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ABSTRACT

This paper is based on a portion of the curriculum analysis of elementary science textbooks that was conducted as part of a larger Elementary Subjects Center study of curriculum materials used in literature, mathematics, science, social studies, and the arts. A commonly used elementary science curriculum series, Silver Burdett and Ginn's "Science," was analyzed using a set of framing questions addressing a number of categories including goals, content selection, teacher-student relationships and classroom discourse, activities and assignments, assessment and evaluation, and directions to the teacher. The focus of this paper is on the analysis of the series in terms of content organization and sequencing and content explication. The content organization of the services is described and analyzed from the perspective of students' conceptual development, examining what students are likely to learn about science concepts from the series and how their understandings of concepts are likely to develop within and across grade levels. The analysis shows that the text series lacks sufficient development of three components of conceptual development identified by science education reformers: connectedness among concepts, connectedness to prior knowledge, and usefulness. The authors consider the issue of concept development in light of several practical realities of elementary science instruction and discuss several alternative visions of elementary science curriculum materials. A copy of the framing questions is appended. (29 references) (Author/KR)

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Center for the Learning and Teaching of Elementary Subjects

The Center for the Learning and Teaching of Elementary Subjects was awarded to Michigan State University in 1987 after a nationwide competition. Funded by the Office of Educational Research and Improvement, U.S. Department of Education, the Elementary Subjects Center is a major project housed in the Institute for Research on Teaching (IRT). The program focuses on conceptual understanding, higher order thinking, and problem solving in elementary school teaching of mathematics, science, social studies, literature, and the arts. Center researchers are identifying exemplary curriculum, instruction, and evaluation practices in the teaching of these school subjects; studying these practices to build new hypotheses about how the effectiveness of elementary schools can be improved; testing these hypotheses through school-based research; and making specific recommendations for the improvement of school policies, instructional materials, assessment procedures, and teaching practices. Research questions include, What content should be taught when teaching these subjects for understanding and use of knowledge? How do teachers concentrate their teaching to use their limited resources best? and In what ways is good teaching subject matter- specific?

The work is designed to unfold in three phases, beginning with literature review and interview studies designed to elicit and synthesize the points of view of various stakeholders (representatives of the underlying academic disciplines, intellectual leaders and organizations concerned with curriculum and instruction in school subjects, classroom teachers, state- and district-level policymakers) concerning ideal curriculum, instruction, and evaluation practices in these five content areas at the elementary level. Phase II involves interview and observation methods designed to describe current practice, and in particular, best practice as observed in the classrooms of teachers believed to be outstanding. Phase II also involves analysis of curricula (both widely used curriculum series and distinctive curricula developed with special emphasis on conceptual understanding and higher order applications), as another approach to gathering information about current practices. In Phase III, models of ideal practice will be developed, based on what has been learned and synthesized from the first two phases, and will be tested through classroom intervention studies.

The findings of Center research are published by the IRT in the Elementary Subjects Center Series. Information about the Center is included in the <u>IRT Communication Quarterly</u> (a newsletter for practitioners) and in lists and catalogs of IRT publications. For more information, to receive a list or catalog, or to be placed on the IRT mailing list to receive the newsletter, please write to the Editor, Institute for Research on Teaching, 252 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

Abstract

This paper is based on a portion of the curriculum analysis of elementary science textbooks that was conducted as part of a larger Elementary Subjects Center study of curriculum materials used in literature, mathematics, science, social studies, and the arts. A commonly used elementary science curriculum series, Silver Burdett & Ginn's Science, was analyzed using a set of framing questions addressing a number of categories including goals, content selection, teacher-student relationships and classroom discourse, activities and assignments, assessment and evaluation, and directions to the teacher. The focus of this paper is on the analysis of the series in terms of content organization and sequencing and content explication. The content organization of the series is described and analyzed from the perspective of students' conceptual development, examining what students are likely to learn about science concepts from the series and how their understandings of concepts are likely to develop within and across grade levels. The analysis shows that the text series lacks sufficient development of three components of conceptual development identified by science education reformers: connectedness among concepts, connectedness to prior knowledge, and usefulness. The authors consider the issue of concept development in light of several practical realities of elementary science instruction and discuss several alternative visions of elementary science curriculum materials.

CRITICAL ANALYSIS OF AN ELEMENTARY SCIENCE CURRICULUM: BOUNCING AROUND OR CONNECTEDNESS?[1]

David Eichinger and Kathleen J. Roth[2]

One of the recurring criticisms of science textbooks over the years has been the lack of conceptual development and the overemphasis on covering vast amounts of content at the expense of students' understanding. From the post-Sputnik era to the present, reformers have called for science curriculum materials that promote the development of a solid and rich understanding of science concepts. One current, commonly used elementary science curriculum series claims to have developed a unique content organization scheme which "assures uninterrupted development of concepts." (Mallinson, Mallinson, Valentino, & Smallwood, 1989, Teacher Edition, p. T6) Yet, under close examination, it is not clear whether the concept development extolled in the curriculum series is similar to or compatible with the kind of conceptual development that has been and continues to be called for by education reformers. This paper will examine these apparent differences, present some possible reasons for the discrepancies, and suggest some alternative methods for improving existing curriculum materials that could help to synthesize these two different perspectives on concept development.

This paper is based on a portion of the curriculum analysis of elementary science textbooks that was conducted as part of a larger Elementary Subjects Center study. Center researchers analyzed commonly used curriculum materials

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[1]This paper was originally presented as part of a symposium on critique of elementary curriculum materials in different subject areas at the annual meeting of the American Educational Research Association, Boston, April 1990.

[2]David Eichinger, a doctoral candidate in teacher education at Michigan State University, is a research assistant with the Center for the Learning and Teaching of Elementary Subjects. Kathleen J. Roth, an assistant professor of teacher education at MSU, is a senior researcher with the Center.

in each of five subject areas (literature, mathematics, science, social studies, and the arts) using a common set of framing questions focused on the following eight categories: goals, content selection, content organization and sequencing, content explication, teacher-student relationships and classroom discourse, activities and assignments, assessment and evaluation, and directions to the teacher. (See Appendix for the framing questions.) The commonly used curriculum series chosen for science was the Silver Burdett & Ginn Science (Mallinson et al., 1989) series. It was selected because it is currently the most widely used science text series in the United States. Particular attention was paid to the second- and fifth-grade texts. (In order to avoid unnecessary repetition of the title of the series, Silver Burdett & Ginn Science will be referred to as "the curriculum series" in the remainder of the paper.)

This paper is also based on analyses of this same series conducted by six experts for another part of the Elementary Subjects Center (ESC) research project. Three university experts were selected to represent a range of perspectives on the elementary science curriculum. The group included two researchers, one with a strong conceptual change orientation and the other whose background includes interests in hands-on, inquiry programs, constructivist views of learning, and the use of technological tools in the science curriculum. The third university-based expert, who brings a strong interest in science, technology, and society issues to his analysis of the elementary science curriculum, is no longer a university researcher but is serving as associate director of a nonprofit science education center.

Three elementary science teachers were also chosen to represent different grade levels (early primary, third grade, and upper elementary), not necessarily different curricular perspectives. They were recognized as teachers who were doing particularly creative and thoughtful work in science teaching and who were involved in different kinds of professional development and curriculum development activities.

All six of the experts were given a common set of questions and asked to provide written analyses of the Silver Burdett & Ginn series. Later, each expert visited Michigan State University for extensive interviews concerning these curriculum materials.

In this paper we draw from our comprehensive analysis of the series (including goals, teacher-student relationships and discourse, activities and assignments, assessment and evaluation, directions to the teacher). However, the focus will be on content organization and sequencing and content explication. We begin by describing the content organization of the curriculum series. Drawing from our own analyses as well as those of the six experts, this conceptual organization will then be analyzed from the perspective of students' conceptual development. What are students likely to learn about science concepts from this text series? How are their understandings of concepts likely to develop within and across grade levels?

What Does This Curriculum Series Mean by Concept Development?

