JOURNAL OF RESEARCH IN SCIENCE TEACHING VOL. 47, NO. 1, PP. 47–70 (2010)

# A Method for Analyzing the Coherence of High School Biology Textbooks

Jo Ellen Roseman,[1] Luli Stern,[2] Mary Koppal[1]

*[1]AAAS Project 2061, 1200 New York Ave., NW, Washington, District of Columbia 20005*
*[2]Havruta High School for Leadership and Culture, Ruppin College, Emek Heffer 40250, Israel*

*Received 4 June 2008; Accepted 8 March 2009*

Abstract: Because textbooks have the potential to be powerful catalysts for improving science teaching and learning, having reliable methods for analyzing important textbook features, such as their coherence, is essential. This study reports on the development of a method in which trained reviewers, following a set of guidelines defining the ideas to be learned and connections among those ideas drawn from relevant maps published by the American Association for the Advancement of Science in the *Atlas of Science Literacy* (2001), were able to analyze the degree to which four widely used high school biology textbooks provided students and teachers with a coherent account of the important topic of matter and energy transformations in living systems. The study method was found to produce consistent results across reviewers and textbooks and can serve those who evaluate, design, and use science curriculum materials. This work represents an important first step in meeting the need for methods to measure, characterize, and, ultimately, to improve textbook coherence. © 2009 Wiley Periodicals, Inc. J Res Sci Teach 47: 47–70, 2010

**Keywords:** biology; physical science; curriculum development; standards; textbooks; science education; science literacy; secondary; critical theory; experimental

## Introduction

A central premise of today's standards-based approach to science education is that science-literate people possess knowledge that is richly interconnected, forming an integrated understanding of the world and how it works (American Association for the Advancement of Science [AAAS], 1989; AAAS, 1993; National Research Council [NRC], 1996). According to this view, rather than knowing fragmented bits and pieces of information, high school graduates would understand how the most important ideas fit together and be able to apply them in a variety of contexts. The knowledge that students acquire by the end of high school would subsequently serve as a foundation for their continuous lifelong learning. This view is shared by Project 2061 of the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and many other national and local organizations. In their recommendations for what all K-12 students should know and be able to do in science, mathematics, and technology, both AAAS and the NRC recognized that the explosion of knowledge in these fields made both a complete and coherent understanding of them difficult, if not impossible, to achieve in the time available for schooling. Both organizations recognized the need to choose, out of all the possibilities, a core set of essential and interconnected ideas and skills in these domains that could serve as a basis for making sense of observable events, making personal and social decisions, and learning more.

Knowledge of the relationships among ideas and of the deeper structures that connect the particulars is critical for science-literate adults. Studies comparing the knowledge and abilities of experts and novices in a discipline illustrate the advantages of a richly connected understanding (Chi, Feltovich, & Glaser, 1981; Larkin & Reif, 1979; Markham, Mintzes, & Jones, 1994). An interconnected understanding has been shown to increase long-term retention of the knowledge (Arzi, Ben-Zvi, & Ganiel, 1985) and to facilitate transfer of

---

*Correspondence to*: M. Koppal; E-mail: mkoppal@aaas.org
DOI 10.1002/tea.20305

knowledge to new situations (Perkins & Salomon, 1988). According to Bruner, understanding the connections among ideas enables learners to integrate new ideas into what they already know: "The only possible way in which individual knowledge can keep proportional pace with the surge of available knowledge is through a grasp of the relatedness of knowledge" (1960/1995, p. 333).

Although science literate adults are not expected to have expert knowledge on any particular science topic, insights about knowledge organization can be gained from studies comparing experts and novices. These studies indicate that expertise itself is characterized by having a large amount of interconnected knowledge and knowing when it can be applied to the situation at hand (Chi et al., 1981). Experts have an "efficient organization of knowledge with meaningful relations among related elements clustered into related units that are governed by underlying concepts and principles" (Chi et al., 1981). A comparison of concept maps created by experts and novices, for example, showed that experts included more concepts and far more connections in their maps (Markham et al., 1994). Based on these studies, one might expect that as students are able to integrate more and more ideas, their understanding of a topic and the ideas encompassed in it also increases.

Nevertheless, a number of other studies indicate that students often have difficulties making the conceptual connections that are needed to integrate ideas. The knowledge that many students have consists of bits and pieces of often naïve and conflicting ideas (Clark & Linn, 2003; Clough & Driver, 1986; Demastes, Good, & Peebles, 1996; diSessa, 1988; diSessa, Elby, & Hammer, 2002). For example, diSessa noted that physics students' attempts at solving problems involved piecemeal explanations that depended on a problem's context rather than on a coherent theory—whether Newtonian or impetus (1988, pp. 56–60). And Clark and Linn showed that students demonstrate between 10 and 25 different ideas about heat at each interview. Although Chi and Slotta (1993) argued that intuitive physics knowledge may be organized around categories (e.g., materials or processes) rather than fragmented, they concluded that these categories are not necessarily useful in helping students organize their knowledge if doing so requires that they link observations and ideas that they have already sorted into alternative categories. Evidently, connections such as those involved in relating phenomena to relevant scientific ideas are not spontaneously made by learners and, hence, need to be brought out explicitly during instruction. Bagno and Eylon (1997) showed that learning of electromagnetism—including recall, conceptual understanding, and problem solving— improves when students are explicitly asked to connect related concepts within a network.

### *Role of Textbooks*

Among the many factors that can affect students' learning, the central role of textbooks has been widely acknowledged (Ball & Feiman-Nemser, 1988; National Educational Goals Panel, 1998; Tyson, 1997; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Because most teachers rely on textbooks to define both what and how they teach, high-quality textbooks can be a powerful catalyst for improving learning for students and teachers alike (Ball & Cohen, 1996; Davis & Krajcik, 2005; Schmidt, McKnight, & Raizen, 1997). We contend that to be considered high-quality, textbooks must themselves be coherent and help students make the connections necessary to organize their new knowledge into a coherent and meaningful whole.

Several studies from the reading comprehension literature provide empirical support for the important role that coherent text-based materials can play in learning (Ainsworth & Burcham, 2007; Britton & Gulgoz, 1991; Linderholm et al., 2000; Best, Rowe, Ozuru, & McNamara, 2005; McKeown, Beck, Sinatra, & Loxterman, 1992; McNamara & Kintsch, 1996; McNamara, Kintsch, Songer, & Kintsch, 1996). For example, Linderholm et al. (2000) showed that improving the causal structure of social studies text passages, including "repairing coherence breaks caused by inadequate explanation, multiple causality, or distant causal relations" (p. 546), benefited undergraduate students regardless of their reading ability.

The literature also points to the significant role that readers' prior knowledge plays in their ability to understand text, generate inferences, and form appropriate mental models. Best et al. (2005) argued that successful comprehension of science texts requires the reader to generate inferences to fill in gaps left by the authors. Readers with organized knowledge on a topic are at an advantage in making such inferences, even when dealing with less coherent text (i.e., text with many gaps). Although earlier studies by McNamara et al. (1996) and McNamara and Kintsch (1996) found that only students with low prior knowledge benefited from reading coherent text, Ainsworth and Burcham (2007) have since found that students with both low and high prior knowledge benefit from coherent text that encourages learners to self-explain. The authors argue that "self-explanation and increasing coherence of text for novices are therefore two independent routes by which learners can be supported" (p. 300). It appears, then, that to form an organized mental model requires a coherent textual presentation of the new ideas, adequate prior knowledge, and active processing by the learner to integrate both new and prior knowledge. Because K-12 students are likely to be novices for most science topics (indeed, one could argue that the purpose of introductory biology texts is to present information to novices), presenting them with a coherent story on these topics is essential.

It should be noted that all of the previously cited reading comprehension studies involved text passages of about a thousand words (the shortest was 400 words; the longest was 3,500 words although these extremes were exceptions). None of the studies examined the cumulative effects of multiple sections or chapters of a textbook on students' comprehension of a set of ideas on a broad topic. Moreover, attempts to repair coherence in the experimental studies did not rely on content-specific strategies, such as connecting the generalizations to the instances presented, but rather on generic strategies, such as clarifying referents and argument overlap between adjacent sentences (e.g., Britton & Gulgoz, 1991; McNamara and Kintsch, 1996; McNamara et al., 1996) or making causal repairs to text (e.g., Linderholm et al., 2000).

### *An Operational Definition of Content Coherence*

Despite the importance of coherent textbooks to student learning, the field lacks adequate methods for characterizing curriculum coherence involving specific ideas across broad topics. The TIMSS analysis of curriculum focused on broad science and mathematics topics within the entire K-12 scope and sequence (Schmidt et al., 2001) but did not consider coherence at the fine grain size of specific ideas within topics or the extent to which connections were made between specific ideas.

For the work reported on here, we define science ideas as propositions that can be investigated and hence supported or refuted by data; ideas are at the grain size of what can be rejected or believed based on evidence and thereby be remembered and connected to other ideas. We argue that learning occurs at the grain size of ideas—whether scientifically correct ideas or misconceptions. If we want to gauge the contribution that textbooks could make to learning and use what we learn as a basis for improving them, we need to understand what textbooks do (and don't do) on each broad topic at the grain size of specific ideas and the interconnections among them. By operationalizing content coherence in science—that is, by developing a consensus on what it means, what it looks like for a given topic, and how to characterize and measure it—the study has produced a method that can serve those who evaluate, design, and use science curriculum materials.

Consistent with the findings of Ainsworth and Burcham (2007), we believe that the coherent presentation of an interrelated set of ideas and connections among them, though not sufficient for learning, is an essential characteristic of curriculum materials that aim to foster the development of an integrated understanding by students (Roseman, Linn, & Koppal, 2008). To further support students' learning, science textbooks should also include a range of pedagogical features that are designed to help students build on their prior knowledge and overcome their misconceptions, experience real-world phenomena and representations of phenomena that clarify abstract ideas and make them plausible, understand the purpose of what they are doing, and make sense of and apply their ideas in a variety of new contexts. Although not a focus of the work reported on here, Project 2061 has developed a set of pedagogical criteria to measure the extent to which these and other instructional supports are included in high school biology textbooks (AAAS, 2005a). We are also studying the extent to which the inclusion of these supports improves mathematics teaching and learning (DeBoer et al., 2004; Willson, Wilson, & Roseman, 2009).

Prior studies have described the two phases of our curriculum-materials analysis procedure (Roseman, Kesidou, & Stern, 1996) and its application to the evaluation of middle school science textbooks (Kesidou & Roseman, 2002, 2003; Stern & Roseman, 2004). The first phase involves a rigorous analysis of the science content presented in curriculum materials on related topics. A subsequent instructional analysis examines the quality of instructional support provided for that content, such as whether materials illustrate the ideas with a range of interesting phenomena, use effective representations of the ideas, and provide questions to guide student interpretation of the phenomena and representations in light of the ideas (Roseman et al., 1996).

