of performance tasks were combined with structured instruction of skills, students saw even greater gains; “Thus, opportunities for students to express their understanding should be planned for every teaching occasion.” (Spektor-Levy, Eylon, & Scherz, 2009, p. 897).

In a study of the role of talk and writing on learning science, Rivard and Straw (2000) found that discussing and writing about science were complementary processes that increased students’ long-term scientific knowledge. Discussing scientific learning with their peers allowed students to share and clarify knowledge, while writing analytically about science enabled them to organize their ideas and transform “rudimentary ideas into knowledge that is more coherent and structured. Furthermore, talk combined with writing appears to enhance the retention of science learning over time.” (Rivard & Straw, 2000, p. 566).

Keys (1994) found that general science students who received a report-writing intervention showed improvement in their scientific reasoning, textbook processing, and ability to draw conclusions and formulate models. (Keys, 1994).

“...writing as a means of self-exploration in mathematics and science learning does seem to achieve two important goals: It provides classroom-based specific feedback, and it gives students opportunity to and experience in identifying and trying to unravel their own misconceptions.” (Tobias, 1989, p. 54).

**Writing in Scientific Genres to “Think like a Scientist”**
According to Keys (1999), using the specific writing genres of scientists helps students to connect the scientific content with the processes used in the scientific community to produce this knowledge. “Writing in scientific genres promotes the production of new knowledge by creating a unique reflective environment for learners engaged in scientific investigations.” (Keys, 1999, p. 119).

Holliday, Yore, and Alvermann (1994) posit that the implied audience in formal scientific writing requires a level of precision and metacognition that more expressive types of writing do not; “Questions that writers might ask themselves in the knowledge-transforming model include: What evidence do I have? What warrants, claims, and logical arguments should I use? What are the array of alternative explanations? What do these ideas mean to the target audience?” (Holliday et al., 1994, p. 886).

“It is important that educators and students recognize and understand the science-specific forms of argumentation and how they differ from the common forms of argumentation...In science, the goals of argumentation are to promote as much understanding of a situation as possible and to persuade colleagues of the validity of a specific idea.” (Michaels, Shouse, & Schweingruber, 2008, p. 89).
Students need to learn the assumptions, procedures, and purposes of scientific writing in order to fully understand the scientific method, explanation, and justification. Knowing these rules allows learners to build conceptual understanding and “construct relationships among ideas.” (Klein, 1999, p. 230).

By learning how to write in scientific genres, Halliday and Martin (1993) conclude that students will also better understand the scientific texts that they read. (Halliday & Martin, 1993).

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

“Although note-taking is not a formal genre of scientific writing, it is, nevertheless, writing that needs scaffolding and supporting if pupils are to improve their rudimentary skills and become independent note-takers…” (Wellington & Osborne, 2001, p. 79).

According to Zywica and Gomez, “the best benefit of annotation…is that because students are focused closely on the structure and content of the text, they become more active and engaged readers.” In addition, scientific knowledge and skills increase; “…students’ annotated science text results, as evaluated by expert teachers, indicated that identification of main ideas, science vocabulary, and transition words was correlated with measures of science achievement.” (Zywica & Gomez, 2008, pp. 156, 164).

“ Asking students to read and understand science content without providing and encouraging the use of strategic reading approaches like annotation, can and frequently does result in poor understanding of content material, limited class discussion (because students don’t understand the material), and lack of interest in science.” (Zywica & Gomez, 2008, p. 157).

According to Sherer et al. (2008), the strategy of annotation can help students to not only comprehend and recall information, but may also help them to read more quickly and accurately because they will know how to identify the most important information while reading. (Sherer et al., 2008).

Boyle and Weishaar (2001) found that note-taking was an effective strategy for students with learning disabilities. When those students were taught a note-taking strategy, they demonstrated higher achievement over the short-term and long-term than students in a control group. (Boyle & Weishaar, 2001).