The curriculum series emphasizes concept development as a key feature of its texts. The teacher's edition for each grade level includes a two-page overview of topic development as well as a seven-page "comprehensive and detailed Scope and Sequence." (Grade 2: pp. 226-232; Grade 5: pp. 416-422) In addition, several introductory pages in the teacher's edition are devoted to explaining how this series promotes concept development (pp. T4-T7), including the following statement: "The only elementary science program with a content organization that assures uninterrupted development of concepts" (p. T6). Disregarding for the time being the question of whether this series is the only one that can do this, we consider this statement worth studying because of what it claims the text is able to do. At first glance, this statement could be interpreted to mean that the series will help students develop a rich understanding of the concepts being developed. But upon closer examination, it is clear that all this carefully worded statement is claiming is that students will have regular and repeated exposure to concepts over the course of the series as a result of its carefully designed content organization plan.

In this section we describe that content organization by first looking at the overall organization scheme and then describing how particular topics are developed within and across the second-, third-, and fifth-grade texts. The Silver Burdett & Ginn science curriculum is organized around four major blocks: Life Science, Physical Science, Earth Science, and The Human Body. These blocks serve as the main content organizers for the entire K-6 series. In addition, the life, physical, and earth science blocks are broken down into content strands, each addressing different aspects of a particular science discipline. For example, life science is composed of three strands: Plants, Animals, and Ecology. Physical science is divided into Matter and Energy, and earth science has three strands: Earth, Space, and Weather. Each strand deals with a number of topics, generally repeating main topics in successive or alternate years. For example, in the physical science strand on energy, the progression of topics from one grade level to the next is as follows:

Energy

Grade	Topic
K	Energy (movement, heat and cold, sound)
1	Moving Things (simple machines)
2	Fun with Magnets; Heat and Light
3	Force, Work, and Energy; Machines; Sound
4	Energy and Machines; Heat Energy; Electricity and Magnetism

5	Understanding Electricity; Sources of Energy
6	Light Energy; Sound Energy; Using Electricity (basic principles, technological advances)

In life science, the sequence of topics for the plants strand is as follows:

Plants

Grade	Topic
K	Seeds and Plants
1	Many Kinds of Plants
2	How Plants Grow
3	Seed Plants (parts); Plants are Important (uses)
4	The World of Plants (classification)
5	Activities of Green Plants (photosynthesis, respiration, reproduction)
6	Plant Growth and Responses

These sequences demonstrate that the content organization is designed to provide students with regular and repeated exposure to a number of concepts and strands within each of the science blocks. While studying about energy in physical science, for example, students repeatedly investigate the topics of heat, light, machines, electricity, and magnetism. Similarly, structures, life processes, and classification represent concepts repeated in the plants strand of life science.

The content organization of the series also provides evidence that, as students move from the lower to the upper grade levels, there is some overlap of content coverage as well as the introduction of some new facets of these concepts. This sort of concept development is demonstrated by the treatment of the topics of plant reproduction and photosynthesis within and across the second-, third-, and fifth-grade levels. This concept development is described below and summarized in Table 1.

In the second-grade chapter on plants (pp. 24-30), students begin looking at the structures and functions of seeds and their role in plant reproduction. In Lesson 1 students read about the many varieties of seeds, the growth of seeds into new plants, and the production of seeds by trees. In Lesson 2, on how seeds grow, students learn the parts of seeds (seed coat, stored food, young plant) and that seeds develop into new plants having roots, stems, and leaves. These plants change in size as they grow, adding new stems, leaves, and roots. In Lesson 3, "Flowers and Fruit," students compare the flowers of different green plants and learn that flowers change into fruits that contain seeds, with new plants growing from these seeds.

In the third-grade chapter on seed plants (pp. 38-55), students review roots, stems, and leaves with a new focus on their functions. In Lesson 3, on leaves, students are given new information indicating that green plants make their own food and that a leaf, like a factory, needs materials brought in before it can make a product. Students are told that leaves need carbon dioxide, water, and energy from the sun in order to produce their food (sugar) and oxygen. Food production in plants is described as occurring in leaves, with no mention of the term "photosynthesis" and no discussion of food production at the cellular level. In Lesson 4, on flowers and seeds, students are told that flowers develop into fruits which contain seeds. Students also learn that some seed plants do not produce flowers; instead, their seeds develop in cones. Once again, students learn about the parts of the seed (seed coat, stored food, small plant), but now they are introduced to the term "germination." They are told that new plants first use the food stored in the seed to grow but later make their own food once the plant has grown leaves.

In the fifth-grade text, the chapter on activities of plants (pp. 2-23) revisits the topics of photosynthesis and plant reproduction but in much more detail than in the previous grade levels. At the beginning of this chapter, students are introduced to the concept of cells for the first time. Before learning about photosynthesis, students first learn about the cellular structure of the leaf with its various kinds of cells (chloroplasts, stomata,

Table 1

Concept Development About Plants in
Second-, Third-, and Fifth-Grade Textbooks

	2nd Grade		3rd Grade		5th Grade
Seeds	Each seed makes a different kind of plant Many kinds of seeds				
	Parts of seeds (seed coat, tiny plant, stored food	---→	Parts of seeds (seed coat, tiny plant, stored food)	---→	Tiny young plant called an embryo
	Trees make seeds		Food stored in seed as starch	---→	Seed is a fertilized ovule that contains tiny plant and stored food
			Grains are seeds we eat Seeds contain oil that people use		
Plant Growth	Seeds grow into tiny plants	---→	"Germination"--Young plant uses food in seed, later makes own food	---→	Germination = growth of plant embryo in seed. -Uses food stored in seed, sugar stored in fruits, starch stored in potatoes -Once it reaches certain size will make its own food by photosynthesis
	Tiny plants have roots, stems, leaves	---→	Functions of roots, stems, leaves	---→	Roots, stems, and leaves have different cells
	Plants change as they grow Plants change with the season				Transport of raw materials to leaf for photosynthesis: -Roots--root hairs, absorb water -Stems--water-carrying tubes food-carrying tubes -Leaves--veins, stomata Leaf cells--food making cells, waxy covering, protecting cells -Chloroplasts, chlorophyll, stomata, air spaces, veins

Note From: G.G. Mallinson, J.B. Mallinson, L. Valentino, & W.L. Smallwood, (1989) Science, Morristown, NJ: Silver Burdett & Ginn.

Table 1 (cont'd.)

	2nd Grade	3rd Grade	5th Grade
Plant Reproduction	Some plants have flowers --->	Some seed plants don't produce flowers (cones) --->	Flowers are reproductive part of a plower plant.
	Diversity of flowers on green plants		-Reproduction is process by which living things produce new living thing of same kind
	Flowers change into seeds --->	Flowers develop into fruits which contain seeds	
	Plants do not always grow from seeds (cuttings)	--->	Structure and functions of 3 main parts of flower: petal, stamen (pollen grains), pistil (ovary, ovule)
			Energy from respiration is used for reproduction
			Pollination = pollen grains move from stamen to pistil; pollen grains grow tube to ovule
			Pollination by insects, wind
			Fertilization = joining of male and female cell
Uses of Plants		Food you eat is part of green plants	
		Nongreen plants are used as food--mushrooms	
		Uses of plants--food, decoration, shade, windbreak, hold soil, compost, medicine, cloth, paper and wood products	
		Harmful plants--molds, mildew, poison ivy, etc.	

Table 1 (cont'd.)