To facilitate judgments about content alignment in the first phase, the individual benchmarks on the selected topics are teased apart into "key ideas," and reviewers are asked to judge whether the textbooks include subject matter that aligns with each one. By unpacking the benchmarks into their component ideas, reviewers are able to reach consensus on the extent of alignment in each textbook. In the middle school science textbook analysis, reviewers were also asked to consider whether textbooks made connections among key ideas and between key ideas and other ideas, but they were given little guidance in what to look for as evidence that such connections had been made. A method for undertaking a more rigorous evaluation of the extent to which textbooks presented a science topic coherently did not exist at that time. The purpose of the study described in this article was to develop and test such a method in the context of high school biology textbooks. Our aim was to help move the field toward textbook analysis that considers broad science topics at the fine grain size of specific ideas and their interrelationships.

## Developing a Method for Analyzing Content Coherence

We began our work by first identifying a high school biology topic that was sufficiently broad and interrelated to serve as the focus of our analysis. We then wrote detailed guidelines to specify what coherence on that topic would consist of—that is, the key ideas and connections among them—and to define criteria for judging whether a textbook presented the key ideas and connections. Review teams were then trained to understand the key ideas and connections and to apply the criteria. The final stage of the study reported here involved testing the method on selected textbooks and analyzing the consistency of the review teams' judgments.

### *Selection of Topic*

We chose the topic of transformations of matter and energy in living systems because the key ideas are included in national and state science standards as well as in all high school biology textbooks, and yet students have considerable difficulty learning them. An extensive research base on K-12 students' learning describes their persistent difficulties in understanding ideas about food, plant and animal nutrition, and matter cycling even after relevant instruction (Anderson, Sheldon, & Dubay, 1990; Bell & Brook, 1984; Leach, Driver, Scott, & Wood-Robinson, 1996a,b; Roth & Anderson, 1987; Smith & Anderson, 1986; Stavy, Eisen, & Yaakobi, 1987; Wandersee, 1985). The seemingly intractable nature of these difficulties is underscored by interviews with new graduates of prestigious universities who reveal that, at best, they hold only a fragmented understanding of the topic, despite having taken relevant courses in high school and even in college (Sadler, Schneps, & Woll, 1989). The research base also offered insights about conceptual connections that students do not appear to make on their own; this along with insights about connections among ideas based on the logic of the relevant disciplines enabled us to specify which connections were important for textbooks to make.

Presenting a coherent story on the topic of matter and energy transformations involves articulating and connecting many different key ideas that span four levels of biological organization (molecule, cell, organism, and ecosystem) and depend heavily on knowledge in physical science (e.g., recombination of atoms in chemical reactions and energy forms and transformations among them). These key ideas and their prerequisites are typically distributed across many chapters in biology textbooks, making the need for explicit connections even more critical. Using this topic provided a stringent test of the analysis method and allowed us to examine the validity and consistency of reviewers' judgments across a range of connections and across a range of books that differed in how they sequenced their presentation of the ideas.

### *Defining Coherence*

In general terms, we think that coherent textbooks should (a) present a set of age-appropriate scientific ideas and connections among them; (b) clarify the ideas and connections with effective representations (Champagne, Gunstone, & Klopfer, 1985; Spiro, Feltovich, Coulson, & Anderson, 1989; Strike & Posner, 1985); (c) illustrate the application of the ideas to objects, events, and processes in the real world (i.e., natural phenomena) (Anderson & Smith, 1987; Champagne et al., 1985; Strike & Posner, 1985); and (d) avoid the use of unnecessary technical terms or details that are likely to distract students from the main story (Garner & Gillingham, 1989; Harp & Mayer, 1998).

A coherent story on the topic of matter and energy transformation in living systems should describe the processes at all four levels of biological organization and relate them to each other. By the end of eighth grade, students are expected to have a basic understanding of matter and energy transformations at all levels of biological organization (see AAAS, 1993; National Center for Education Statistics, 2009; NRC, 1996). A high school biology textbook could, in principle, start its presentation of the topic at any level, stitching the unknown ideas to the known (using well-chosen examples of phenomena and effective representations) as it moves from one level to the next. For example, on the matter side of the story, a textbook could show how the carbon-containing sugar molecules made in plant cells are building blocks for a variety of macromolecules that plants assemble to make their body parts (leaves, stems, roots, flowers). When animals, including humans, eat plants, they break the macromolecules back down to building blocks (not individual atoms) and then adapt and reassemble the building blocks to make their own body parts. To present a coherent story, a textbook could also show how both plants and animals return carbon atoms to the air, where plants can then incorporate them into sugar molecules. In doing so, textbooks would be able to explain the growth and decay of organisms and matter cycling in ecosystems in terms of a small number of chemical reactions in which atoms are conserved.

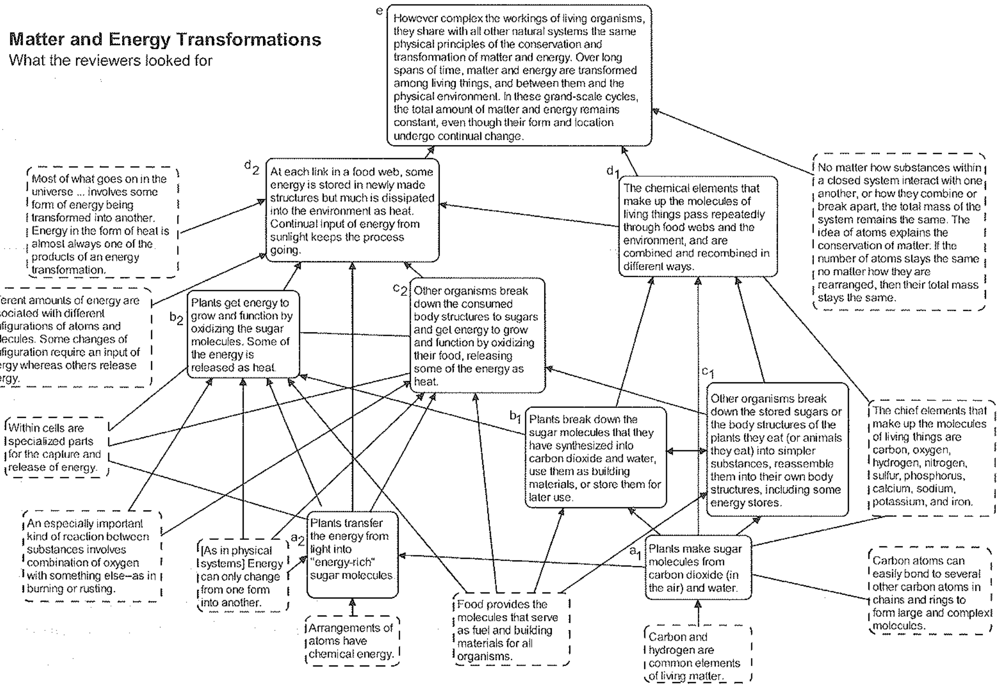
If students are well grounded in conservation in terms of observable mass and numbers of atoms in simple inorganic reactions, a coherent textbook presentation could start at the atomic/molecular level and show that the same principles apply in simple biochemical reactions. If students are well grounded in human body systems, a coherent presentation could start at the organism level and show that organisms grow by building macromolecules from digestion products and using the macromolecules to build body structures. If students have studied how single-celled organisms satisfy their needs, a coherent presentation could start at the cell level and show that prior to its division into two cells, a cell grows by synthesizing macromolecules from smaller molecules it takes in from its environment. Or if students have an understanding of the interactions of organisms in ecosystems, a coherent presentation could start there and then zoom down to interactions at the level of organisms, cells, and molecules. Since the prerequisites for any level are included in national and many state standards, a textbook could, in principle, start the matter story at any level.

The story of energy transformations, particularly transformations involving chemical potential energy, is much more abstract, and, therefore, likely to be more challenging for students and for textbook developers. However, if introductory biology students can already make sense of energy transformations involving more directly observable forms (e.g., light to thermal energy, gravitational potential energy to motion) and also understand ideas about the conservation of matter in living systems, then textbooks could present energy conservation in living systems by making the analogy to matter conservation. Chemical energy could then be introduced to account for energy that seems to appear from nowhere or to disappear (e.g., body motion is possible because muscle cells transform chemical energy to motion energy).

### *Written Guidelines*

As noted above, our analysis of content coherence took place at the grain size of ideas and the connections among them. To assist textbook reviewers in carrying out their analyses, written guidelines were developed by consultants and members of the Project 2061 staff who had a sophisticated understanding of the set of ideas on the topic, familiarity with the research on students' learning difficulties, knowledge of Project 2061's instructional criteria, and experience in interpreting and using the national standards documents. The guidelines were designed to ensure the consistency of review teams' judgments and to allow the teams to devote most of their time to considering the textbooks and making their judgments rather than to reaching consensus on the meaning of the ideas or the intent of benchmarks and standards. Nonetheless, the review teams were given time during their training to make sense of and apply the guidelines, challenge them, and to suggest changes if needed. The full text of the guidelines is available on the Web (AAAS, 2005c,d).

*Specification of Key Ideas.* The set of key ideas is displayed in Figure 1 and includes ideas about both matter transformation (indicated with subscript 1) and energy transformation (indicated with subscript 2) in the context of food making in plants (Ideas $a_1$ and $a_2$) and their breakdown or use in further synthesis in plants (Ideas $b_1$ and $b_2$), other organisms (Ideas $c_1$ and $c_2$), and in ecosystems (Ideas $d_1$ and $d_2$). The set culminates



e However complex the workings of living organisms, they share with all other natural systems the same physical principles of the conservation and transformation of matter and energy. Over long spans of time, matter and energy are transformed among living things, and between them and the physical environment. In these grand-scale cycles, the total amount of matter and energy remains constant, even though their form and location undergo continual change.

$d_2$ At each link in a food web, some energy is stored in newly made structures but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going.

$d_1$ The chemical elements that make up the molecules of living things pass repeatedly through food webs and the environment, and are combined and recombined in different ways.

Most of what goes on in the universe ... involves some form of energy being transformed into another. Energy in the form of heat is almost always one of the products of an energy transformation.

No matter how substances within a closed system interact with one another, or how they combine or break apart, the total mass of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.

Different amounts of energy are associated with different configurations of atoms and molecules. Some changes of configuration require an input of energy whereas others release energy.

$b_2$ Plants get energy to grow and function by oxidizing the sugar molecules. Some of the energy is released as heat.

$c_2$ Other organisms break down the consumed body structures to sugars and get energy to grow and function by oxidizing their food, releasing some of the energy as heat.

$c_1$ Other organisms break down the stored sugars or the body structures of the plants they eat (or animals they eat) into simpler substances, reassemble them into their own body structures, including some energy stores.

Within cells are specialized parts for the capture and release of energy.

$b_1$ Plants break down the sugar molecules that they have synthesized into carbon dioxide and water, use them as building materials, or store them for later use.