Notebooking is another strategy that has been shown to empower students for science achievement; “an interactive notebook can be a powerful instructional tool, allowing students to take control of their learning while processing information and engaging in self-reflection.” (Waldman & Crippen, 2009, p. 51).

“…working in a science notebook gives students a chance to practice thinking and writing concisely and clearly. This systematic documentation also allows teachers to gain a new window into the inner thinking of their students and provides a basis for more effective formative assessment.” (Buczynski & Fontichiaro, 2009, p. 7).
A series of studies were conducted to examine the impact of a program of instruction using notebooks on students’ achievement in science. “These studies 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.” (Klentschy, 2005, p. 27).

From their experiences implementing science notebooks in one Arizona school district, Gilbert and Kotelman (2005) conclude that of the many benefits of using notebooks in science, the five most compelling are:

1. Notebooks are thinking tools…
2. Notebooks guide teacher instruction…
3. Notebooks enhance literacy skills…
4. Notebooks support differentiated learning…
5. Notebooks foster teacher collaboration.” (Gilbert & Kotelman, 2005, p. 28-32)
From Research to Practice

The *Houghton Mifflin Harcourt ScienceFusion* program was designed to provide students with numerous opportunities to write about and reflect on the processes they used to make sense of new scientific concepts. Throughout the program, students are asked to write in response to prompts that ask them to engage in various types of thinking and reflection, including:

*Applying and extending concepts.* In order to help students integrate new science concepts with understanding, students are given numerous opportunities before, during, and after reading to apply and extend concepts by considering them in new or different contexts or by making inferences and drawing conclusions.

*Writing expressively about science.* In order to help students integrate new science concepts into their existing schema, and to reflect on what they have learned, students are given opportunities for writing expressively—through letters about concepts or interviews with scientists—about the scientific concepts they are learning.

*Using scientific writing forms and language.* By engaging in the work of scientists, students learn to think like scientists. By writing about experiments—including setting purposes, reflecting on procedures, recording data, and drawing conclusions—students learn the scientific process and the language of science.

*Taking notes while reading and annotation to support comprehension.* Students are guided to take notes and annotate their texts while reading to ensure a focus on key terms and main ideas. Doing so helps students become active readers, and better comprehend and recall important concepts in what they have read.
Strand 2: Vocabulary

…for many pupils the greatest obstacle in learning science – and also the most important achievement – is to learn its language. One of the most important features of science is the richness of the words and terms it uses. (Wellington & Osborne, 2001, p. 3).

Defining the Strand

Sometimes what we say or what we mean to say is misunderstood by others. The words we choose are vital components of our communication with others. Whether that communication is heard or spoken, read or written, or viewed or performed, the vocabulary we select to convey our message is critical.

Broadly defined, vocabulary is knowledge of words and word meanings. It is important to note, however, that vocabulary does not solely consist of knowing words and their meanings; vocabulary encompasses comprehending how words are used in oral and written formats. As Steven 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. 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 et al., 2008, p. 11).

In addition, specific instruction in the science classroom is particularly crucial because “In science, words are often given specific meanings that may be different from or more precise than their everyday meanings.” (Michaels, Shouse, & Schweingruber, 2008, p. 4). Words such as theory, data, or evidence have very specific meanings in the science classroom. In order to avoid confusion, teachers must make clear to students the specific usage of words in science.
Research that Guided the Development of the Houghton Mifflin Harcourt ScienceFusion program

Vocabulary to Comprehend Science Topics

One early researcher in the field of reading comprehension, Frederick B. Davis, focused on specifying the skills most important for comprehension. From his research, he concluded “that two components, word knowledge and reasoning in reading, accounted for 89% of the variance in individuals’ test scores.” (Johnson, Pittelman, & Heimlich, 1986, p. 778; Davis, 1944). In his 1968 article on factors in reading comprehension, Davis concluded that to foster comprehension, teachers must familiarize students with word meanings. (Davis, 1968).