	2nd Grade	3rd Grade	5th Grade
Plants' Food Production (Photo-synthesis)		Without green plants there would be no meat, milk, eggs Green plants make their own food ---> Carbon dioxide and water are turned into sugar ---> Leaves need carbon dioxide, water, and sun to make food Leaf is like a factory that brings in materials to make a product --->	Green plants get food differently than animals--make own food during photosynthesis Plants need water, carbon dioxide, and sunlight to make food Water + carbon dioxide + energy ---> sugar + oxygen Food-making process is like a factory Steps in photosynthesis: Sunlight trapped by chlorophyll in cells, water carried to food-making cells by veins, sun's energy changes water into hydrogen and oxygen. Oxygen goes out stomata, carbon dioxide goes to food-making cells. Hydrogen joins with carbon dioxide to make sugar. Sugar carried to rest of plant.
Plants' Use of Food (Respiration)			Respiration: how plants release energy stored in food--occurs in cells of all living things -Use oxygen to release energy in food -Steps in the process -O_2 + food ---> energy + CO_2 + H_2O -Comparison to photosynthesis--opposites

food producing cells) and their functions. In Lesson 3 photosynthesis is discussed using the analogy of a factory, but this time the process is studied at the cellular level. Students then learn the term "photosynthesis" and are given the equation "water + carbon dioxide + energy --> sugar + oxygen" to describe the food production process. In Lesson 5, "Producing New Plants," students are introduced to the term "reproduction" and learn how flowers produce seeds. The vocabulary list for this lesson includes 14 new terms (compared to the usual two or three new words for most lessons), and students get a detailed explanation of how seeds are formed (pollination of pistil by pollen grain, growth of pollen tube, fertilization of female cell by male cell, formation of ovule). The chapter ends with the idea that embryos use food stored in the seeds until the young plant can make its own food during photosynthesis. This concept was first introduced in the third-grade text, but now the term "photosynthesis" is attached to it. Once again students read about the parts of the seed (stored food and embryo).

Thus, this apparently tight spiral of content organization provides multiple opportunities for students to revisit a series of science concepts while moving from one grade level to the next. But is this what is commonly meant by the term "concept development?" Content organization and repeated exposure to concepts may be necessary conditions of concept development, but are they sufficient? Are there other interpretations of concept development that include components not found in this textbook series?

What Do the Experts Mean by Concept Development?

Experts in science education, including scientists and educational researchers, recommend a shift in the elementary science curriculum from an emphasis on science as isolated bits of knowledge to an emphasis on integrated, cohesive understandings of central science concepts (American Association for the Advancement of Science, 1989; Anderson & Roth, 1989; Bybee et al., 1989; Champagne & Hornig, 1987; Linn, 1987; Murnane & Raizen, 1988; National Research Council, 1985; Roth, in press; Rutherford & Ahlgren, 1988). They are concerned that students are memorizing information about science without coming to understand science concepts. Students equate understanding with memorization of facts, but they are unable to use and apply those facts. To help students develop meaningful conceptual understandings, these experts and others recognize that the curriculum will have to address fewer concepts in more depth ("less is more") and that the curriculum will have to be organized in ways that support students' connecting and using science concepts. Research on student learning of science suggests that the development of a concept takes time and that students need many opportunities to work with new concepts to see the relationships among science concepts, to link them with their prior knowledge, and to appreciate their usefulness in a wide variety of contexts. Thus, the experts' definition of concept development focuses on student development of conceptual understanding and focuses on three components of scientific understanding.

Connectedness Among Science Concepts

Many experts are critical of a topical approach to science teaching, because students are not supported in making connections among science concepts. In building a rationale for this position, scientists working on Project 2061--an American Association for the Advancement of Science (AAAS) effort to redefine the K-12 science curricula--criticized the current science curricula:

> The present curricula in science and mathematics are overstuffed and undernourished. Over the decades, they have grown with little

> restraint, thereby overwhelming teachers and students and making it difficult for them to keep track of what science, mathematics, and technology is truly essential. (AAAS, 1989, p. 14)

Their recommendations call for an emphasis on ideas and thinking over the rote learning of specialized vocabulary and the memorization of isolated facts. In Science For All Americans, a Project 2061 set of recommendations, the scientists call for a different approach to the traditional treatment of topics in the science curriculum. This approach emphasizes connectedness of ideas:

> One difference is that boundaries between traditional subject-matter categories are softened and connections are emphasized. Transformations of energy, for example, occur in physical, biological, and technological systems, and evolutionary change appears in stars, organisms, and societies. . . . A second difference is that the amount of detail that students are expected to retain is considerably less than in traditional science . . . courses. Sets of ideas are chosen that not only make some satisfying sense at a simple level but also provide a lasting foundation for learning more. Details are treated as a means of enhancing, not guaranteeing, understanding of a general idea. (AAAS, 1989, p. 4)

> [The curriculum must be changed to] reduce the sheer amount of material covered; to weaken or eliminate rigid disciplinary boundaries; to pay more attention to the connections among science, mathematics, and technology (p. 5).

The Center for the Improvement of Science Education (Bybee et al, 1989) also recommends that the elementary science curriculum be conceptually integrated. Instead of exposing students to a series of disconnected topics, center staff suggest that the curriculum should be organized around themes and central concepts. The nine organizing concepts recommended include organization, cause and effect, systems, scale, models, change (cycles), structure and function, variations, and diversity. "The major organizing concepts, attitudes, and skills . . . should be integrated into themes or topics that school personnel select for study" (p. 57). Thus, schools would select topics or themes that would integrate content. Instead of organizing the curriculum as a series of separate units such as light, plants, and oceanography, for example, the schools could organize a grade-level curriculum around an organizing concept such as change and cycles. All topics addressed would link to each other and to this central theme.

Anderson and Roth (1989) argue that, because connectedness is a key feature of scientific understanding, it should also be a key feature of understandings that K-12 students develop in science classes. They note that scientists do not study light one day and photosynthesis the next without making connections between the two. However, students in elementary school typically learn about science in disconnected ways; they study all about light in one unit and then study all about plants in a separate unit. Connections between the two are rarely made. Thus, if scientific concepts are going to be useful to students, they must be connected in meaningful ways.

Connectedness to Prior Knowledge

The emphasis on teaching science in depth rather than quickly and topically stems from research on student learning which demonstrates that science learning involves a complex process of conceptual change for students (Anderson & Roth, 1989; Champagne, Klopfer, & Gunstone, 1982; Driver & Oldham, 1986; Erickson, 1984; Hewson & Hewson, 1984; Johansson, Marton, & Svensson, 1985; Minstrell, 1982; Nussbaum & Novick, 1982; Resnick, 1983; West & Pines, 1985). Looking at classroom science learning from a constructivist perspective, researchers have provided important insights about the central role played by a student's prior knowledge. Even before children study science in school, they have already constructed their own "theories" to explain natural phenomena. These personal theories are often strikingly different from scientific explanations and thus are sometimes referred to as misconceptions. They play a critical role in students' understanding of the natural world.

Research demonstrates how difficult it is for children to relinquish or change these personal conceptions even after instruction. For students entering instruction holding alternative theories, meaningful learning will not result if new knowledge is simply added into memory. Meaningful learning cannot occur unless new knowledge is appropriately linked to prior knowledge. Students must grapple with the conflicts between their own explanations and scientific explanations. Anderson and Roth (1989) describe the nature of "understandings" developed by students who fail to make such connections between prior knowledge and scientific knowledge:

> Many students fail to do this; they view scientific knowledge as separate and distinct from their personal knowledge. They perceive scientific knowledge as being about objects that are too small, too distant, too abstract, or too unusual to be part of the everyday world; such as atoms, quasars, momentum or strange chemicals. . . . In contrast, successful learners of science develop clear conceptual linkages between scientific conceptions and their common sense understandings. The two fit together into a single integrated understanding of the world. (p. 270)

This constructivist view of learning suggests that concept development takes both time and support. Students need time and support in comparing their existing viewpoints with scientific conceptions. Anderson and Roth emphasize the need for students to have multiple opportunities to try out new concepts in new contexts, receiving careful modeling and coaching from their teachers in these efforts to change and modify their personal theories and perspectives.

<u>Usefulness of Concepts</u>

A third feature of meaningful concept development emphasized by many experts is the usefulness of concepts in explaining and predicting natural phenomena. Researchers assert that students will develop meaningful understandings of science concepts only if they can see the wide usefulness of concepts in explaining and making sense of their personal world (Anderson &

Roth, 1989; Bybee et al., 1989; Posner, Strike, Hewson, & Gertzog, 1982). Students will not "see" the usefulness of scientific ideas by teachers or textbooks telling them about it. Instead, students need to grapple with problems in which they attempt to use science concepts to explain phenomena within their experience in new ways. It is not sufficient to ask students one or two application questions about a concept at the end of the chapter. Students need to work with the same concept over and over again in different contexts. This work should form the core of students' science learning and should not be relegated to assignments tacked on the end of a chapter or unit where the primary goal is to evaluate student performance.