The chief elements that make up the molecules of living things are carbon, oxygen, hydrogen, nitrogen, sulfur, phosphorus, calcium, sodium, potassium, and iron.

An especially important kind of reaction between substances involves combination of oxygen with something else—as in burning or rusting.

[As in physical systems] Energy can only change from one form into another.

$a_2$ Plants transfer the energy from light into "energy-rich" sugar molecules.

$a_1$ Plants make sugar molecules from carbon dioxide (in the air) and water.

Carbon atoms can easily bond to several other carbon atoms in chains and rings to form large and complex molecules.

Food provides the molecules that serve as fuel and building materials for all organisms.

Arrangements of atoms have chemical energy.

Carbon and hydrogen are common elements of living matter.

*Figure 1.* The map shows the set of ideas and connections that served as the basis of the analysis. Key ideas are in solid boxes; related ideas are in broken boxes. Matter ideas are on the right half of the map, and energy ideas are on the left half. Arrow heads indicate a sequential relation between ideas, and lines indicate a non-sequential relation.

with an idea (Idea e) relating both matter and energy transformations in living systems to the physical principles of transformation and conservation of matter and energy.

*Specification of Connections.* In addition to identifying a set of key ideas, the guidelines also specified important conceptual connections among ideas within the set that would be required to tell a coherent story for the topic. We designated which connections needed to be made explicit in textbooks and characterized the nature of each connection through the use of examples.

To represent the connections we wanted reviewers to look for within the set of ideas, we adapted two conceptual strand maps from *Atlas of Science Literacy* (AAAS, 2001) that display progressions of ideas from kindergarten through 12th grade. Focusing on the high school grade band of the maps, we then added prerequisite ideas (including some from physical science) and ideas from other strand maps that were conceptually related (Roseman, Kurth, Kesidou, & Stern, 2004). We used arrows and lines to identify the connections between ideas and articulated the nature of each connection in accompanying prose. Sometimes the nature of a connection is simple, such as when one idea is an instance or a consequence of another idea. Such connections were explicit in *Science for All Americans* (AAAS, 1989) through the use of the phrases "for example" and "as a result." Hence, *Science for All Americans* provided valuable insights into the relationship between ideas and was used to clarify the kinds of connections we expected textbooks to make. For convenience, we organized the connections into (1) connections among key ideas and (2) connections to other ideas, both prerequisite and related ideas. The set of desired connections is shown in Figure 1.

*Connections Among Key Ideas.* Connections among key ideas about matter and energy transformations are shown in Figure 1. These connections involve relating the processes of transformation at different levels of biological organization and between matter and energy. For example, matter transformation in ecosystems (Idea $d_1$) is a consequence of the individual transformations of matter in the organisms that make up the ecosystems (Ideas $a_1$, $b_1$, and $c_1$). For students to appreciate that the chemical elements that make up the molecules of living things pass repeatedly through food webs and through the environment and are combined and recombined in different ways (Idea $d_1$), they need to understand key ideas about the synthesis of sugar molecules (Idea $a_1$) and the breakdown, further synthesis, and storage of sugar molecules in plants and other organisms (Ideas $b_1$ and $c_1$). They also need to understand that the recycling of elements in food webs results from repeated cycles of synthesis, storage, and breakdown in the organisms that make up the ecosystem.

*Connections to Other Ideas.* Presenting a coherent story involves linking the new ideas to be learned to students' prior knowledge (Bishop & Anderson, 1990; Eaton, Anderson, & Smith, 1984; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; McDermott, 1984) and to other related ideas that add depth or detail to the story. For example, the *prerequisite idea* that "carbon and hydrogen are common elements of living matter" provides important information that is needed to understand a few simple transformations of matter in organisms, starting with the idea that "plants make sugar molecules from carbon dioxide (in the air) and water" (Idea $a_1$). Textbooks could make a connection between these two ideas by explaining that carbon dioxide and water contain the elements carbon and hydrogen (and also oxygen) and that photosynthesis by plants begins the process of incorporating these elements into larger molecules, which can then lead to their incorporation into even larger molecules and body structures (part of Ideas $b_1$ and $c_1$). Connections such as these between key ideas and their prerequisites are represented in Figure 1.

Prerequisites for this topic were identified from strand maps in *Atlas* (AAAS, 2001), lists of learning goals in *Benchmarks for Science Literacy* (AAAS, 1993), or from the list of related ideas suggested in the "Also see" box in *Benchmarks* (AAAS, 1993, p. 118). Prerequisites for this topic typically come from the sections of Chapter 4 of *Benchmarks* that deal with the structure of matter (pp. 78–79) and energy transformations (pp. 84–86).

In principle, any set of key ideas connects with many other ideas; defining boundaries for a topic—or story—is always somewhat arbitrary. Because of the demands of carrying out first the content phase and then the instructional phase of the analysis for each idea, we considered only a limited number of key ideas for each topic. Nevertheless, there were additional *related ideas*, other than prerequisite ideas, that, if treated in the textbook, could strengthen students' understanding of one or more of the key ideas and provide additional coherence to their understanding of the topic.

If, for example, a textbook presented the idea that "within cells are specialized parts for the capture and release of energy," it could be used to reinforce students' understanding of key ideas about the release of that energy by plants and animals (Ideas $b_2$ and $c_2$). A textbook could make a connection between this idea and Ideas $b_2$ and $c_2$ by pointing out that cells with high energy needs tend to have more of the specialized parts for releasing energy than cells with lower energy needs. Likewise, a textbook could point out that cells located on the upper surface of leaves—where there is more direct access to light energy—have more specialized parts for capturing the sun's energy than cells located on the undersurface of leaves. Our selection of related ideas was informed by *Science for All Americans*, which, in its discussion of matter and energy transformations, explicitly mentions that energy-releasing chemical processes occur in cells (AAAS, 1989, p. 66). The related ideas and connections between them and the key ideas that reviewers were to look for are shown in Figure 1.

### *Training Reviewers*

We identified eight reviewers with the knowledge and experience needed to carry out the analysis of content coherence. All held a bachelor's degree in biology or chemistry, six had a master's degree in science or science education, one had a Ph.D. in science, and one had a Ph.D. in science education. All reviewers had some science teaching experience, and at least one member of each team was an experienced high school biology teacher. All were proficient in clarifying and using the learning goals in *Benchmarks*. Based on their individual qualifications, reviewers were paired so that each two-member review team had all of the scientific and educational expertise needed to carry out the work.

Review teams participated in a one-day training to familiarize themselves with the key ideas and their connections to prerequisite and related ideas for the topic of matter and energy transformations. Their training consisted of:

- reading the prepared guidelines that clarify the meaning of the key ideas, connections that might be made among them, and criteria for judging the extent to which textbooks actually present the ideas and make the connections;
- discussing the guidelines with their partner and the other reviewers;
- applying their understanding of the guidelines to make judgments about content alignment and the presence of connections in a sample material; and then
- reconciling their judgments with the other reviewers, based on evidence found in the sample material and on arguments consistent with the written guidelines.

Review teams used the textbook *BSCS Biology: An Ecological Approach* (Biological Sciences Curriculum Study, 1998) as a case study during their training. As described below, this textbook provided a range of examples that were used to illustrate the kinds of issues that could arise when making judgments about alignment and connections.

*Judging Alignment.* Alignment of a textbook's content was determined for each of the ideas (key, prerequisite, and related) for the topic. A positive judgment about alignment could be made on the basis of only a single reference to explicit evidence found in either the student textbook or in the teacher guide. Moreover, a textbook did not need to present all parts of an idea in the same place; if different parts of an idea were presented on different pages, a textbook could still receive credit for alignment to the full idea. As indicated in the written guidelines, review teams could also give textbooks partial credit for alignment if they presented some but not all parts of an idea.

The guidelines described in detail the requirements for a content match. For instance, the guidelines explained that matter transformations were to be viewed as chemical reactions and that chemical reactions involve the rearrangement of atoms of the starting materials to make the molecules of the products:

> The essence of all these ideas is transformation (as opposed to just naming the reactants and products). It must be explicit that something is being transformed (or converted, made into, changed, etc.) into something else. Furthermore, at the grades 9–12 level transformations of matter are dealt with at the molecular level (as opposed to substances changing into other substances)... (AAAS, 2005d)

To receive credit for alignment to *particular* key ideas about matter transformation, textbooks needed to be explicit about transformation of molecules in the context of the particular process involved. Reviewer guidelines for judging alignment to Idea $b_1$, for example, stated that:

> This idea describes the three possible fates of the sugar molecules plants make: plants can transform some of the sugar molecules back into carbon dioxide and water molecules, they can assemble them to make body structures, or they can store them for later use. A material gets credit for an incomplete match for covering fewer than three of these fates. Look to see [if] there is something explicit about transforming molecules or about atoms combining or rearranging. And look to be sure that the material is explicit about what the sugar molecules will be used for (as opposed to being just used or used up). The material must also be explicit about plants. Although credit is given for a statement that "all living things" carry out this process, note in the report if this is the case. (AAAS, 2005d)

The training case study textbook provided a straightforward example of a *complete content match* for this idea and illustrated how a textbook could be explicit about the rearrangement of atoms and the alternative fates of the sugar molecules synthesized during photosynthesis. These ideas were treated completely and most simply in two chapters early in the book:

> Both energy and matter are stored in sugars...the plant can use the sugar molecules to make other molecules that it needs to build its body. To do this, a plant rearranges the atoms in the sugar molecules and adds new atoms. (Biological Sciences Curriculum Study [BSCS], 1998, pp. 12–13s)

> The sugars created during photosynthesis can be used in four ways by the plant, as shown in Figure 4.24 on page 86. First, the plant may break down the sugar molecules immediately to release the stored energy. This happens during respiration. The energy that is released from the sugars during respiration may be used by plant cells to continue the activities of life. Second, a plant may use the sugar molecules for growth. In this case, many sugar molecules are joined together to make the building materials necessary for more cells . . . Third, the plant may store sugars for future use . . . Fourth, sugar molecules may be converted into the other biological molecules needed for life . . . A plant also returns carbon dioxide to the air when it uses its own sugars as a source of energy. (BSCS, 1998, pp. 84s and 86s)

In a much later chapter, the ideas were embedded in details of the photosynthesis reactions:

> Several things can happen to the 3-carbon sugar that leaves the Calvin cycle. In the stroma of the chloroplast, the sugar can be converted into starch and stored . . . or it can be used to synthesize . . . compounds needed in the plant cell . . . The 3-carbon sugar also may enter the pathway of glycolysis and cellular respiration, providing energy for all plant cells. (BSCS, 1998, pp. 493–494s)

For some of the key ideas, making judgments about what and what not to count as evidence of alignment was particularly challenging for the review teams. Consider, for example, the following guidelines for judging alignment to Idea $d_1$:

> There are several parts to this idea: that chemical elements (as opposed to just examples of elements such as carbon or nitrogen) pass through food webs, that elements pass repeatedly through food webs (so more than one round in a cycle needs to be indicated), and that as the elements pass through food webs they are combined and recombined in different ways. To receive full credit for a content match, the material must treat all parts. The material gets incomplete credit for treating only some parts. Furthermore, full credit is given only if the three parts all deal with matter in terms of molecules. As with other ideas that state generalizations, describing instances without explicitly stating the generalization receives credit for an incomplete match. For example, giving examples of elements that recycle (such as in the carbon cycle or the nitrogen cycle) without making clear that all the elements that make up the molecules of living things recycle receives only incomplete credit for this part of the key idea. "Repeatedly" means over and over again, so describing a single cycle of carbon through a food chain and back to carbon dioxide is insufficient for full credit. The material should indicate that plants can then reuse the carbon dioxide (that was released during respiration) to make sugars. (AAAS, 2005d)

The relevant content presented in the case study textbook was difficult for review teams to analyze and required several readings and much discussion before they were able to make a judgment about the textbook's treatment of matter cycles (Idea $d_1$). Because the textbook dealt only with instances—that is, with carbon and nitrogen—rather than with generalizations that could be applied to all elements that make up the bodies of living things, the review teams found it to be only *partially aligned.* As evidence, they noted that although the *BSCS Biology* text mentioned iron, sodium, and calcium in the context of describing the nutrients in pizza (p. 373s), it did not point out that the pizza is but one step in the continual recycling of these elements. Moreover, the review teams determined that the textbook treated ideas about recycling at the substance rather than the molecular level. Although the textbook included the phrase, ". . . carbon containing molecules are broken apart, releasing both carbon atoms and energy . . ." (p. 86s), it did not make clear that atoms are recombined into different molecules during the cycle. Additional evidence for this judgment on the alignment of content in the case study textbook to Idea $d_1$ is presented in the online content analysis report (AAAS, 2005b).

*Judging Connections.* The guidelines also described connections in the textbooks that review teams were to look for and suggested ways that textbooks might link ideas through the use of proximity, context, comparison, analogy, causality, or example. Given the many links that might be made from one idea to another and the lack of empirical data demonstrating that some kinds of connections are more helpful than others, the guidelines for judging connections were less precise than those for judging alignment.

Whatever the type of connection being made, textbooks were expected to state the ideas that were being connected and describe explicitly what the relationship was between them or between parts of them. The following excerpt from the guidelines illustrates how a textbook could make connections among key ideas about matter transformations:

> One way to make connections between ideas about matter transformations in individual organisms (Ideas $a_1$, $b_1$, and $c_1$) and matter transformations in ecosystems (Idea $d_1$) would be to state that the combination and recombination of molecules in food webs is the sum of all the combinations and recombinations of molecules that occur among the individual organisms that make up the food web. This also serves to make the link at the molecular level. (AAAS, 2005c)

The review teams found that the case study textbook explicitly related the making of sugar molecules by plants (Idea $a_1$) to their use of sugar molecules for growth (Idea $b_1$) in terms of the rearrangement of atoms:

> Plants and animals are made up of many different compounds, but the atoms used to make up these compounds occur all around you in the non-living world. For example, plants use the simple compounds of carbon dioxide and water in photosynthesis . . . During photosynthesis, the plants build complex compounds. Using light energy, they link together the atoms from carbon dioxide and water to make sugars . . . the plant can use the sugar molecules to make other molecules that it needs to build its body. To do this, a plant rearranges the atoms in the sugar molecules and adds new atoms. (BSCS, 1998, pp. 12–13s)

Later in the book, the case study text related plant growth (Idea $b_1$) to animal growth (Idea $c_1$) in terms of the rearrangement of atoms:

> As a plant grows, its body becomes larger. If the plant is eaten, the carbon in the plant is passed from producer to consumer. For the consumer to use the food, it must break down the plant body. As this happens, the carbon containing molecules are broken apart, releasing both carbon atoms and . . . Some of the carbon from the body of the plant is added to the body of the consumer. The rest of the carbon is exhaled into the air as carbon dioxide . . . (BSCS, 1998, p. 86s)

In the next example, the guidelines described how and why textbooks needed to make connections between key ideas and prerequisite ideas about energy transformations (Ideas $a_2$ and $c_2$ in Figure 1):

> These grades 6–8 prerequisite establishes the possibility that molecules can be "energy-rich" and thus frames the way key idea $a_2$ is to be viewed: sugars are "energy-rich" because of the arrangements of their atoms. One way to make a connection between this key idea and its prerequisite is to restate the key idea using the language of the prerequisite: the synthesized sugars are "energy-rich" because of the arrangement of carbon, hydrogen, and oxygen atoms that make it up. (AAAS, 2005c)

The review teams found that in this case *BSCS Biology: An Ecological Approach* missed opportunities to make connections between the key ideas and their prerequisites:

> . . . the text could have connected the prerequisite idea that "arrangements of atoms have chemical energy" to energy transformation in photosynthesis (Idea $a_2$) but failed to do so. The text states that "chemical energy is found in the structure of the molecules that make up the meat and potatoes" (p. 10s) but does not state the prerequisite itself or explain that the energy to arrange the atoms in the molecules of meat and potatoes came from the sun's energy. Similarly, a figure that compares burning and cellular respiration (p. 77s, Figure 4.10) could have been used to connect the prerequisite that "an especially important kind of reaction between substances involves combination of oxygen with something else—as in burning or rusting" and cellular respiration (Idea $c_2$). However, the prerequisite idea is not presented. (AAAS, 2005b)

### *Testing the Method*

The study was designed to assess whether our method for analyzing content coherence produced consistent results when applied by two independent teams of trained reviewers to different materials under well-defined conditions. This meant working with a range of textbooks that provided sufficient content coverage of the matter and energy transformations topic to adequately test the method. It also meant that review teams needed to examine the same content in each of the textbooks. To reduce unnecessary variability in review teams' judgments and ensure that they were working with a uniform set of content "sightings" in the textbooks, the teams were provided with a comprehensive set of page number references in both the student and teacher editions. Compiled by the same consultants and Project 2061 staff who had prepared the guidelines, the references pointed to pages in the textbooks where content relevant to each key idea was presented—in text segments, activities, assessments, and elsewhere. (See Appendix for the handout of page references used to locate key ideas, prerequisites, and related ideas in each of the four textbooks included in the study.) While review teams were encouraged to identify and cite additional evidence in the textbooks, and all attempted to do so, only rarely was additional evidence found.

To ensure that the study would provide information on how well our analysis method worked when applied to different types of textbooks, we selected both commercially developed materials and materials developed with funding from the National Science Foundation (NSF). Our middle school textbook evaluation had shown that NSF-funded books often organized content differently from commercially developed books (Kesidou & Roseman, 2002; Stern & Roseman, 2004). The following textbooks were selected: *Biology: A Community Context*, South-Western Educational Publishing (Leonard & Penick, 1998); *Biology: Principles & Explorations*, Holt, Rinehart and Winston (Johnson & Raven, 1998); *Biology: Visualizing Life*, Holt, Rinehart and Winston (Johnson, 1998); and *Insights in Biology*, Kendall/Hunt Publishing Company (Educational Development Center, 1998).

*Applying the Method.* Each of the four textbooks was analyzed by two independent review teams. Each two-member team used the guidelines and list of content sightings to analyze two textbooks. The team then compared and reconciled its judgments about the books' content alignment and connections with the judgments made by another team that had analyzed the same books using the same guidelines and sightings.

The review teams spent about six hours analyzing each textbook. To ensure that the time and effort required of the teams were similar, each pair of teams examined one NSF-funded textbook and one commercially developed textbook. Because the NSF-funded textbooks tended to contextualize content more than the commercially developed books did (and used alternatives to the discipline-based organization of the content found in the commercial textbooks), teams might have had more difficulty making judgments about alignment and connections in the NSF-funded texts. We also attempted to balance the sheer volume of material that pairs of teams needed to examine. For example, the NSF-funded *Insights in Biology* (Education Development Center, 1998), which devoted more pages to the matter and energy transformations topic, was paired with the "thinner" commercially developed *Holt Biology: Visualizing Life* (Johnson, 1998).

Review teams were expected to adhere to the written guidelines for judging content alignment and connections and to cite evidence for their judgments that was consistent with these guidelines. In applying the written guidelines, the teams looked at sightings in both the student and teacher editions of a textbook. They did not count as evidence any background information that textbooks provided solely for teachers; the information had to be intended for use by students as well. However, they did count as evidence material included in the teacher's guide, such as assessment tasks and classroom questions, when it was made clear that teachers were to discuss the task expectations and the suggested responses with their students. After examining each of the referenced pages, review teams first determined whether the content presented there was salient to a judgment about alignment or connections and then whether it supported a positive or negative judgment. Because of the vast scope of the matter and energy transformations topic, our focus was on gathering data for as many ideas and connections as possible within the limited time available for the study. For that reason, the teams were asked to make relatively straightforward "yes" or "no" judgments rather than to "grade" or "rate" the quality of alignment or connections. However, more detailed descriptions of precisely what the review teams found for each idea—including commentary on the nature and quality of a textbook's content alignment and connections—are provided in reports written by Project 2061 staff after review teams had reconciled their judgments. For example, the reports indicate the contexts and locations in which ideas were presented in the textbooks, whether ideas appeared only once or multiple times, and whether ideas were represented in diagrams or were the focus of discussions or investigations. Reports for each textbook in the study are available on the Web at http://www.project2061.org/publications/textbook/hsbio/report/browse.htm, and an example from the report on *Insights in Biology* is presented below.

To summarize and report on their judgments and facilitate discussion within and, later, between review teams, the teams recorded their findings on the "Matter and Energy Transformations: What reviewers looked for" map (see Figure 1). For each judgment about the alignment of a textbook's content to an idea or about a connection between two ideas, the teams represented their findings by highlighting on the map those specific ideas or parts of ideas for which there was evidence of alignment in the textbook's content and recorded page numbers where evidence was found to support that judgment. Similarly, they highlighted arrows on the map to represent instances when a textbook had made the appropriate connections between ideas and recorded the page numbers. To assist in reconciling their findings with those of the other review teams analyzing the same textbooks, reviewers also noted the reasons for their judgments. In addition, some teams distinguished between strong and weak connections by representing the latter with a dashed arrow. Figure 2 shows a detail from a map prepared by a review team prior to reconciliation.