“The vocabulary load in science textbooks also presents a great challenge to middle school and secondary readers because of the heavy use of scientific terminology to explain concepts…This heavy load of technical vocabulary…impedes the reading comprehension of many students.” (Harmon, Hedrick & Wood, 2005, p. 271).

“Science 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). These content words are technical terms, which must be deeply learned in order to learn the science behind them. For example, biology students must not only know that digestion is the assimilation of food in the body, but also understand the process by which digestion occurs.” (Shanahan & Shanahan, 2008, p. 52).

In a study comparing two pre-reading activities, overviews and vocabulary tasks, Snouffer and Thistlethwaite (1979) found that engaging in vocabulary pre-reading tasks positively impacted students’ comprehension of physical science texts. (Snouffer & Thistlethwaite, 1979).

“Pre-reading vocabulary instruction can improve students’ comprehension of their texts and help them retain the concepts that are taught.” (Stahl & Kapinus, 1991, p. 36).

In a study of reading in the content areas, Artley identified both general vocabulary and content-specific vocabulary as key correlates with students’ reading comprehension. His conclusion was that classroom teachers must teach the vocabulary of their content areas and that “the development of a specialized vocabulary should receive equal attention to that given to the development of the facts of the course.” (Artley, 1983, p. 448).

Vocabulary to Connect Scientific Concepts and Terminology

In a discussion of the differences between vocabulary in literature, Armbruster and Nagy (1992) point out the inherent connection of vocabulary terms with concepts. “…[First] Content area vocabulary often represents major concepts that are essential for comprehension and learning. For example, students who cannot give some explanation of the meaning of photosynthesis after a science lesson have probably failed to grasp the
very heart of the lesson. [Second] …new vocabulary in content area lessons is rarely associated with familiar concepts. As students learn new vocabulary, they are also learning whole new concepts. [Third] …vocabulary words in content area lessons often are related in meaning…” (Armbruster & Nagy, 1992, p. 550).

Halliday and Martin (1993) also emphasize the interconnectedness of vocabulary terms and concepts in science, arguing that science language is a resource for reasoning in science and an instrumental resource for communicating scientific ideas. (Halliday & Martin, 1993).

According to Groves (1995) the focus of vocabulary instruction should be on using the terms as a guide to conceptual learning, rather than rote memorization. (Groves, 1995).

"Of the methods of vocabulary instruction that go beyond simple definitions, several are well suited to the content areas because they focus on the relationships among concepts. These methods include semantic mapping…, semantic feature analysis…, and definition maps… What is important is not the particular method, but the emphasis on relationships among concepts.” (Armbruster & Nagy, 1992, pp. 550-551).

Discussion is one 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. Stahl and Clark (1987) investigated the effects of discussion on the science vocabulary learning of fifth-grade students. They found that discussion proved to be more effective in vocabulary learning than having no discussion about the words.” (Harmon, Hedrick, & Wood, 2005, p. 273); (Stahl & Clark, 1987).

**Vocabulary to Increase Achievement in Science**

"Enhancing students’ academic background knowledge…is a worthy goal of public education from a number of perspectives. In fact, given the relationship between academic background knowledge and academic achievement, one can make the case that [vocabulary instruction] should be at the top of any list of interventions intended to enhance student achievement.” (Marzano, 2004, p. 4).

Research by Stahl and Fairbanks indicates that student achievement will increase by 33 percentile points when vocabulary instruction focuses on specific words that are important to what students are learning. (Stahl & Fairbanks, 1986).

From Research to Practice

The *Houghton Mifflin Harcourt ScienceFusion* program 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.

*Explain meanings of words and how they are used.* In addition to teachers explaining vocabulary words and their specialized meanings, students are offered reminders about the definitions of words. Students are also provided with contexts for new vocabulary as related to the concept they are studying. The interactive glossary feature helps students make the new terms part of their own vocabularies.