Analysis of the Curriculum Series from the Experts' Perspective

If we apply the experts' vision of concept development to this textbook series, what do we find? To what extent does the content organization in the textbook series support students in developing connected and useful understandings of science concepts? In this section these questions will be explored in two ways. First, we present a case description of the content organization and content explication in the fifth-grade Silver Burdett & Ginn textbook. This case details one portion of our analysis which revealed that the text's vision of concept development did not emphasize connections among concepts in ways that were likely to support students' developing understandings of science concepts. Second, we present a summary of our six experts' analyses of the ways in which the text's definition of concept development included or failed to include the three components of concept development identified by science education reformers: connectedness among concepts, connectedness to prior knowledge, and usefulness.

Content Organization and Explication in the Fifth-Grade Text: Connectedness?

The fifth-grade text begins with a Life Science block that includes four chapters: Activities of Green Plants, Animals Without a Backbone, Animals With a Backbone, and Living Communities. The first chapter begins with a section on similarities of plants and animals. This section emphasizes life processes of all living things: getting food, releasing energy (cellular respiration), removing wastes, growing, and reproducing. The first page of the student text introduces the concept of the cell as the basic unit of all living things. In discussing life processes, the text suggests both similarities and differences between plants and animals:

> Living things are alike in another way. All living things must satisfy certain needs in order to stay alive. All animals and plants need food, water, and air. However, plants and animals meet these needs in different ways. Green plants can make their own food, while animals must get food from plants or other animals. (p. 5)

This page ends with a chart summarizing the life processes of living things. How are these concepts about life processes developed in the rest of the Life Science block?

The section on plants begins with a clear reference to these life processes and emphasizes the "food-getting" process as an example of ways in which living things differ: "You have learned some ways in which living things are alike. One way in which living things differ is in how they carry out some of the life processes" (p. 6). Thus the section begins with a clear conceptual link to the idea of life processes. The rest of the chapter is organized into sections that focus on three of the life processes introduced on page 5: food getting (photosynthesis), releasing energy (cell respiration), and reproducing. However, this organization is not explicitly called to students' attention. Only one more reference to life processes is made across the five lessons on plants: "Living things need energy to carry out the life processes" (p. 16).

The text describes food making in green plants (photosynthesis) across two lessons. The first lesson describes how plants are structured to get materials transported (roots, stems, and leaves). The second lesson explains how plants make food from materials transported to the leaves. The explanation includes a description of the cell structure of a leaf. Connections back to the ideas introduced on the first page about cells and life processes are not explicitly made. For example, the text does not remind students about the idea introduced earlier that there are different kinds of cells in living things. Instead, the text simply launches into a description of the cell organization in leaves, noting the location, structure, and function of different kinds of cells. The text authors here apparently assume that a brief mention of the theme of specialization of cells in living things is sufficient for students to use that concept to organize their study of living things.

The next section again talks about cells, this time in the context of cell respiration: "Respiration is the process by which living things use oxygen to release energy in food. This process takes place in the cells of all living things" (p. 16). Here it is easy to imagine the difficulties a learner might have in connecting the ideas about specialization of cells and cell respiration. Are there special cells that take care of respiration? Or do all cells respire? This is not made clear in the text.

Since students have just read about special food-making and protecting cells in the leaf, they are likely to make the incorrect inference that there are special respiration cells. This would also fit with common student misconceptions about human breathing: that air taken in simply goes into the lungs and then out again. If there are only special cells that release energy, this naive conception makes sense. If you appreciate that all living cells must release energy (respire), then the idea of oxygen (and food) going into the bloodstream and traveling all over the body makes more sense.

When we turned to the chapters on animals, we expected to find links between the idea of life processes and comparisons between plants' and animals' ways of accomplishing these life processes. However, Chapter 2 begins by introducing a new conceptual organization--classification--without mentioning life processes at all. Instead, the ways in which animal structures are used to classify animals is emphasized. There is no mention of plants at all. The chapter then begins a series of lessons on sponges, animals with stinging cells, animals with spiny skin, animals with soft bodies, and animals with jointed legs. Thus, the text organization follows the classification scheme, emphasizing body structures of different groups of invertebrates. The presentations are "all-about" descriptions of organisms, with an emphasis on the particularly unusual creatures within each group (e.g., planaria that can regenerate body parts).

The descriptions focus on structures and interesting bits of information. Sometimes these information bits are related to the concepts of life processes or cells, but the text does not help students make these connections. In discussing regeneration in planaria, for example, cells are not mentioned. On another occasion, the text asks students to consider why sponges are sometimes confused with plants. The suggested answer in the teacher's guide focuses on plants not moving from place to place. No mention of photosynthesis or food-making cells is made.

How well does the chapter help students understand the new conceptual scheme about classification? The only place that the text addresses this theme explicitly is in Lesson 1: Classifying Living Things. In this lesson students are encouraged to think about all the different ways that you could divide animals into groups. The text then states that scientists classify animals by features, or structures, that are alike. No reason is given for why scientists prefer this organization over any other system. If the text were going to develop a classification scheme, the meaningful conceptual framework would be evolution. The authors avoid this connection, thereby trivializing the meaning and usefulness of biological classification. Even ignoring this omission of evolutionary concepts, we did not find occasions other than the first lesson where the classification theme was mentioned either in the student pages or in the teacher's guide.

Teachers were encouraged to ask many questions about body structures (What are the three types of insect mouth parts? What are the holes in a sponge's body called? How can you describe the body of a roundworm?). But the only suggested questions in the teacher's guide related to classification or comparisons across groups of animals were in Lesson 1: (a) "How do scientists classify animals? (b) Describe two groups of animals. (c) If animals were classified simply on appearance, the jellyfish, octopus, and squid might all be grouped together. Why aren't these animals in the same group." (p. 368).

The organization of content around a classification scheme continues in Chapter 3 on vertebrates. However, this classification organization is not made explicit to students. The chapter simply begins with fish: "Fish are vertebrates that live in water" (p. 58). No mention of scientists' use of classification schemes are made; no comparisons to classification of invertebrates from Chapter 2 are made. Again, plants are never mentioned. Students or their teachers would have to supply these classification and comparison organizational frames.

As in Chapter 2, the classification theme centers around animal body structures without linking these structures to functions and without linking classification schemes to evolutionary concepts. The chapter begins, for example, with a four-page attention-grabber about flying squirrels and walking catfish. This introduction describes these two animals without mentioning either adaptations or evolutionary change. The introduction ends with an easily overlooked paragraph that describes the concepts the authors do intend to emphasize in this chapter:

> In this chapter you will discover the five groups of animals that have a backbone. You will learn how the animals in each group differ from the animals in the other groups. These pages invite you to explore the vertebrates. Learn what a fish, a frog, a snake, a bird, and a dog have in common. (p. 57)

To what extent does the chapter support students in developing this conceptual theme of differences and similarities across these five groups of animals? The chapter is organized into five lessons: fish, amphibians, reptiles, birds, and mammals. Each lesson consists of information all about the "animal group of the day," emphasizing unusual attention-grabbing examples wherever possible (chameleon, platypus). Students are rarely supported in making links across the groups.

The only way that similarities among the groups are developed is through the first sentence of each lesson which defines the group as a particular kind of vertebrate. For example, "Fish are vertebrates that live in water," or "Mammals are the most complex vertebrates." These ideas are also summarized at the end of the chapter in a chart:

> A fish is a cold-blooded vertebrate with fins. It uses gills to breathe under water. Most fish have scales.
> An amphibian is a cold-blooded vertebrate that lives part of its life in water and part on land.
> A reptile is a cold-blooded vertebrate that has lungs and dry skin. Most reptiles have scales and live on land.
> A bird is a warm-blooded vertebrate that has feathers and wings.