Analysis of the coherence of the content for the topic of matter and energy transformations in living systems required the review teams to make 25 judgments per book about alignment[1] and 22–33 judgments per book about connections.[2] Each team reviewed two textbooks, requiring it to make 50 judgments about alignment and either 48 or 63 judgments about connections. After each team reported its initial judgments,

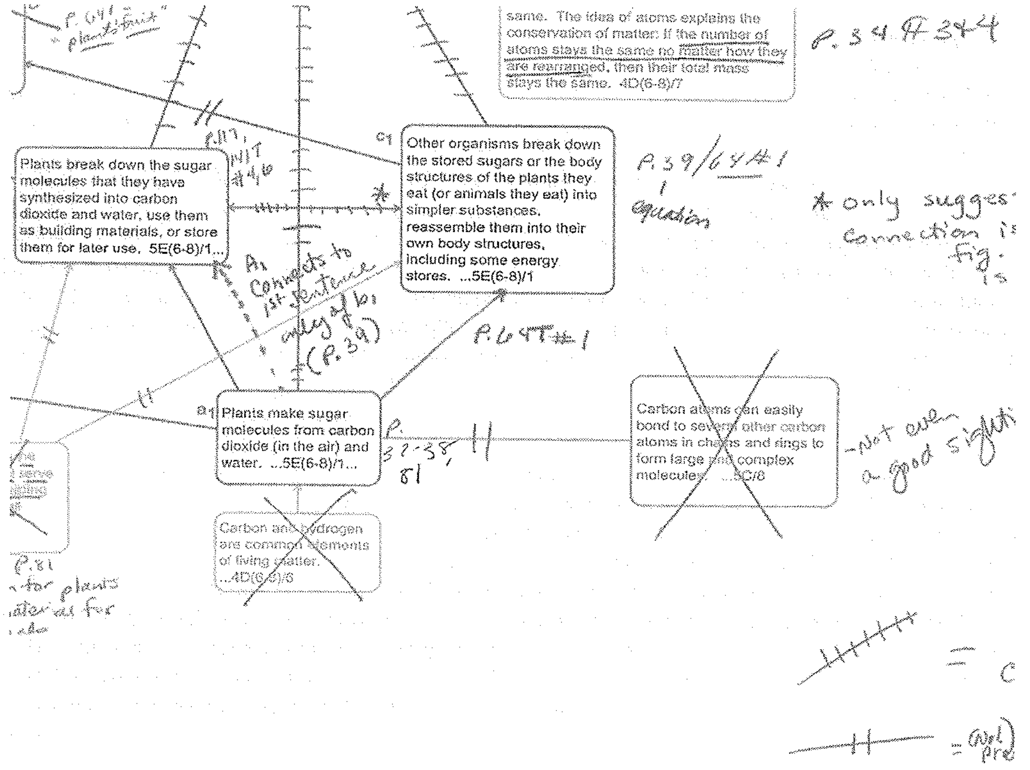


*Figure 2.* Reviewers note where there is evidence in the textbooks to support their judgments about alignment and connections.

Table 1
*Agreement about judgments on alignment*

| Textbook (Type of Developer) | Review Teams | % Agreement (No. of Judgments) | % Agreement by Team Pairs |
|---|---|---|---|
| Biology: A Community Context (NSF-funded) | A and B | 96 (25) | 96 (50) |
| Biology: Principles and Explorations (commercial) | A and B | 96 (25) | |
| Insights in Biology (NSF-funded) | C and D | 92 (25) | 94 (50) |
| Biology: Visualizing Life (commercial) | C and D | 96 (25) | |

pairs of review teams met to discuss their findings and reconcile their judgments. Their final reconciled judgments were based on a reconsideration of the evidence cited by both teams and on the written guidelines. The consistency of judgments about the four selected textbooks was examined by the study staff before the reconciliation process began. Judgments made by the review teams on each part of each idea and on each connection were compared to see whether or not they agreed.

*Results on Alignment.* As shown in Table 1, out of 100 judgments about alignment (25 judgments for each of four textbooks) review teams agreed on 95 and disagreed on five. There was little difference in the extent of agreement across review teams or textbooks. Although not shown in Table 1, the results across the key ideas showed very little variability as well.

The following examples illustrate the nature of the teams' judgments and the ways in which their initial judgments agreed and disagreed. In their reviews of *Biology: A Community Context* (Leonard & Penick, 1998), for instance, Teams A and B both pointed to the following text statements (the first from the student edition and the second from the teacher edition) as evidence for alignment to parts of Idea $b_1$ that deal with use and storage of sugars by plants:

> [P]lants convert light energy (sunlight) to chemical energy (sugars). Plants use these sugars for growth, the production of biomass, and metabolism. Plants store within their cells any sugars that they do not need for growth. Usually, these are stored in the form of starch. (p. 88s)
>
> The mass of plants increases as a result of photosynthesis because only about 50 percent of the sugar (carbohydrates) made from photosynthesis is consumed as fuel. . .Some of the remaining sugars are linked together to make . . . cellulose. Cellulose is a major component of cell walls . . . the remaining sugars are made into starch, which can be stored more easily than can the sugars . . . Cellulose and stored starch make up a large portion of a plant's mass. (p. 141t)

Both teams also pointed to other sections of the textbook where additional relevant information could be found. As evidence for alignment to the part of Idea $b_1$ that deals with the breakdown of sugar molecules, for example, the teams referred to a discussion in the student edition of the combination of the symbolic equation for respiration (p. 39s) and a diagram of the carbon cycle (p. 40s), which notes that respiration is carried out by plants and animals.

Similarly, in their reviews of *Insights in Biology* (Education Development Center, 1998), both Teams C and D pointed to the following paragraph in the student edition as evidence for content alignment to parts of Idea $b_1$ that deal with plants' use and storage of synthesized sugars:

> Sucrose is synthesized when fructose and glucose are joined together to form a molecule containing two separate sugar molecules (disaccharide). Sucrose is the major sugar that is transported throughout a plant and is the starting material for many other molecules in the plant. Sugar molecules can also join together as links in long chains called polysaccharides. The starch that you tested for in the "You Light Up My Life" investigation is an example of a polysaccharide. Starch consists of many glucose molecules joined together. Starch serves as food storage for the plant: when food is needed the starch is broken down into simple sugars. The sugars can then be transported wherever in the plant they are needed as building blocks and energy sources. (p. 24s)

However, Teams C and D differed in their initial judgments about whether the textbook aligned to the part of Idea $b_1$ that deals with the breakdown of synthesized sugars by plants into carbon dioxide and water. Team C initially credited the textbook with alignment, citing the paragraph quoted above, but Team D thought that although the paragraph was explicit about plants' use of sugars to make and store starch and to break down starch into sugar molecules, it did not address the breakdown of those sugar molecules into carbon dioxide and water. Without this part of the story, students could not be expected to understand why germinating seeds produce carbon dioxide and water or why a sprouting bulb decreases in mass as it grows underground. In reconciling differences in their judgments, the teams agreed that the idea of breakdown of sugar into carbon dioxide and water is not treated explicitly in the paragraph quoted above or elsewhere in the textbook. The report on *Insights in Biology* (Education Development Center, 1998) explains their reconciled findings:

> The idea that plants break down sugar molecules into carbon dioxide and water is treated only in a question following the text presentation of the metabolism of glucose: "Do you think that photosynthetic organisms carry out this process? Why or why not? Where would the glucose come from?" (p. 67s, question 2). However, the teacher's guide provides no answer to this question, indicating only that "This reading presents a summary overview of the processes of metabolism and the critical role that oxygen plays" (p. 94t). The reading itself deals with inputs and outputs of glycolysis, the subsequent breakdown of pyruvate, and the transfer of electrons to oxygen in living organisms, but is not explicit about plants (pp. 62–66s). Plants are only mentioned at the beginning of the reading, when mentioning the role plants play in converting sunlight into chemical energy (in sugar) and their use of sugar as building blocks for carbohydrates, proteins, lipids, and nucleic acids (p. 62s). (AAAS, 2005a)

As in the example above, disagreements about initial judgments usually involved a review team reading more meaning into a textbook's content than the textbook actually presented.

*Results on Connections.* As shown in Table 2, the consistency of review teams' judgments about connections among key ideas was considerably lower (ranging from 47% to 73% agreement) than the consistency of judgments about connections between key ideas and other ideas (from 78% to 100% agreement).

Review teams resolved differences about their judgments during the reconciliation process, and their consensus judgments for each textbook were recorded on a "what the reviewers found" map as part of the detailed reports on biology textbooks (AAAS, 2005c). The following examples illustrate the nature of the judgments that review teams made and the nature of their agreements and disagreements.

In their reviews of *Biology: Principles and Explorations* (Johnson & Raven, 1998), both Team A and Team B pointed to a diagram and accompanying text statement as evidence of an explicit connection being made between ideas about energy transformation in plants (Idea $b_2$) and in animals (Idea $c_2$). In the context of its presentation of the carbon cycle in ecosystems, the text states that "nearly all living organisms... perform cellular respiration," and the diagram shows that both plants and deer carry out respiration (p. 351s, Figure 16.16), thus relating Ideas $b_2$ and $c_2$. Both teams agreed that this text makes it explicit that plants and other organisms share the main process of energy release. Teams C and D also reached agreement on the same connection in their review of *Insights in Biology* (Education Development Center, 1998), finding that the textbook did not make a connection between the two ideas.

In contrast, Teams A and B initially disagreed in their judgments of the following text from *Biology: Principles and Explorations* (Johnson & Raven, 1998). Team A gave it credit for connecting ideas about matter transformation among organisms (Ideas $a_1$, $b_1$, and $c_1$) and between organisms and ecosystems (Idea $d_1$), but Team B found it to be insufficient:

> [Photosynthesizing plants, algae, and bacteria] trap the carbon atoms of carbon dioxide within the living world. Carbon atoms return to the pool of carbon dioxide in the air and water in three ways. One way is through cellular respiration. Nearly all living organisms, including plants, perform cellular respiration. They use oxygen to oxidize organic molecules during cellular respiration, and carbon dioxide is a byproduct of this reaction... (p. 351s)

During the reconciliation process, Team A argued successfully that the first two sentences in this example traced carbon atoms from the air to plants and from them to the rest of the living world (making a connection between Idea $a_1$ and both Ideas $c_1$ and $d_1$). They also found that the remaining sentences, along with a diagram illustrating plant and animal respiration, traced carbon atoms from plants and animals to the air in the environment (making a connection between both Ideas $b_1$ and $c_1$ and Idea $d_1$). Team B had initially not thought the description of the fate of carbon atoms was sufficiently explicit about transformation for students to grasp this important point. In the end they agreed that they were applying too rigorous a standard to this particular piece of text.

Arguments used by review teams to justify their judgments were consistent with the written guidelines which included clarifications of the key ideas and the connections between ideas. Reviewers typically explained a lack of alignment to the key ideas by citing a textbook's failure to treat an idea at the molecular level, to be explicit about the rearrangement of atoms to make new molecules, or to present the generalization stated in the key idea rather than just an instance of the idea. When explaining their judgments about the presence of connections in the textbooks, review teams were careful to note which parts of ideas were being connected. When reviewers found that textbooks did not make the necessary connections, they noted missed opportunities to connect ideas or to present the relevant ideas in close proximity.