*Gain strategies for understanding new scientific terms.* In addition to the direct teaching of specific scientific terms, students are also explicitly taught strategies for acquiring vocabulary. Some of these strategies are provided for specific student populations, such as for second-language learners to reflect on multiple-meaning words. Others are provided for all students, such as using word parts or context clues to understand unfamiliar terms.

*Practice vocabulary as related to the scientific concepts.* In order to help students understand and use the terminology of science, they are presented with questions before, during, and after reading which are designed to help students think more fully about the scientific terms and the concepts they describe.

*Review meanings of words and how they are used.* Prior to each new lesson, students are given a chance to show what they know from previous study. Students are given opportunities to use the terms in various ways, such as word play activities, written responses, flow maps, and fill-in-the-blank sentences to further verify what they have learned about a concept.
Strand 3: Scaffolding

Learners face many obstacles in learning science as practice, and they require support in order to engage in it productively. (National Research Council, 2007, p. 271).

Defining the Strand

Many times 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. Similar to scaffolds used by contractors to erect a structure, scaffolds are put in place to support students while gaining knowledge in school.

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. 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).

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. “[Scaffolding] connotes a custom-made support that can be easily disassembled when no longer needed. It also connotes a structure that allows for the accomplishment of some goal that would otherwise be either unattainable or quite cumbersome to complete” (Stone, 1998, p. 344).

In science, educators who seek to achieve conceptual change 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, Shouse, & Schweingruber, 2008, pp. 42-43).
Research that Guided the Development of the Houghton Mifflin Harcourt ScienceFusion program

Scaffolding to Deepen Scientific Understanding and Inquiry

“Scaffolding can help students examine, scrutinize, and critically appraise their understanding of key scientific concepts.” (National Research Council, 2007, p. 277).

“Carefully chosen and sequenced questions and tasks are necessary to scaffold students’ attempts to construct the intended meaning of experiences or presentations of ideas…” (Kesidou & Roseman, 2002, p. 536).

“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 over multiple years. These are known as ‘learning progressions.’ …Learning progressions for K-8 science are anchored at one end by the concepts and reasoning abilities that young children bring with them to school and at the other end by what eighth graders are expected to know about science.” (Michaels, Shouse, & Schweingruber, 2008, p. 63).

In a study of students’ science learning in technology-based environments, Zydney found that scaffolds improved students’ understanding. (Zydney, 2010).

In a series of experiments, Scruggs, Mastropieri, and their colleagues looked at the impact of highly structured inquiry methods. Units on animals, their features, and the uses of those features were taught to students in elementary school. From these studies, researchers concluded that students who were coached to derive their own explanations and elaborate on their own reasoning recalled information more fully and consistently than students who were in an explicitly taught, direct instruction group. (Scruggs, Mastropieri, & Sullivan, 1994; Scruggs, Mastropieri, Sullivan, & Hesser, 1993; and Sullivan, Mastropieri, & Scruggs, 1995).

“Overall, it can be concluded that students with mild disabilities can benefit from guided inquiry and higher-order questioning, but instruction using these methods must be highly structured and supportive.” (Scruggs, Mastropieri, & Okolo, 2008, p. 6).

Scaffolding to Address Previously Held Ideas and Misconceptions

“Teachers … need to know if students hold significant misconceptions about a topic. For example, if students believe that plants have stomachs and digest food much like people, they may not be ready for a lesson on photosynthesis. Before students read content area text, then, teachers must address gaps in background knowledge or misconceptions, even if this means postponing the reading.” (Armbruster & Nagy, 1992, p. 550).

“It takes more than a simple statement of the scientific conception to alter the beliefs of students…Their strong commitment to their misconceptions and the subtle reinforcement of those misconceptions during instruction prevented most of them from even realizing that an alternative way of understanding…existed. The scientific conception must be carefully explained and contrasted with common misconceptions. In a sense, it must be proven to the students’ satisfaction.” (Eaton, Anderson, & Smith, 1984, p. 377).
“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…” (Kesidou & Roseman, 2002, p. 532).