A mammal is a warm-blooded vertebrate that is usually covered with fur or hair. It breathes through lungs and feeds milk to its young. (p. 77)

Nowhere does the teacher's guide suggest that the teacher discuss or ask students about similarities across these groups of animals. In fact, the teacher is not even encouraged or reminded to link one lesson to the next, except on one occasion in the amphibians lesson: "Tell the students that amphibians are more complex animals than fish. Like fish, amphibians share common characteristics" (p. 61). However, even here the suggested discussion question that follows this direction does not ask students to make any comparisons among groups: "Ask: What are the common characteristics of amphibians?" (p. 61).

The text also does not make explicit comparisons of differences across the animal groups. No comparison statements are made in the student text, none of the chapter check questions ask students to make comparisons, and only once does the text suggest that the teacher make comparisons across lessons: "You may wish to have students compare the egg-laying birds to the internal development of the young of mammals. Discuss the advantages of internal development over egg-laying" (p. 76). Thus, not only does the text fail to help students understand the classification scheme in a way that would help them understand how scientists use this scheme (an evolutionary focus) it also does not support students in developing the text's stated conceptual theme of comparisons among groups. It would make sense for the text to compare the groups using the life processes theme developed in Chapter 1: food getting, releasing energy, waste removal, reproduction. However, these comparisons are left for individual teachers to create.

Within this chapter there are scattered bits of information related to the life processes theme emphasized in Chapter 1, but these occasions are not used to develop that theme. For example, the text describes fish gills as being able to get oxygen from the water. A fairly detailed description of what happens to that oxygen inside the fish is given without any mention of oxygen's role in cell respiration (releasing of energy in each cell)--the idea stressed in Chapter 1:

> All animals need oxygen. Animals that live on land get oxygen from the air. You may wonder how fish get oxygen under water. There is oxygen dissolved in the water. Fish take in the oxygen found in water through their gills. Gills are thin, feathery structures that are filled with blood. Fish use gills for breathing. To breathe, a fish takes water into its mouth. The water then flows over the gills. Oxygen from the water goes into the blood in the gills. Blood in the gills contains a waste material called carbon dioxide. Carbon dioxide passes through the gills and then out of the body into the water. At the same time, oxygen from the water goes into the blood in the gills. This is how the fish breathes under water. (p. 59)

This description leaves one wondering, Where did the carbon dioxide in the blood come from? It seems to be just an ingredient of blood in the gills. In fact, the text explained in Chapter 1 where this carbon dioxide comes from: It is a waste product of cell respiration:

sugar + oxygen ------> energy + carbon dioxide + water (p. 17)

A similar missed opportunity occurs in the description of frogs' lungs and mud puppies' gills. Reference is made to oxygen but nothing is mentioned about cell respiration and releasing energy from food. The questions suggested for discussion focus on structures for getting oxygen and not the functions: "How do most amphibians get oxygen? (They breathe through lungs and also get oxygen through their skin.) Which amphibian does not have lungs? (mud puppy) How does it breathe? (through gills outside its body)" (p. 62). This pattern continues in the lesson on birds. On page 69 the text explains that birds are very active organisms and need a great deal of energy. Therefore, they eat a lot of food. This would be a perfect occasion to raise some interesting questions about cell respiration and the life process of releasing energy: Does this mean that birds have cells that can release more energy than cells in other animals? Or does it mean that birds have more cells? Or do birds' cells release energy faster? Instead, the teacher's guide suggests a discussion about what kinds of food different birds eat.

Similarly the text captures students' attention by describing how snakes swallow their food whole. This could have been an opportunity to pose an intriguing question that would link to cell respiration: If the snake swallows the food whole, how can the food get small enough to get to each cell in the snake's body for cell respiration? Instead, the text simply describes how the snake's body structure (jaws) enables it to swallow whole animals (p. 65).

Chapter 4 is about ecosystems and provides an excellent opportunity to help students link their studies of plants and animals together. For example, through exploring food-getting relationships, students could come to appreciate that, because plants are the only living things that can make energy-containing food out of raw materials (carbon dioxide, water, energy from sun), they are critical in ecosystems. All animals depend on plants' ability to make food. Thus, the idea of producers, consumers, and food webs would be a meaningful link back to ideas about photosynthesis and cell respiration. However, in this series of four lessons, photosynthesis and respiration are never mentioned by name and the idea of plants' food making and cell respiration are only alluded to once in an introductory paragraph describing interactions in a fish aquarium. While the text introduces concepts such as populations, communities, ecosystem, habitat, niche, predator, prey, and succession, the concepts of producers and consumers are omitted. Of course, the idea of photosynthesis is assumed to be connected to discussions of succession and interactions in ecosystems. However, this link is never explicitly pointed out by the authors.

Given that the text did not link concepts together between chapters in the Life Science block, we did not expect to find links between life, physical, and earth science blocks. In studying these blocks, we identified many occasions when the text could have referred back to life science concepts such as photosynthesis, cell respiration, and other life processes. In the introduction to the chapter about matter, for example, the text asks how scientists know about things like photosynthesis: "How do scientists study matter? . . . Suppose a scientist asks the question, 'How is food made in a leaf?'" (p. 112). This sets up a perfect context in which to explore concepts about atoms, molecules, elements, and compounds related to the photosynthesis process studied earlier. However, the text glosses over the problem of how we know about photosynthesis by saying scientists have to use indirect evidence.

In their examples of elements, compounds, atoms, and molecules, the authors talk about silver, iron, aluminum, salt. They could have used the matter involved in photosynthesis to talk about elements (oxygen) and compounds (carbon dioxide, water, sugar). Similar missed connections occur in the chapter about energy. Despite a lesson on fossil fuels, the connections to photosynthesis and energy flow and change are not made.

We did expect to find some interesting conceptual connections between the block on Life Science and the Human Body block. The Human Body block has two chapters: "Support and Movement" and "Transport Systems of the Body." In both chapters the emphasis is on descriptions of body structures without much discussion of functions. The themes begun in the Life Science unit about life processes and classification are hard to detect. For example, the chapter about Support and Movement begins with a discussion of the human skeleton. While the first paragraph does mention some similarities and differences with animals ("Some animals have a hard outer covering that supports and protects their bodies. Still other living things have bones inside their bodies," p. 314), it is never suggested that humans fit into the classification scheme developed earlier. The bones of the body (including vertebrae!) are discussed without ever mentioning that humans would be classified as vertebrates.

The life processes theme is also not carried over explicitly into the human body section. The title of Chapter 14, "Transport Systems," sets up an expectation of comparisons to transport in plants discussed in the first chapter of the book. In discussing the circulatory system, the text does begin by mentioning life processes: "It [transport system] carries needed materials, such as food and oxygen, to the cells of the body. It also carries away waste products" (p. 336). However, cell respiration is not mentioned.

The student text and the suggested discussion questions in the teacher's guide quickly move away from this functional emphasis. Six pages develop descriptions of structural aspects of the circulatory system: blood, blood cells, parts of the heart, veins and arteries, path of blood flow. The same pattern follows in the discussion of the respiratory system. Following an explicit link to cellular respiration defined earlier as a basic life process, the text emphasizes structures of the lungs and how air moves in and out of the lungs. Although links to life processes are not emphasized, this lesson stands out in this text because of its explicit mention of concepts developed earlier. The lesson was very unusual, for example, because it mentioned explicitly cellular respiration and cells releasing energy twice (on different pages!--346 and 348) in one lesson. This chapter also included a very rare suggestion to the teacher to review a concept introduced earlier: "Review with the students the fact that respiration is the process by which each body cell gets oxygen and releases energy from digested food" (p. 346).

In sum, our case analysis of the fifth-grade student text and teacher's guide suggests that the notion of concept development in this curriculum series does not include components considered critical by science education researchers. In our view the text does not support students in developing connected understandings of science concepts. In the next section we discuss the reactions of our six experts (three teachers, three university researchers) to this text series. How do they view the text's efforts to develop concepts?

Six Experts' Analysis of the Curriculum Series: Connectedness?