## Summary and Discussion

The results of our study show that two pairs of review teams conducting parallel analyses of biology textbooks, carried out under the conditions described above, were able to reach highly consistent judgments about alignment to the ideas that served as the basis of the analysis (96% for Teams A and B and 94% for Teams C and D; see Table 1). The difference between the two pairs of teams amounted to only a single judgment. In making judgments about connections, however, both pairs of teams were less consistent (an average of 67% agreement for Teams A and B across two books and an average of 79% for Teams C and D across the other two books; see Table 2).

This difference between the consistency of judgments about connections compared with judgments about alignment may be attributed to the more complex judgments that teams were required to make when analyzing connections and the lower level of guidance provided for making such judgments. An alignment judgment involved a relatively simple consideration: Does a piece of text or a suggested response to a discussion question match a key idea? In contrast, a connection judgment required a more nuanced consideration: Is the connection sufficient to relate the two ideas to each other?

In general, we think that the nuanced judgments about the presence or absence of connections were more difficult to make, leading to greater variation in each review team's judgments and hence to increased differences in judgments between review teams. This explanation is supported by our data showing differences in the consistency of judgments about different kinds of connections: teams were less consistent in their judgments about connections among key ideas than in their judgments about connections between key ideas and other ideas. Because textbooks were more likely to make connections among key ideas, review teams had to make more of the difficult, nuanced, and, ultimately, less consistent judgments about them.

Table 2
*Agreement on judgments about connections*

| | | % Agreement (No. of Judgments) | | | |
|---|---|---|---|---|---|
| Textbook (Type of Developer) | Review Teams | Among Key Ideas | Between Key Ideas and Others | Across All Ideas | % Agreement by Team Pairs |
| Biology: A Community Context (NSF-funded) | A and B | 47 (15) | 87 (15) | 67 (30) | 67 (63) |
| Biology: Principles and Explorations (commercial) | A and B | 53 (15) | 78 (18) | 67 (33) | |
| Insights in Biology (NSF-funded) | C and D | 73 (11) | 100 (11) | 86 (22) | 79 (48) |
| Biology: Visualizing Life (commercial) | C and D | 67 (15) | 82 (11) | 73 (26) | |

Because textbooks were much less likely to make connections between key ideas and other ideas and rarely presented the ideas in close proximity, review teams were much more likely to determine that the textbooks had simply not made the necessary connection at all. In these cases, review teams did not move on to the next step and make the more nuanced judgments about the quality of the connections.

Moreover, as noted above, the guidelines for making judgments about connections were less explicit than the guidelines for making judgments about alignment. The guidelines for making judgments about alignment reflect what was learned from observing reviewers make similar judgments on this topic during the earlier middle school textbook analysis; a comparable base of experience for making judgments about connections did not exist. Subsequent studies on this topic will be able to build on work reported here and include more explicit guidance about connections.

The connections judgments of Teams C and D showed somewhat greater consistency than the judgments of Teams A and B. Averaging across key ideas and connections the pairs of teams made, Teams C and D agreed on 79% of their connections judgments whereas Teams A and B agreed on 67% of their judgments about connections. We do not know whether these differences reflect variations in the proficiency of review teams in applying the method, in the number of connections judgments (63 vs. 48) teams had to make, in the difficulty of the connections judgments required by the different textbooks the pairs of teams were asked to analyze, or some combination of these.

Although we did not systematically study the conditions that contributed to the consistency of reviewers' judgments we think that both the written guidelines and the training played important roles. Review teams' use of evidence and arguments closely adhered to the written guidelines that were provided to them, and the more explicit the guidelines were in clarifying the key ideas, the higher the level of consistency reviewers reached in their judgments about alignment. The training gave reviewers time to reflect on and apply the written guidelines in the context of analyzing a "case study" textbook that was chosen for its potential to surface the kinds of issues that arise. As reviewers worked together to make judgments and reconcile them, they made sense of the written clarifications, increased their knowledge of the rules governing judgments, and practiced their skills in applying them. Based on these results, a similar set of written guidelines are being used in the development of assessment items that are carefully aligned to specific science ideas. The guidelines are also used in the training of reviewers who analyze the items for their likely effectiveness as accurate measures of students' understanding of the targeted ideas (DeBoer, Dubois, Herrmann Abell, & Lennon, 2008).

### *Implications for Student Understanding*

Although the method described in this article takes account of important contributors to content coherence, it is important to note that a positive judgment about a connection in no way guarantees that students would understand the connection or what it might imply. To promote an integrated understanding, content coherence in textbooks must be more carefully elaborated. For example, textbooks could explain to teachers the significance of specific connections rather than merely pointing to them. More importantly, textbooks could actively engage students in thinking about the connections and encourage them to reflect on their ideas and to monitor their own growth of understanding as was examined in our instructional analysis (see below) and confirmed in Bagno and Eylon (1997). Textbooks that included these desired qualities would foster the self explanations shown by Chi (2000) to be valuable for learning.

Nor does this method address the variety of ways in which textbooks' instructional design could either support or undermine students in forming a coherent, well-integrated understanding of that content. To study these aspects of textbook quality, we have developed a set of criteria for evaluating the instructional strategies that textbooks use to help students make sense of science ideas and apply them appropriately. Derived from what is known about effective science teaching and learning, the criteria have been used in multiple studies to evaluate whether and how textbooks take account of students' preexisting knowledge; provide a variety of phenomena and representations to make science ideas plausible and intelligible to students; use questions and other activities to guide students' interpretation and reasoning; and foster a sense of purpose, motivation, and classroom environment that promote learning in students from diverse backgrounds (AAAS, 2000, 2002; Kesidou & Roseman, 2002; Stern & Roseman, 2004).

Analyses using both the content coherence method and the instructional criteria can generate important and useful insights on textbooks' potential for helping students learn specific ideas. Nevertheless, such theoretical studies, however valuable, can take the field only so far. Empirical studies are needed to identify the kinds of connections among ideas and the nature of the instructional strategies that contribute most to students' coherent understanding of particular ideas. Our own research with students in the context of assessment development has revealed significant and persistent gaps in their understanding of a wide range of science topics (DeBoer, Herrmann Abell, Wertheim, & Roseman, 2009; Varnum & DeBoer, 2008). Our assessment findings point to the need for a new generation of science curriculum materials that are based on a solid theoretical foundation and tested through rigorous empirical studies.

### *Implications for Science Curriculum Research and Development*

In light of the consistent judgments achieved in our study, we think this approach to analyzing content coherence can contribute to further research on curriculum coherence and to the design of more coherent curriculum materials. Keeping in mind the purposes and limitations of the method used in our study, we think this method could be applied to other topics typically covered in high school biology textbooks as long as the ideas and connections for each topic are thoroughly defined and clarified. Indeed, in a subsequent evaluation, we used this method to analyze the extent to which four additional high school biology textbooks presented coherent content for the matter and energy transformations topic. The method was also applied to three other biology topics—cell structure and function, natural selection, and heredity (AAAS, 2005a).

Likewise, we see no reason why this method could not be used to analyze textbooks across other subject areas and grade levels, provided the steps described above are strictly followed. These steps include identifying a coherent and developmentally appropriate set of key ideas on a topic, clarifying in writing the relevant ideas and connections among them, analyzing a case study textbook and then using it to train reviewers, and giving reviewers enough time to make sense of and practice applying the written guidelines to a variety of relevant examples (and to modify the guidelines to address any issues that arise).

The role that the written guidelines play in assuring consistent and reliable results cannot be overstated. As noted earlier, efforts to develop adequate guidelines began with an evaluation of middle school science textbooks some years prior to the work described here (AAAS, 2002). Those guidelines specified the ideas to be used as the basis for the evaluation of the middle school textbooks and described what alignment to each idea might look like. More elaborate guidelines were used in the high school biology textbook evaluation (AAAS, 2005c,d) and in the development of assessment items aligned to benchmark ideas (DeBoer, Lee, & Husic, 2008).

It should be evident that considerable time is needed to prepare a set of useable guidelines on a topic, but resources do exist that can be helpful. The conceptual strand maps in *Atlas of Science Literacy* (AAAS, 2001, 2007) provide a reasonable starting point for identifying related ideas on many of the most important topics in science, mathematics, and technology. *Science for All Americans* (AAAS, 1989), with its rich prose and many examples, is another valuable resource. And, through an effort to design assessment items on a dozen middle school science topics, written clarifications are being prepared on each key idea to be learned and assessed. Findings from interviews with students and from pilot and field tests of the assessment items will further clarify which connections are most essential to students' understanding (DeBoer, Dubois, et al., 2008).

Our approach to analyzing content coherence can also play a role in the development of new curriculum materials by providing developers with methods for taking a more systematic look at the overall structure and narrative of their materials and how the individual pieces fit together. The approach can help developers to describe the conceptual story to be presented in a material, identify the specific learning goals to be targeted, and clarify the connections to be made among the relevant ideas. Taking this approach generates a set of content design specifications to guide the material's development at each stage of the process.

This kind of careful thinking about the ideas to be learned has been part of the process used by developers as they worked on two middle school science curriculum materials: *Interactions in Physical Science* (formerly *Constructing Ideas in Physical Science*) (Goldberg, Bendall, Heller, & Poel, 2003) and *Investigating and Questioning our World through Science and Technology* (*IQWST*) (Krajcik & Reiser, 2007). Describing their approach as a "learning-goals-driven design model," the *IQWST* developers began their work by first identifying in *Benchmarks* and *National Science Education Standards* the content to be targeted in their curriculum units. To ensure a close alignment of the ideas addressed in the curriculum with those specified in the standards, the *IQWST* developers unpacked each standard to consider "the science concepts articulated. . .in depth and how they link to other science ideas" (Krajcik, McNeill, & Reiser, 2008). The science content was then mapped beginning first with the relevant maps from *Atlas of Science Literacy* followed by the construction of more detailed maps for each sequence of ideas. According to the developers, mapping enabled them to "[see if the ideas] hang together, determine what the big ideas. . .are, and develop learning progressions or an instructional sequence for the development of more complex understandings over time" (Krajcik et al., 2008). Heller (2001) described a similar effort used in the early stages of development of *Interactions* and notes important implications of this approach. First, the initial thinking through of the conceptual stories across a year's worth of physical science topics took the developers several months. Second, the attempts by developers to incorporate into the materials adequate scaffolds and supports for effective teaching and learning led to a considerable reduction in the number of learning goals that could be targeted—from 45 to 19 (Heller, 2001).

### *Implications for Teacher Learning*

Curriculum materials that do not present a coherent and interconnected story of the science content place a huge burden on teachers. Arzi and White (2008) showed that even experienced teachers have an incomplete and fragmented knowledge of the content they teach. As a result, teachers may not on their own recognize the connections between ideas that students need to appreciate.