One way to scaffold is to make sure students have a firm handle of concepts they need for future learning, which may include identifying students’ preconceptions and challenging their misconceptions. Making sure students have a solid and accurate grasp of prior knowledge is important to future knowledge acquisition. This relationship “…has a direct effect on their acquiring new knowledge and skill. For example, the student who does not understand addition will be ill-equipped to learn multiplication…” (Barton & Heidema, 2002, p. 4).

“These three features of presentations of scientific conceptions—direct contrast with student misconceptions, immediate application to explaining a phenomenon, and explicit emphasis with repetition—were common to the successful instances of teaching for conceptual change.” (Anderson & Smith, 1987, p. 96).

**Scaffolding to Meet Individual Student Needs**

In describing how her research shows that scaffolding meets varying student needs, Walker (2008) noted, “After demonstrations, teachers continue to support or scaffold the new learning. They often provide continuous support and sustain learning by scaffolding students’ attempts. For example, teachers can deal effectively with inappropriate student responses by using part of the response to probe reasoning.” (Walker, 2008, pp. 18-19). This account demonstrates that scaffolding can be used to intervene with students on an individual level by using an incorrect response to explore thinking.

**Scaffolding to Build Confidence and Independence**

Scaffolding is necessary support to enable students to become responsible for their own learning. As Hyde notes, “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. Like scaffolding along the side of a building that enables the painter to safely work on the outside wall, the scaffolding does not do the work. It enables the person to do it.” (Hyde, 2006, p. 28).

Larkin (2001) learned from interviewing and observing teachers who scaffolded instruction that their students became more independent learners. “Scaffolding principles and techniques can guide teachers to assist students on any grade level to become more independent learners.” (Larkin, 2001, p. 34).

“Our work suggests that providing students with an explicit instructional model for explanation and written explanation scaffolds results in students creating stronger explanations. Specifically, we were interested in whether the fading of the written supports results in greater student learning compared to students who received continuous written supports…Our findings suggest that fading written prompts that include both context-specific and generic explanation supports better equips students to write explanations when they are not provided with support…” (McNeill, Lizotte, Krajcik, & Marx, 2006, pp. 180-181).
Scaffolding to Improve Performance in Science

Mastropieri, Scruggs, and their colleagues (2006) conducted a study to look at the impact of use of multi-tiered (easier to more complex) activities in eighth grade science classrooms. Students in the experimental group who completed the multi-tiered activities demonstrated higher achievement on content tests and end-of-year, high-stakes assessments. (Mastropieri et al., 2006).

“…Our findings suggest that [scaffolding produces] a significant effect on students' test scores…” (McNeill, Lizotte, Krajcik, & Marx, 2006, p. 181).
From Research to Practice

The *Houghton Mifflin Harcourt 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. Throughout the program, scaffolds exist to help students solidify what they know in order to build on it. The program also provides guidance on suggestions for removing these types of scaffolds as students become more advanced in their learning and skills. Scaffolds are in place to help students in the following ways:

**Build meaningful learning experiences.** Students are given opportunities to engage in inquiry on topics that are relevant to the world around them. Offering students meaningful contexts that engage their prior knowledge base is one way to support them as they learn new concepts.

**Review and reflect on previous concepts before moving on.** In order to prepare students for new learning, they are given a chance to review the concepts and vocabulary they have learned previously. This scaffold allows for students to show what they know or reflect on what they have not quite mastered yet, and responsibility for learning can shift to the student.

**Complete activities in a graduated way.** In order to help students as they practice on their own, graduated learning opportunities are used as a scaffold. The program provides guidance for easy, average, and challenging activities and for meeting the needs of beginning, intermediate, and advanced learners. Providing greater scaffolds to learners who need that support, and gradually taking away these scaffolds for learners who can work more independently, has been shown by research to be particularly effective.