The analysis of the science curriculum series conducted by the three university experts and the three elementary teacher experts revealed several points of consensus concerning the lack of adequate concept development in this textbook series. One major criticism of the text was its overemphasis on reading comprehension, vocabulary acquisition, and the memorization of apparently isolated facts, especially at the upper grade levels. When asked about the ratio of facts to big ideas, one teacher expert included the following statement in his written analysis: "Too much factual recall--not enough understanding--they are giving teachers what they want--lots of activities, pictures, text, tests--not leading to good understanding or concept development." One university expert noted that the view of science this series communicated to students would be that science is always knowing "what" but never knowing "why." Several university and teacher experts also pointed out that, although the text contains a series of activities for each chapter that are relevant to the topics being discussed in the text, it is not always clear to what extent these activities would help students further develop their understanding of the concepts being presented.

Rather than designing a series of activities that would help students progressively develop their ideas on a particular topic, the text seems to present a series of disconnected, separate activities. When describing the activities included in the second-grade book on seeds, one university expert stated:

> They all had something to do with describing seeds, but there's no way that one ever built on another or . . . that one chapter built on another. . . . It's just all totally level and it's like each lesson is separate from each other lesson in terms of skill sequencing or concept sequencing. . . . You start over again and the only connections are these kind of thematic connections as far as I can tell. You have a chapter full of stuff that's all about the same topic but you wouldn't have to read the first page of the chapter in order to understand the last page of the chapter and the odds are that most kids would understand neither, at the higher [grade] levels especially. (Interview 133, p. 11)

The six experts were nearly unanimous in their criticism of the lack of attention paid to students' prior knowledge and the failure of the series to provide teachers with any means for preassessing students' knowledge of the science content. The content organization of the curriculum series carries with it the assumption that students have learned the material at each grade level and that this knowledge can serve as a foundation upon which new information can be added in subsequent years. However, no means for assessing students' knowledge is provided before instruction of each unit or chapter begins. In addition, the experts saw little evidence of the text attempting to connect the science concepts being presented with students' prior knowledge and experience. As one university expert noted,

> The kids never understand at one level what they're supposedly building on at the next level. I mean, you have to ask is the spiral a spiral of coverage or a spiral of student knowledge? And if you're talking about the spiral as a spiral of student knowledge, which I think is probably what Bruner had in mind, then there's no provision for that happening. You know it's usually not particularly useful to ask what's been covered in the previous grade levels because the kids don't understand it, so what does it matter? If you want to know what you ought to teach, what you've got to do is talk to the kids and find out what they know and go from there. (Interview 135, p. 10)

Several of the experts agreed that the text does a fairly good job of developing concepts within strands and across grade levels. One university expert felt that the chapters on plants developed coherent, general themes across the grade levels. However, the experts noted that there was very little connectedness of concepts across strands or across units. An example cited by several university and teacher experts was the presentation of the concept of respiration in plants and humans in the fifth-grade textbook that we discussed earlier. The experts noted that respiration is presented in some detail at the cellular level in the chapter on plants (Teacher Edition, pp. 16-17) where it is discussed as the life process by which food is broken down and energy is released. However, when respiration is discussed in the unit on The Human Body (Teacher Edition, pp. 346-349), it is discussed in conjunction with the respiratory system as the process by which oxygen is provided to all parts of the body. Only a brief reference is made to the earlier treatment of respiration in the plants chapter, and no attempt is made to link the process of respiration in plants with the process of respiration in animals.

Another example of the lack of connections across strands was mentioned by one of the university experts. He noted that the fifth-grade text uses the concept of life processes and the carbon cycle to organize the presentation of the plants chapter:

> The life processes as an organizer for structure/function teaching and the carbon cycle as an organizer for teaching about food chains, relationships between populations . . . to me those seem like very basic organizers and they were presented that way and the plant chapter is used that way. They don't transfer over to animal chapters and the animals chapters don't have some other kind of organizing framework that takes the place of that. (Interview 134, p. 9)

Two of the university experts were also puzzled by the text's deliberate separation of the study of the human body from the rest of life science. An entire unit on the biology of humans is presented with very few connections to the unit on plants and animals.

Practical Realities

Given the interpretation of conceptual development that science education reformers are calling for, it appears that the curriculum series falls short of meeting their criteria. But in all fairness to the authors and the publishers of this series, we need to consider the possibility that conceptual connections have been deliberately left vague or excluded. Perhaps there are factors related to the practical realities of how teachers teach elementary science and the nature of their backgrounds in science that might contribute to this possibility. For example, the introductory pages of the Teacher Edition point out that this series "presents substantial content in a flexible format," allowing teachers to "customize the program in a variety of ways to meet your time requirements and teaching needs" (Teacher Edition, p. T33). The publishers point out that the four major science blocks "can be taught in any desired sequence" (p. T33). If this flexibility is deliberately built into the content organization of the series, then explicit connections among science blocks, units, and chapters may be purposefully left out in order to give teachers the greatest amount of freedom in determining the order of presentation of the science topics.

As one of the elementary teacher experts who analyzed this text series pointed out, many teachers do a lot of "bouncing around" in the text, not necessarily teaching topics or chapters in the order given in the textbooks. He noted that many teachers base their decisions on which topics to teach and the order in which to teach them on their own teaching styles and their personal interests in particular topics. Once again, given these practical realities of how elementary science is taught, perhaps explicit conceptual connections would not be particularly useful.

Even if we allow for the possibility that the lack of explicit connections between concepts, strands, and science blocks is deliberate on the part of the textbook publishers, there in another practical reality that needs to be considered. While a topic-oriented text may be designed to facilitate teachers' bouncing around and to maximize flexibility of topic coverage, it is clear that this approach to content organization makes it very hard for either students or teachers to get any sense of the depth of concepts or their interrelationships. As one teacher expert noted, the view of science that would likely be communicated by this kind of content organization would be that science is an accumulation of isolated pieces of information.

A second practical reality concerns the nature of elementary science teachers' subject matter knowledge. If teachers had strong backgrounds in science and if they felt confident about their ability to teach science, then the lack of explicit conceptual connection in textbooks might not be as much of problem. Even if they were "bouncing around" in the text, teachers could use their rich subject matter knowledge to make their own conceptual connections and communicate these to their students. One of our teacher experts, a science resource teacher with a B.S. and an M.S. in fisheries and wildlife, noted that he was able to see the ways concepts could be connected within and across grade levels. He recognized, however, that the teachers he works with would be unlikely to make those connections because of their limited background in science. Unfortunately this lack of science background is common among elementary school teachers. As Roth (1989) points out:

> Survey data indicate that teachers avoid science teaching because of a lack of confidence in their own subject matter knowledge (Weiss, 1978), because of a lack of materials (Miller, 1986), and because of

> lack of training in how to teach science. Horn and James (1981) found that teachers not only feel unqualified to teach science, but many of them do not see science as important to teach. (p. 20)

These practical realities tend to minimize the possibility that students will come away from their elementary science classes with the rich understanding of science that curriculum reformers continue to advocate. Is this trade-off between designing curriculum materials for convenience and flexibility and teaching for conceptual development and understanding inevitable?

Discussion: Alternative Visions of Elementary Science Curriculum Materials

The discussion above has highlighted the conflict between the interpretation of concept development that is evident in one commonly used elementary science textbook series, the practical realities that influence the nature of current elementary science teaching, and the significantly different interpretation of concept development presented by education reformers. Given the prevalence and the popularity of the topic-oriented approach to the development of elementary science curriculum materials; given the fact that teachers often "bounce around" in science textbooks, choosing topics that match their personal interests and teaching styles; and given the experts' continuing calls for curriculum materials that promote the development of connected and useful understandings of science concepts, how can this conflict be resolved?

Certainly, teacher education--both preservice and inservice--needs to help teachers develop connected understandings of science concepts. Teachers need to learn at least some science in depth so that they understand what it means to know in science. Teacher education also needs to help teachers develop new visions of science teaching and learning. Thus, curriculum materials must be supplemented with meaningful teacher education. But curriculum materials can also play a role in supporting efforts to teach science for understanding and conceptual change. How might curriculum materials better support student's conceptual development?