Drawing on their 17-year longitudinal study of factors affecting changes in teachers' content knowledge, Arzi and White concluded that curriculum is the tool "with the highest potential for promoting teacher knowledge" (2008, p. 248). Although Ball and Cohen (1996) argued that textbooks can be an important source of teacher learning, they suggested that the nature of that learning depends in large measure on how the text is written and how it attends to what teachers may already know. And although Ball and Cohen (1996) and Davis and Krajcik (2005) have pointed to the role that a textbook's teacher guide could play in improving teachers' content knowledge—for example, by making clear the important ideas and connections among them that are addressed in the textbook—the authors did not elaborate or explain how a textbook might accomplish this. We believe that by providing succinct yet accurate descriptions of the ideas to be learned and examples of how those ideas connect to prerequisite and other related ideas, similar to the written guidelines used in this study, textbooks could become more effective tools for improving teachers' knowledge and practice.

Unfortunately, textbooks are not fulfilling their potential as supports for teachers. When the analytical approach described in this paper was applied to the evaluation of high school biology textbooks, we found that across four important biology topics—matter and energy transformations, molecular basis of heredity, cell structure and function, and evolution and natural selection—textbooks did not make important connections among ideas (AAAS, 2005a; Kurth & Roseman, 2001; Roseman & Caldwell, 2001; Roseman & Kurth, 2000). None of the textbooks presented the necessary connections nor did they alert teachers to the need for making these relationships among ideas explicit to their students. In the absence of curriculum materials that are designed to educate teachers about these connections, teachers could benefit from examining the written guidelines prepared for reviewers in this study. We think that understanding the interconnectedness of these ideas is an essential component of teachers' content knowledge and should be part of their professional development.

Understanding the purpose and use of the analytical method described in this paper may also have value to pre-service and in-service teachers who need to be able to recognize and evaluate the key features of curriculum materials. Aspects of the method have been incorporated into modules used in pre-service elementary and secondary science methods courses used at Michigan State University and the University of Michigan (Davis, 2006; Fortus & Kanter, 2005; Schwarz et al., 2008). The modules are designed to help beginning teachers identify the strengths and weaknesses of their materials and to adapt the materials accordingly (Davis & Varma, 2008).

## Conclusion

The findings presented here indicate that the coherence of high school biology textbooks can be consistently judged using *Science for All Americans*, *Benchmarks for Science Literacy*, *National Science Education Standards*, and the strand maps in *Atlas of Science Literacy* as the basis for defining coherence, in conjunction with the learning research that informed the substance and grade-level placement of ideas in these documents. It is likely that similar results could be obtained if high school chemistry, physics, or earth science textbooks were analyzed under similar conditions. This is because, like the biology story chosen as the basis for the study reported on here, the high school-level stories for these subjects as described in *Science for All Americans* are coherent from the perspective of their disciplines. These are the kinds of stories that in Bruner's words help students "... sense the simpler structure that underlies a range of instances." (1960/1995, p. 333).

We offer this analytical approach as one that is consistent with the recommendations of the National Research Council, which has called for multiple approaches to evaluating the effectiveness of curriculum materials, including "careful and ... sophisticated content analyses" that can be used to "inform the conduct of comparative studies" (2004, p. 95). Although it requires a painstaking and time-consuming effort, this approach can be a cost-effective first step towards identifying materials that are ready for large-scale and more expensive empirical testing. If science educators, policy makers, and the public are serious about having students actually understand a set of important science ideas (rather than simply memorizing isolated facts that will soon be forgotten), then it is essential that textbook coherence be taken seriously.

## Notes

[1] Each key idea required between one and five judgments, depending on the number of parts specified in the clarification document.

[2] If a textbook did not show alignment to any part of an idea then it could not earn credit for a connection. This reduced the number of possible connections that reviewers needed to look for.

## References

Ainsworth, S., & Burcham, S. (2007). The impact of text coherence on learning by self-explanation. Learning and Instruction, 17(3), 286–303.

American Association for the Advancement of Science. (1989). Science for all Americans. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). Benchmarks for science literacy. New York: Oxford University Press.

American Association for the Advancement of Science. (2000). Middle grades science textbooks: A benchmarks-based evaluation. Retrieved on October 16, 2006, from http://www.project2061.org/publications/textbook/mgsci/report/index.htm.

American Association for the Advancement of Science. (2001). Atlas of science literacy, Vol. 1. Washington, DC: American Association for the Advancement of Science.

American Association for the Advancement of Science. (2002). Algebra textbooks: A benchmarks-based evaluation. Retrieved on January 15, 2009, from http://www.project2061.org/publications/textbook/algebra/report/index.htm.

American Association for the Advancement of Science. (2005a). High school biology textbooks: A benchmarks-based evaluation. Retrieved on October 16, 2006, from http://www.project2061.org/publications/textbook/hsbio/report/content.htm.

American Association for the Advancement of Science. (2005b). High school biology textbooks: A benchmarks-based evaluation of BSCS Biology: An Ecological Approach. Retrieved on January 12, 2009, from http://www.project2061.org/publications/textbook/hsbio/report/reports/bscsEcological/meContent.htm.

American Association for the Advancement of Science. (2005c). High school biology textbooks: A benchmarks-based evaluation. Connections among ideas used in evaluating the textbooks' content coherence, matter and energy transformations. Retrieved on November 2, 2008, from http://www.project2061.org/publications/textbook/hsbio/report/ConnectionsAmongIdeas.htm#metMenu.

American Association for the Advancement of Science. (2005d). High school biology textbooks: A benchmarks-based evaluation. Key science ideas used in evaluating the textbooks' content alignment, matter and energy transformations. Retrieved on November 2, 2008, from http://www.project2061.org/publications/textbook/hsbio/report/KeyScienceIdeas.htm.

American Association for the Advancement of Science. (2007). Atlas of science literacy, Vol. 2. Washington, DC: American Association for the Advancement of Science.

Anderson, C., Sheldon, T., & Dubay, J. (1990). The effects of instruction on college nonmajors' conceptions of respiration and photosynthesis. Journal of Research in Science Teaching, 27, 761–776.

Anderson, C.W., & Smith, E.L. (1987). Teaching science. In V. Richardson-Koehler (Ed.), The educator's handbook: A research perspective (pp. 84–111). New York: Longman, Inc.

Arzi, H.J., Ben-Zvi, R., & Ganiel, U. (1985). Proactive and retroactive facilitation of long-term retention by curriculum continuity. American Educational Research Journal, 22(3), 369–388.

Arzi, H., & White, R. (2008). Change in teachers' knowledge of subject matter: A 17-year longitudinal study. Science Education, 92(2), 221–251.

Bagno, E., & Eylon, B. (1997). From problem solving to a knowledge structure: An example from the domain of electromagnetism. The American Journal of Physics, 65(8), 726–736.

Ball, D.L., & Cohen, D.K. (1996). Reform by the book: What is–or might be–the role of curriculum materials in teacher learning and instructional reform? Educational Researcher, 25(6), 8–14.

Ball, D.L., & Feiman-Nemser, S. (1988). Using textbooks and teachers' guides: A dilemma for beginning teachers and teacher educators. Curriculum Inquiry, 18, 401–423.

Bell, B., & Brook, A. (1984). Aspects of secondary students' understanding of plant nutrition. Leeds, UK: University of Leeds, Centre for Studies in. Science and Mathematics Education.

Best, R.M., Rowe, M., Ozuru, Y., & McNamara, D. (2005). Deep-level comprehension of science texts: The role of the reader and the test. Topics in Language Disorders, 25(1), 65–83.

Biological Sciences Curriculum Study. (1998). Biology: An ecological approach. Dubuque, IA: Kendall/Hunt Publishing Company.

Bishop, B.A., & Anderson, C.W. (1990). Student conceptions of natural selection and its role in evolution. Journal of Research in Science Teaching, 27, 415–427.

Britton, B.K., & Gulgoz, S. (1991). Using Kintsch's computational model to improve instructional text: Effects of repairing inference calls on recall and cognitive structures. Journal of Educational Psychology, 83, 329–345.

Bruner, J.S. (1995). Retrospective: On learning mathematics. Mathematics Teacher, 8(4), 330–335. (Reprinted from Mathematics Teacher, 53, 610–619, December 1960).

Champagne, A., Gunstone, R., & Klopfer, L. (1985). Effecting changes in cognitive structures among physics students. In: L. West & A. Pines (Eds.), Cognitive structure and conceptual change (pp. 61–90). Orlando, FL: Academic Press.

Chi, M.T.H. (2000). Self-explaining: The dual processes of generating inferences and repairing mental models. In: R. Glaser (Ed.), Advances in instructional psychology (Vol. 5). Mahwah, NJ: Lawrence Erlbaum.

Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Sciences, 5, 121–152.

Chi, M.T.H., & Slotta, J.D. (1993). The ontological coherence of intuitive physics. Cognition and Instruction, 10(2 & 3), 249–260.

Clark, D., & Linn, M. (2003). Scaffolding knowledge integration through curricular depth. Journal of Learning Science, 12(4), 451–493.

Clough, E., & Driver, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. Science Education, 70(4), 473–496.

Davis, E.A. (2006). Preservice elementary teachers' critique of instructional materials for science. Science Education, 90(2), 3–14.

Davis, E.A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3–14.

Davis, E.A., & Varma, K. (2008). Supporting teachers in productive adaptation. In: Y. Kali, M. Linn, & J.E. Roseman (Eds.), Designing coherent science education: Implications for curriculum, instruction, and policy (pp. 94–122). New York: Teachers College Press.

DeBoer, G.E., Dubois, N., Herrmann Abell, C., & Lennon, K. (2008, March). Assessment linked to middle school science learning goals: Using pilot testing in item development. Paper presented at the conference of the National Association for Research in Science Teaching, Baltimore, MD.

DeBoer, G.E., Herrmann Abell, C., Wertheim, J.A., & Roseman, J.E. (2009, April). Assessment linked to middle school science learning goals: What middle school students know. Paper accepted for presentation at the annual conference of the National Association for Research in Science Teaching, Garden Grove, CA.

DeBoer, G.E., Lee, H., & Husic, F. (2008). Assessing integrated understanding of science. In: Y. Kali, M. Linn, & J.E. Roseman (Eds.), Designing coherent science education: Implications for curriculum, instruction, and policy (pp. 153–182). New York: Teachers College Press.

DeBoer, G.E., Morris, K., Roseman, J.E., Wilson, L., Capraro, M.M., Capraro, R., et al. (2004, April). Research issues in the improvement of mathematics teaching and learning through professional development. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Demastes, S.S., Good, R.G., & Peebles, P. (1996). Patterns of conceptual change in evolution. Journal of Research in Science Teaching, 33, 407–431.

diSessa, A. (1988). Knowledge in pieces. In: G. Forman & P. Pufall (Eds.), Constructivism in the computer age (pp. 49–70). Hillsdale, NJ: Erlbaum.

diSessa, A., Elby, A., & Hammer, D. (2002). J's epistemological stance and strategies. In: G.M. Sinatra & P.R. Pintrich (Eds.), Intentional conceptual change (pp. 237–290). Mahwah, NJ: Erlbaum.

Eaton, J.F., Anderson, C.W., & Smith, E.L. (1984). Student preconceptions interfere with learning: Case studies of fifth-grade students. Elementary School Journal, 64, 365–379.