**Address misconceptions.** 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. To help students develop new conceptual understandings, the program provides alerts to teachers on common misconceptions students may hold. The teacher background sections highlight common misconceptions that teachers should be alert for among their students.

**Provide opportunities to model or show what they can do.** The 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.
Strand 4: 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

Metacognition is thinking about thinking—knowing “what we know” and “what we don’t know”—and how we can use that information.

Developing a range of thinking strategies needed to approach investigations and solve problems and knowing which strategy to choose are important developments for students. Students need to be aware of what they do well and how they can improve. This encourages them to think about their thinking and learning in order to increase their learning and achievement. Supporting metacognition in school fosters the development of good thinkers who are successful problem-solvers and lifelong learners. Recognizing, developing, and improving the metacognitive capabilities of students is fundamental to learning.

Some basic metacognitive strategies include connecting new information to that previously learned, selecting thinking strategies purposefully, and planning, monitoring, and evaluating thinking processes (Dirkes, 1985). Studies show that the use of metacognitive strategies increases learning. These results suggest that supporting thinking strategies is useful and that independent learning will develop gradually. (Scruggs & Tolfa, 1985).

Regardless of the content area in school, problem-solving and other activities provide opportunities for strengthening metacognitive strategies. It is therefore important to focus student attention on how tasks are accomplished. Emphasizing content goals and process goals will help students discover that understanding and applying thinking processes expands learning.

“Appropriate kinds of self-monitoring and reflection have been demonstrated to support learning with understanding in a variety of areas.” (National Research Council (NRC), 2005a, p. 11). Helping students become more metacognitive about their own thinking and learning is closely tied to teaching practices that emphasize self-assessment. (NRC, 2005a, p.12). Providing support for self-assessment is an important component of effective teaching. This can include giving students opportunities to test their ideas by building things and seeing whether they work, performing experiments that seek to falsify hypotheses. (NRC, 2005a, p. 12).

Reflection is an essential strand 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 science learners. “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, Shouse, & Schweingruber, 2008, p. 20).
Research that Guided the Development of the
Houghton Mifflin Harcourt ScienceFusion program

Metacognition to Comprehend Science Texts

“Much of the research on metacognition focused on the comprehension of text…clearly applies to science, where texts can be quite complex and difficult for many students to comprehend.” (National Research Council, 2005a, p. 407).

Metacognition to Develop Scientific Reasoning

“…more recent research targeted specifically to the monitoring of and reflection on scientific reasoning has also shown promising effects.” (National Research Council, 2005a, p. 407).

In a study on students using a computer-enhanced, middle-school science program, researchers White and Frederiksen (1998) compared the performances of students taught with a curriculum which included a metacognitive component with that of students taught without such a component. Students with the metacognitive component outperformed students not taught with this component – with particularly noticeable gains among lower-achievers. (White & Frederiksen, 1998).

“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…” (National Research Council, 2007, pp. 4-14).

Metacognition to Produce Conceptual Change

“Elementary schoolchildren have much more capacity for metacognitively guided learning than has been commonly supposed…These abilities are typically overlooked and untapped in traditional approaches to science teaching, and, as a result, they not only fail to develop those abilities further, but also reduce the changes of conceptual change.” (National Research Council, 2007, pp. 4-15).

“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, pp. 4-14)

Georghiades’ findings suggest that metacognition is associated with a more durable, long-term understanding of scientific concepts. In a study with primary school science students, Georghiades (2006) concluded that “the experimental application of metacognitive activities achieved some positive impact on pupils’ ability for contextual use of their conceptions of science…pupils may have become more conscious of the potential use of their knowledge and were, therefore, better prepared to identify links between the newly-encountered contexts and their knowledge.” (Georghiades, 2006, p. 44).