One way to improve science textbooks might be as simple as the suggestion made by one of the teacher experts. She recommended that the text include cross-references between units and across grade levels so that teachers would have a better idea of how particular concepts are being developed in various parts of the textbook and in different parts of the text series. However, given the nature of the practical realities discussed above, it is uncertain whether this would make a significant difference in most teachers' or students' understandings of science concepts.

It seems likely that meeting the reform goals of scientists and educational reformers will require more radical changes in the way science curriculum materials are developed. One approach to curriculum materials development that is being tested is the development of K-6 elementary science materials organized around yearlong conceptual themes. The new Biological Sciences Curriculum Study science materials (BSCS, 1988) use a series of content themes similar to those recommended by the Center for the Improvement of Science Education as the basis for their content organization scheme. For example, the second-grade curriculum is organized around the concept of change. Students study about change in different contexts (units) across the year (tools and machines, wellness and personal care, endangered animals). An introductory unit introduces change concepts and an integrative unit at the end of the year emphasizes connections among concepts and helps students draw together concepts studied in different units. A similar pattern at the fifth-grade level allows students to explore the concept of energy in food chains, in technology, in health, and in the environment.

An alternative curriculum development approach that is currently being tested puts primary emphasis on designing science curricula and supporting materials that use students' prior knowledge as the basis for content organization and concept development. In this approach units are developed that directly address students' prior knowledge and organize the content around a limited number of concepts that are treated in depth and are related to students' experiences with natural phenomena. Students' conceptual development is measured in terms of their ability to relate concepts and to use the concepts to explain everyday phenomena.

Linn (1987) has used such an approach in developing a unit addressing basic concepts related to heat and temperature for middle school students. Students explore ideas about heat and temperature across a 10- to 14-week period. Using computers as lab partners, they conduct numerous investigations as they explore and learn to use thermodynamics principles. The unit is based on research about students' personal theories about heat and temperature and is designed to challenge those ideas and help students confront and change their misconceptions. Careful research on the unit as it is taught focuses on the extent to which unit activities and discussions engage students in meaningful conceptual development.

Researchers at Michigan State University are pursuing a similar model of curriculum materials development (Anderson, Roth, Hollon, & Blakeslee, 1987; Berkheimer, Anderson, Lee, & Blakeslee, 1988; Roth, 1985; Roth & Anderson, 1987). Based on research on students' conceptions, these researchers have developed conceptual change-oriented units on photosynthesis, cellular respiration, and matter and molecules. Designed for upper elementary and middle school students, these materials begin with students' ideas about food for plants or about matter and molecules. F example, The Power Plant (Roth &

Anderson, 1987) materials begin by asking students about their definitions of food and about their ideas about how plants get their food. The student "text" does not then proceed to explain photosynthesis. Instead, students are presented with opportunities to address the problem of how plants get their food and to check out the reasonableness of their personal explanations. They make predictions and conduct experiments that challenge their predictions. They are continually engaged in trying to use new pieces of information to change their beginning explanations of how plants get their food.

Only after many common student misconceptions are challenged is the idea of photosynthesis explained. Thus, the ideal student would be wondering, "Wait a minute! If soil isn't food for plants, and water isn't food for plants, then what is food for plants?" The explanation of photosynthesis is then presented and contrasted with students' typical explanations. Following two different representations of photosynthesis, students then engage in a series of activities (including hands-on work, overhead transparencies, discussion questions, writing) that engage students in using the idea of photosynthesis to explain familiar, everyday phenomena. At first students receive much support and scaffolding in tackling these questions and problems. As the unit proceeds, however, students are given less scaffolding in addressing these application questions and activities. Thus, the text is organized around students' conceptual development: What will it take to support students in meaningful conceptual development?

Last year Roth extended the work with the photosynthesis unit by teaching a series of conceptual change-oriented units to fifth graders across an entire school year. She was particularly interested in studying the effects of a series of units that were conceptually linked, providing opportunities for students to deepen their understandings of concepts across time. She studied her students' learning to explore what is possible in terms of student conceptual development when the curriculum and instruction are designed to support conceptual change.

The conceptual integration she developed across units contrasts with the organization in the Silver Burdett & Ginn series. In Roth's scheme, photosynthesis followed a unit about plant and animal adaptations. The adaptations unit focused on the ideas of structure and function. Students studied plant and animal adaptations for getting water, linking their study to the past summer's drought. The photosynthesis unit allowed for continued development of these themes. Students studied how plants are adapted internally for food making, and they studied plants' needs for water in new and deeper ways: Why do plants need water and what do they do with it?

After studying photosynthesis across more than 20 lessons, the students next explored human body cells and systems. This study focused on digestion, circulation, and respiration in the context of exploring several focus questions: What happens to the food that plants make and we eat? Why do we need to breathe? Why is energy-containing food so important to us? Thus, the focus of the unit was on cellular respiration--the releasing of energy from food in each of the body cells. This theme was then explored in different animals and finally in plants.

Photosynthesis was revisited in helping students understand that plants take in and use both oxygen and carbon dioxide but for different purposes (photosynthesis and cell respiration). This conceptual integration continued throughout a unit on ecosystems and a study of chemical change. Photosynthesis and cell respiration were the contexts in which students explored producers, consumers, and decomposers in food chains, chemical change, and distinctions between matter and energy. A culminating study of rain forests allowed for the development of some new concepts about diversity while providing a context to use ideas developed in all of the units. Two other units--on weather and forces--were part of Roth's original plan but were not taught because of time. However, these units were designed once again to focus on a few ideas that were conceptually connected to the other units and that would enable students to understand concepts in increasingly complex and connected ways.

Conclusion

We are struck by the consensus among our experts that the Silver Burdett & Ginn series is not likely to support teachers in helping students develop connected and useful understandings of science concepts. Students are not likely to develop conceptual understandings without much more support in linking ideas together and especially in linking science concepts with their prior knowledge. New models of curriculum development, such as those being pursued by Bybee, Linn, Berkheimer, Anderson, and Roth provide promising new visions of science curriculum materials. The curriculum development process needed to turn these visions into reality depends on continued research on students' conceptions as well as research on the influence of new instructional strategies on student learning and students' misconceptions. Research is also needed on teacher development: How can teachers be helped to develop a new vision of science teaching that is much more sensitive to students' thinking? It is clear that curriculum materials, while important, are not going to be sufficient to help fact-oriented teachers who are used to bouncing around come to understand and use an approach that emphasizes the connectedness and usefulness of science knowledge.

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APPENDIX

Framing Questions

Phase II Study 2: Curriculum Materials Analysis Framing Questions

A. GOALS

1. Are selective, clear, specific goals stated in terms of student outcomes? Are any important goals omitted? As a set, are the goals appropriate to students' learning needs?

2. Do goals include fostering conceptual understanding and higher order applications of content?

3. To what extent does attainment of knowledge goals imply learning networks of knowledge structured around key ideas in addition to the learning of facts, concepts, and principles or generalizations?

4. What are the relationships between and among conceptual (propositional), procedural, and conditional knowledge goals?

5. To what extent do the knowledge goals address the strategic and metacognitive aspects of processing the knowledge for meaning, organizing it for remembering, and accessing it for application?

6. What attitude and dispositional goals are included?

7. Are cooperative learning goals part of the curriculum?

8. Do the stated goals clearly drive the curriculum (content, activities, assignments, evaluation)? Or does it appear that the goals are just lists of attractive features being claimed for the curriculum or post facto rationalizations for decisions made on some other basis?

B. CONTENT SELECTION

1. Given the goals of the curriculum, is the selection of the content coherent and appropriate? Is there coherence across units and grade levels? (Note: all questions in this section should be answered with the goals in mind.)

2. What is communicated about the nature of the discipline from which the school subject originated?

   a. How does content selection represent the substance and nature of the discipline?

   b. Is content selection faithful to the discipline from which the content is drawn?

   c. What does the relationship among conceptual (propositional), conditional, and procedural knowledge communicate about the nature of the discipline?