Educational Development Center. (1998). Insights in biology. Dubuque, IA: Kendall/Hunt Publishing Company.

Fortus, D., & Kanter, D. (2005, January). Curriculum driven practice-based professional development. Paper presented at the annual meeting of the Association for the Education of Teachers in Science, Colorado Springs.

Garner, R., & Gillingham, M. (1989). Effects of "seductive details" on macroprocessing and microprocessing in adults and children. Cognition and Instruction, 6(1), 41–57.

Goldberg, F., Bendall, S., Heller, P., & Poel, R. (2003). InterActions in physical science. Armonk, NY: It's About Time.

Harp, S., & Mayer, R. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. Journal of Educational Psychology, 90(3), 414–434.

Heller, P. (2001). Lessons learned in the CIPS curriculum project. Paper presented at the AAAS Conference on Developing Textbooks that Promote Science Literacy. Washington, DC. Retrieved on October 17, 2006, from http://www.project2061.org/events/meetings/textbook/literacy/default.htm.

Johnson, G.B. (1998). Biology: Visualizing life. Austin, TX: Holt, Rinehart and Winston.

Johnson, G.B., & Raven, P.H. (1998). Biology: Principles & explorations. Austin, TX: Holt, Rinehart and Winston.

Kesidou, S., & Roseman, J.E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review study. Journal of Research in Science Teaching, 39(6), 522–549.

Kesidou, S., & Roseman, J.E. (2003). Project 2061 analyses of middle-school science textbooks: A response to Holliday. Journal of Research in Science Teaching, 40(5), 535–543.

Krajcik, J., McNeill, K.L., & Reiser, B. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. Science Education, 92(1), 1–32.

Krajcik J., & Reiser B.J. (Eds.). (2007). IQWST: Investigating and questioning our world through science and technology. Ann Arbor: University of Michigan.

Kurth, L., & Roseman, J.E. (2001, March). Findings from the high-school biology curriculum study: Molecular basis of heredity. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Larkin, J.H., & Reif, F. (1979). Understanding and teaching problem-solving in physics. European Journal of Science Education, 1(2), 191–203.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996a). Children's ideas about ecology 2: Ideas found in children aged 5-16 about the cycling of matter. International Journal of Science Education, 18(1), 19–34.

Leach, J., Driver, R., Scott, P., & Wood-Robinson, C. (1996b). Children's ideas about ecology 3: Ideas found in children aged 5-16 about the interdependency of organisms. International Journal of Science Education, 18(2), 129–141.

Lee, O., Eichinger, D.C., Anderson, C.W., Berkheimer, G.D., & Blakeslee, T.S. (1993). Changing middle school students' conceptions of matter and molecules. Journal of Research in Science Teaching, 30, 249–270.

Leonard, W.H., & Penick, J.E. (1998). Biology: A community context. Cincinnati, OH: South-Western Educational Publishing.

Linderholm, T., Everson, M., van den Broek, P., Mischinski, M., Crittenden, A., & Samuels, J. (2000). Effects of causal test revisions on more- and less-skilled readers' comprehension of easy and difficult texts. Cognition and Instruction, 18(4), 525–556.

Markham, K., Mintzes, J., & Jones, G. (1994). The concept map as a research and evaluation tool: Further evidence of validity. Journal of Research in Science Teaching, 31(1), 91–101.

McDermott, L.C. (1984). Research on conceptual understanding in mechanics. Physics Today, 37(7), 24–34.

McKeown, M.G., Beck, I.L., Sinatra, G.M., & Loxterman, J.A. (1992). The contribution of prior knowledge and coherent text to comprehension. Reading Research Quarterly, 27(1), 78–93.

McNamara, D.S., & Kintsch, W. (1996). Learning from texts: Effects of prior knowledge and text coherence. Discourse processes, 22, 247–288.

McNamara, T.P., Kintsch, E., Songer, N.B., & Kintsch, W. (1996). Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. Cognition and Instruction, 14, 1–43.

National Center for Education Statistics. (2009). Science framework for the 2009 National Assessment of Educational Progress (NAEP) [Prepublication edition]. Retrieved October 16, 2007, from http://nagb.org/pubs/sci_fw_prepub_0119.pdf.

National Education Goals Panel. (1998) Recommendations regarding the implementation of standards. Retrieved on October 17, 2006, from http://govinfo.library.unt.edu/negp/page1-13-9.htm.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Research Council. (2004). On evaluating curricular effectiveness: Judging the quality of K-12 mathematics evaluations. Washington, DC: National Academies Press.

Perkins, D.N., & Salomon, G. (1988). Teaching for transfer. Educational Leadership, 46,1:. 22–32.

Roseman, J.E., & Caldwell, A. (2001, March). Findings from the high-school biology curriculum study: Matter and energy transformations. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Roseman, J.E., Kesidou, S., & Stern, L. (1996, November). Identifying curriculum materials for science literacy: A Project 2061 evaluation tool. Paper presented at the National Research Council Colloquium "Using the National Science Education Standards to Guide the Evaluation, Selection, and Adaptation of Instructional Materials," Washington DC.

Roseman, J.E., & Kurth, L. (2000, April). Can high-school biology textbooks help students learn important ideas about natural selection? Findings from Project 2061's curriculum evaluation study. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Roseman, J., Kurth, L., Kesidou, S., & Stern, L. (2004, April). Mapping for curriculum coherence. Symposium presented at the annual meeting of the National Association for Research in Science Teaching, Vancouver, Canada.

Roseman, J.E., Linn, M., & Koppal, M. (2008). Characterizing curriculum coherence. In: Y. Kali, M. Linn, & J.E. Roseman (Eds.), Designing coherent science education: Implications for curriculum, instruction, and policy (pp. 13–36). New York: Teachers College Press.

Roth, K., & Anderson, C. (1987) The power plant: Teacher's guide to photosynthesis (Occasional Paper No. 112.). East Lansing, MI: Michigan State University, Institute for Research on Teaching.

Schmidt, W.H., McKnight, C.C., Houang, R.T., Wang, H., Wiley, D.E., Cogan, L.S., et al. (2001). Why schools matter: A cross-national comparison of curriculum and learning. San Francisco: Jossey-Bass.

Schmidt, W.H., McKnight, C.C., & Raizen, S.A. (1997). A splintered vision: An investigation of the U.S. science and mathematics education. Dordrecht: Kluwer Academic Publishers.

Sadler, P.M. (Producer), Schneps, M.H., Woll, S. (1989). A private universe: Misconceptions that block learning/Harvard College [Videorecording]. Santa Monica, CA: Pyramid Film & Video.

Schwarz, C., Gunckel, K., Smith, E., Covitt, B., Bae, M., Enfield, M, et al. (2008). Helping elementary preservice teachers learn to use curriculum materials for effective science teaching. Science Education, 92(2), 345–377.

Smith, E., & Anderson, C. (1986). Alternative conceptions of matter cycling in ecosystems. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Spiro, R.J., Feltovich, P.J., Coulson, R.L., & Anderson, D.K. (1989). Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition. In: Vosniadou S. & Ortony A. (Eds.), Similarity and analogical reasoning (pp. 498–531). Cambridge, MA: Cambridge University Press.

Stavy, R., Eisen, Y., & Yaakobi, D. (1987). How students aged 13-15 understand photosynthesis. International Journal of Science Education, 9(1), 105–115.

Stern, L., & Roseman, J.E. (2004). Can middle school science textbooks help students learn important ideas? Findings from Project 2061's curriculum evaluation study: Life science. Journal of Research in Science Teaching, 41(6), 538–568.

Strike, K.A., & Posner, G.J. (1985). A conceptual change view of learning and understanding. In: L.H. West & A.L. Pines (Eds.), Cognitive structure and conceptual change (pp. 211–231). Orlando, FL: Academic Press.

Tyson, H. (1997). Overcoming structural barriers to good textbooks. Washington, DC: National Education Goals Panel.

Varnum, S.J., & DeBoer, G.E. (2008, November). Along the continuum: A discussion of standards and expectations. Presentation at the National Science Foundation DRK-12 Principal Investigators' Meeting, Washington, DC.

Wandersee, J.H. (1985). Can the history of science help educators anticipate students' misconceptions? Journal of Research in Science Teaching, 23(7), 581–597.

Weiss, I.R., Pasley, J.D., Smith, P.S., Banilower, E.R., & Heck, D.J. (2003). Looking inside the classroom: A study of K-12 mathematics and science education in the United States. Chapel Hill, NC: Horizon Research, Inc.

Willson, V., Wilson, L.D., & Roseman, J.E. (2009, April). A quantitative analysis of the relationships among teaching strategies, professional development, curriculum, and student learning of the algebraic concept of change. Paper accepted for presentation at the annual meeting of the American Education Research Association, San Diego.

## Appendix
## Relevant Sightings for Judging Alignment and Coherence: Page References for Key Ideas

| Name of Material | Treatment of Key Ideas | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Matter Transformations | | | | Energy Transformations | | | | Matter and Energy |
| | $a_1$ | $b_1$ | $c_1$ | $d_1$ | $a_2$ | $b_2$ | $c_2$ | $d_2$ | e |
| Holt Biology: Principles and Explorations | 45, 95 (98–106, 113–115) | 96, (107–110, 113–115) | 343–344, 351, 356–357t #28, 899–900, 904 | 29–30, 96t, 349–352 | 45st, 76–77, 79st #3, 96 | 77, 96, 345 | 76, 85, 345, 591, 904 | 77, 78st, 346, 336t | 75, 76, 349 |
| Biology: A Community Context | 37–39, 64t, 81 | 39–40, 117s/141t #6 | 31, 37, 40, 64t #1 | 39–40, 92–93, 37s/64t #1App & #5Int | 38–39, 88, 134s #3&4/ 141t | 39–40, 129t, 117s/ 141t #4 | 14–15, 29–31, 39, 40, 42s/68t #2, 107, 117s/141t #4. | 103, 107, 128t, 117s/ 141t #4 & 7 | 27, 88, 102, 117 #7 |
| Holt Biology: Visualizing Life | 52, 77, 85, 89 | 30, 84, 89, 92st, 391 | 77, 262, 706, 709 | 84, 260, 262, 270st #10 | 52, 84–85, 96st #11, 256 | 77, 90–91, 96s/95–96t #3, 4, 15; 258 | 77, 82, 83, 84, 90 | 18, 84, 258 | |
| Insights in Biology | ML16–20, 23, 43, 62–66, 31t | ML 24–25, 62–66, 67 #2, 94t | ML 27–33, 39, 47–50, 52–53, 64–66, 67 #1, 74–75t | ML 43, 92t; WE 28–31s/45t, 31s #2, 5, 46–47t | ML 16–20, 23, 62; WE 23 | ML 23, 67s/94t #2, 62–66; WE 23–24 | ML 53, 65, WE 23–24s/ 40–42t | ML 62, WE 23, 24s/40t, 42t | WE 23, 28, 29#6, 41t |