Metacognition to Increase Performance

Research by Pogrow (1999) suggests that helping students understand their own metacognitive processes and strategies will help their academic performance. (Pogrow, 1999).
“In earlier studies, students were taught individual reading comprehension strategies such as summarizing and finding main ideas compared with conditions that included self-monitoring (e.g., Graves, 1986; Malone & Mastropieri, 1992). Findings indicated that students who were taught the cognitive strategy plus self-monitoring procedures outperformed peers who had not been taught self-monitoring.” (Mastropieri, Berkeley, Scruggs, & Marshak, 2008, p. 74).

In a scaffolded intervention designed to promote the use of self-directed learning strategies, Conner (2007) concluded that “this study has shown that the students who used metacognitive strategies to plan and monitor their work produced essays of higher quality.” (Conner, 2007, p. 13).

**From Research to Practice**

The *Houghton Mifflin Harcourt ScienceFusion* program was designed to provide students with numerous opportunities to think about their thinking and learning while learning new scientific concepts and engaging in scientific inquiry. Throughout the program, students are asked to respond to prompts that ask them to engage in the following types of planning, monitoring, and reflecting:

*Apply and extend concepts.* Throughout the program, students are asked to apply and extend concepts through think-along questions while reading and prompts for writing after reading. After reading, students are asked to summarize, to check their understanding of key ideas. By asking for these kinds of ongoing checks on comprehension, students take the responsibility for their own comprehension.

*Monitor success by periodic assessment.* In order to help students remember what they have learned, they are given chances to show what they know throughout the worktext. By providing these sections, students are able to assess their own strengths and weaknesses regularly.

*Reflect in a visual or written format.* Students are asked to show what they know by drawing pictures or providing written explanations of scientific concepts. Visual and written responses challenge students to think about what they understand.
Strand 5: Engaging in Inquiry

...there 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

Across the disciplines, active learning has proven to be more effective than passive learning. When students are actively engaged in the process of learning they learn more and retain this knowledge.

Active learning is especially crucial in the sciences. To learn science students must do science. They must describe what they observe, ask questions of themselves and others, formulate hypotheses and explanations, test explanations, and communicate their conclusions.

Becoming a scientist involves both the acquisition of knowledge (laws and theories) and skill with the practices of scientists (observation, experimentation, argumentation). Inquiry is both a process of active exploration and a way of thinking about learning.

Inquiry-based learning has the potential to increase students’ understanding of concepts and their understanding of the nature of science, its skills, and abilities. It has the power to engage students and motivate them to learn.

The National Research Council, in a publication entitled, *Taking Science to School: Learning and Teaching Science in Grades K-8*, 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.
4. Participate productively in scientific practices and discourses.

The National Science Education Standards (NSES 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.
Research that Guided the Development of the Houghton Mifflin Harcourt ScienceFusion program

Inquiry-Based Learning to Improve Understanding and Achievement

“When science teaching emphasizes the results rather than the process of scientific inquiry, students can easily think about science as truths to be memorized, rather than as understandings that grow out of a creative process of observing, imagining, and reasoning by making connections with what one already knows.” (Stewart, Cartier, & Passmore, 2005, p. 523).

“Effective teaching provides students with opportunities to relate the scientific concepts they are studying to a range of appropriate phenomena through hands-on activities, demonstrations, audiovisual aids, and discussions of familiar phenomena…Students need opportunities to apply ideas in a variety of contexts.” (Kesidou & Roseman, 2002, pp. 533-534).

“In pursuit of scientific answers, students engage in practices akin to those of real scientists, such as posing scientific questions, using data to examine complex phenomena, and generating explanations to account for their observations. … there is compelling evidence that when classrooms function to support real scientific practice, students’ understandings of science can flourish.” (Michaels, Shouse, & Schweingruber, 2008, p. 127).

“Appropriate phenomena helps students to view scientific concepts as plausible, or enhance students’ sense of usefulness of scientific concepts…” (Kesidou & Roseman, 2002, p. 533).