3. To what extent were life applications used as a criterion for content selection and treatment? For example, in social studies, is learning how the world works and how it got to be that way emphasized?

4. What prior student knowledge is assumed? Are assumptions justified? Where appropriate, does the content selection address likely student misconceptions?

5. Does content selection reflect consideration for student interests, attitudes, dispositions to learn?

6. Are there any provisions for student diversity (culture, gender, race, ethnicity)?

C. CONTENT ORGANIZATION AND SEQUENCING

1. Given the goals of the curriculum, is the organization of the content coherent and appropriate? Is there coherence across units and grade levels? (Note: All questions in this section should be answered with goals kept in mind.)

2. To what extent is the content organised in networks of information structured in ways to explicate key ideas, major themes, principles, generalisations?

3. What is communicated about the nature of the discipline from which the school subject originates?

   a. How does content organization represent the substance and nature of the discipline?

   b. Is content organisation faithful to the discipline from which the content is drawn?

   c. What does the relationship among conceptual (propositional), conditional, and procedural knowledge communicate about the nature of the discipline?

4. How is content sequenced, and what is the rationale for sequencing? For example, is a linear or hierarchical sequence imposed on the content so that students move from isolated and lower level aspects toward more integrated and higher level aspects? What are the advantages and disadvantages of the chosen sequencing compared to other choices that might have been made?

5. If the content is spiralled, are strands treated in sufficient depth, and in a non-repetitious manner?

D. CONTENT EXPLICATION IN THE TEXT

1. Is topic treatment appropriate?

a. Is content presentation clear?

b. If content is simplified for young students, does it retain validity?

c. How successfully is the content explicated in relation to students' prior knowledge, experience, and interest? Are assumptions accurate?

d. When appropriate, is there an emphasis on surfacing, challenging, and correcting student misconceptions?

2. Is the content treated with sufficient depth to promote conceptual understanding of key ideas?

3. Is the text structured around key ideas?

a. Is there alignment between themes/key ideas used to introduce the material, the content and organization of the main body of material, and the points focused on in summaries and review questions at the end?

b. Are text structuring devices and formatting used to call attention to key ideas?

c. Where relevant, are links between sections and units made explicit to students?

4. Are effective representations (e.g., examples, analogies, diagrams, pictures, overheads, photos, maps) used to help students relate content to current knowledge and experience?

a. When appropriate, are concepts represented in multiple ways?

b. Are representations likely to hold student interest or stimulate interest in the content?

c. Are representations likely to foster higher level thinking about the content?

d. Do representations provide for individual differences?

5. When pictures, diagrams, photos, etc. are used, are they likely to promote understanding of key ideas, or have they been inserted for other reasons? Are they clear and helpful, or likely to be misleading or difficult to interpret?

6. Are adjunct questions inserted before, during, or after the text? Are they designed to promote: memorizing; recognition of key ideas; higher order thinking; diverse responses to materials; raising more questions; application?

7. When skills are included (e.g., map skills), are they used to extend understanding of the content or just added on? To what extent is skills instruction embedded within holistic application opportunities rather than isolated as practice of individual skills?

8. To what extent are skills taught as strategies, with emphasis not only on the skill itself but on developing relevant conditional knowledge (when and why the skill would be used) and on the metacognitive aspects of its strategic application?

E. TEACHER-STUDENT RELATIONSHIPS AND CLASSROOM DISCOURSE

1. What forms of teacher-student and student-student discourse are called for in the recommended activities, and by whom are they to be initiated? To what extent does the recommended discourse focus on a small number of topics, wide participation by many students, questions calling for higher order processing of the content?

2. What are the purposes of the recommended forms of discourse?

a. To what extent is clarification and justification of ideas, critical and creative thinking, reflective thinking, or problem-solving promoted through discourse?

b. To what extent do students get opportunities to explore/explain new concepts and defend their thinking during classroom discourse? What is the nature of those opportunities?

3. Who or what stands out as the authority for knowing? Is the text to be taken as the authoritative and complete curriculum or as a starting place or outline for which the discourse is intended to elaborate and extend it? Are student explanations/ideas and everyday examples elicited?

4. Do recommended activities include opportunities for students to interact with each other (not just the teacher) in discussions, debates, cooperative learning activities, etc.?

7. ACTIVITIES AND ASSIGNMENTS

1. As a set, do the activities and assignments provide students with a variety of activities and opportunities for exploring and communicating their understanding of the content?

   a. Is there an appropriate mixture of forms and cognitive, affective, and/or aesthetic levels of activities?

   b. To what extent do they call for students to integrate ideas or engage in critical and creative thinking, problem-solving, inquiry, decision making, or higher order applications vs. recall of facts & definitions or busy work?

2. As a set, do the activities and assignments amount to a sensible program of appropriately scaffolded progress toward stated goals?

3. What are examples of particularly good activities and assignments, and what makes them good (relevant to accompli-~ment of major goals, student interest, foster higher level thinking, feasibility and cost effectiveness, likelihood to promote integration and life application of key ideas, etc.)?

   a. Are certain activities or assignments missing that would have added substantially to the value of the unit?

   b. Are certain activities or assignments sound in conception but flawed in design (e.g., vagueness or confusing instruction, invalid assumptions about students' prior knowledge, infeasibility, etc.)?

   c. Are certain activities or assignments fundamentally unsound in conception (e.g., lack relevance, pointless busy work)?

4. To what extent are assignments and activities linked to understanding and application of the content being taught?

   a. Are these linkages to be made explicit to the students to encourage them to engage in the activities strategically (i.e., with metacognitive awareness of goals and strategies)? Are they framed with teacher or student questions that will promote development?

   b. Where appropriate, do they elicit, challenge, and correct misconceptions?

   c. Do students have adequate knowledge and skill to complete the activities and assignments?

5. When activities or assignments involve integration with other subject areas, what advantages and disadvantages does such integration entail?

6. To what extent do activities and assignments call for students to write beyond the level of a single phrase or sentence? To what extent do the chosen forms engage students in higher order thinking?

8. ASSESSMENT AND EVALUATION

1. Do the recommended evaluation procedures constitute an ongoing attempt to determine what students are coming to know and to provide for diagnosis and remediation?

2. What do evaluation items suggest constitute mastery? To what extent do evaluation items call for application vs. recall?

   a. To what extent are multiple approaches used to assess genuine understanding?

   b. Are there attempts to assess accomplishment of attitudinal or dispositional goals?

   c. Are there attempts to assess metacognitive goals?

   d. Where relevant, is conceptual change assessed?

   e. Are students encouraged to engage in assessment of their own understanding/skill?

3. What are some particularly good assessment items, and what makes them good?

4. What are some flaws that limit the usefulness of certain assessment items (e.g., more than one answer is correct; extended production form, but still asking for factual recall, etc.).

9. DIRECTIONS TO THE TEACHER

1. Do suggestions to the teacher flow from a coherent and manageable model of teaching and learning the subject matter? If so, to what extent does the model foster higher order thinking?

2. To what extent does the curriculum come with adequate rationale, scope and sequence chart, introductory section that provide clear and sufficiently detailed information about what the program is designed to accomplish and how it has been designed to do so?

3. Does the .combination of student test, advice and resources in teachers manual, and additional materials constitute a total package sufficient

to enable teachers to implement a reasonably good program? If not, what else is needed?

a. Do the materials provide the teacher with specific information about students' prior knowledge (or ways to determine prior knowledge) and likely responses to instruction, questions, activities, and assignments? Does the teachers manual provide guidance about ways to elaborate or follow up on text material to develop understanding?

b. To what extent does the teachers manual give guidance concerning kinds of sustained teacher-student discourse surrounding assignments and activities?

c. What guidance is given to teachers regarding how to structure activities and scaffold student progress during assignment completion, and how to provide feedback following completion?

d. What kind of guidance is given to the teacher about grading or giving credit to participating in classroom discourse, work on assignments, performance on tests, or other evaluation techniques?

e. Are suggested materials accessible to the teacher?

4. What content and pedagogical knowledge is required for the teacher to use this curriculum effectively?

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