“Thus, conceptual change researchers are finding that involving elementary, middle, and high school students in discovery argumentation via cycles of model-based reasoning—practices very similar to those used by scientists themselves—are highly effective means of building these new understandings.” (National Research Council, 2007, pp. 4-16).

“…Carlisle, Fleming, and Gubrandsen (2000) found in two studies that incidental word learning occurred among fourth-grade and eighth-grade students in science classes where teachers used hands-on activities and discussion.” (Harmon, Hedrick, & Wood, 2005, p. 273).

In a study of an inquiry-based learning instructional model in science, Kipnis and Hofstein (2008) found that inquiry-based learning provides a conducive environment for metacognitive thinking; the researchers “found that while performing the inquiry activity, the students…practiced their metacognition in various stages of the inquiry process” by demonstrating an awareness of the task, its demands, and effective strategies for completing the task and by checking and reflecting on their success on the task. (Kipnis & Hofstein, 2008, p. 620).

In a study which compared direct instruction with discovery teaching, students in both groups performed equally well on a posttest administered immediately after intervention, but the discovery-teaching group demonstrated better performance on a measure administered two weeks later, suggesting that active learning can lead to more durable, longer-term knowledge of science. (Bay, Staver, Tanis, & Hale, 1992).
In a study of 172 fourth-grade students, 33 of whom were learning disabled, Dalton, Morocco, Tivnan, & Rawson Mead (1997) implemented to an experimental group a hands-on, inquiry-based science curriculum which included a focus on scaffolding and addressing students’ misconceptions. Students in this experimental group, including LD and urban students, outperformed peers in a control group, which engaged in hands-on activities but without attention to misconceptions and metacognition. (Dalton et al., 1997).

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

Inquiry-based learning empowers students. As Kuhn, Black, Keselman, & Kaplan (2000) argued, 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.” (Kuhn et al., 2000, p. 496)

Active learning can take many forms, among them modeling and demonstrations by teachers. These types of demonstrations can lead to increased achievement, as shown by NAEP results: “Across all racial/ethnic and school disadvantage groups, scores are lowest in the ‘never or hardly ever’ category and highest in the category of ‘one or two times a week’ [for the instructional strategy of teachers doing a science demonstration]. For all levels of school disadvantage, Black students are 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).

In a research study of the impact of an inquiry-based, computer-enhanced, middle-school science program on urban middle school students, researchers White and Frederiksen (1998) summarized their findings as follows. “Our first major finding is that one can successfully teach sophisticated, inquiry-based science in urban schools….We also found that learning inquiry improves students' learning of science concepts, laws, and models as well as their ability to use them in analyzing new situations. We found correlations between measures of students' success in learning and applying science knowledge and their success in learning to do inquiry….Learning inquiry is particularly effective in meeting the needs of educationally disadvantaged students….[and] It is desirable to introduce inquiry-based science early in the school curriculum.” (White & Frederiksen, 1998, pp. 73-76).

In a study of special education students, Scruggs, Mastropieri, Bakken, and Brigham (1993) found that students who engaged in inquiry-based instruction that was oriented towards activities and experiments consistently outperformed control-group students who studied the same topics in a textbook-only condition. (Scruggs, Mastropieri, Bakken, & Brigham, 1993).
From Research to Practice

The *Houghton Mifflin Harcourt ScienceFusion* program was designed to provide students with numerous opportunities to observe and engage in scientific inquiry. In order to develop students’ skills with inquiry, 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 to reflect on their thinking and develop stronger inquiry skills.

Throughout the program, in the print path, hands-on inquiry activities, and the digital path, students are engaged in scientific inquiry in the following ways:

**Investigations and labs.** 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.

**Inquiry flip charts.** The Inquiry Flip Charts provide students with additional opportunities to explore scientific concepts further, and to continue to engage in the thinking and practices of scientists.

**Digital virtual labs.** Taking advantage of the benefits of instruction via computer, the program provides online virtual lab experiences for students.
Bibliography


