Tools and Traits for Highly Effective Science Teaching, K–8

Jo Anne Vasquez, PhD

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CHAPTER

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Designing and Delivering Effective Science Instruction

Knowing What to Teach and How to Teach It

Dr. Molina-Walters discussed her expectations of a highly effective elementary teacher of science; knowing what to teach (the content), knowing how to teach (the pedagogy), and having the essential background knowledge (the depth of conceptual understanding). In *How Students Learn Science,* the authors describe effective science instruction at the elementary level by saying core to teachers' decision making is the need to manage individual students' learning of both targeted scientific knowledge and the *ways* of knowing. For this to happen, teachers must have sufficient subject matter knowledge, including aspects

VOICE FROM THE FIELD

To be an effective teacher of science [teachers] first need to have a passion for science and then develop the skills for effective teaching; [they need] a balance between knowing what to teach and how to teach it. They also need to have essential background knowledge. In my science methods classes I hold students responsible for not only learning how to teach science but also knowing and understanding the content they are going to be teaching.

—Dr. Molina-Walters Ed.D., School of Educational Innovation and Teacher Preparation, Arizona State University Polytechnic Campus

of the culture of science that guide knowledge production, and must fully understand the nature of the learning goals. Therefore, when a student says that light "disappears" into paper but reflects off mirrors, a teacher's uncertainty about whether that claim is accurate will hamper their effective decision making or if a student claims an object is opaque and the question at hand is how light interacts with matter, the teacher needs to recognize that the word "opaque" describes the object and not light. Teachers need to have accurate subject matter knowledge combined with pedagogical content knowledge to be a truly effective practitioner (National Resource Council 2005, 467–68).

To improve the future of elementary science instruction, teachers must be held responsible for their content knowledge as well as pedagogical knowledge. Unfortunately, many elementary teachers who are presently in the classroom have not had the depth of preparation nor the professional development experiences to bring them up to the level needed to be effective teachers of science. The difference I have found between those who just teach science and those who do it effectively is the latter have gone beyond traditional training to acquire the needed content and skills. Most effective elementary teachers are part of a science "community of learners," either within their district or state, and belong to professional science organizations. They choose to participate in professional development experiences to improve their instruction and content knowledge base. Along with having the essential skills and knowledge base, teachers need to manage and execute inquiry-based instruction. They also need to be supported with effective curricula and materials if they are going to be truly effective. These are points we will explore in this chapter.

Defining Curriculum Coherence and Articulation

The National Science Education Standards (NSES) and Benchmarks for Science Literacy from the American Association for the Advancement of Science (AAAS) define the content of instruction by outlining what a student should know and be able to do. It is the district curriculum, usually guided by state science standards, that provides a road map of what content will be taught at which grade level, and how it will be aligned throughout the grade levels. How this content is organized, presented, and assessed is the backbone of classroom science instruction. In other words, classroom science instruction is driven, for the most part, by the curriculum map the district lays out for their teachers. An effective curriculum map is coherent, aligned, and makes sense as a whole.

A carefully designed curriculum is a road map to promote learning with understanding, and usually is framed around a series of lesson and unit structures. Such a structure helps teachers organize factual information around "big ideas" of science rather than teaching facts in isolation. *How People Learn* describes the enterprise of education as moving students in the direction of more formal understanding (or greater expertise). To do this will require both a deepening of the information base and the development of a conceptual framework for that subject matter (NRC 2000, 17). To facilitate this type of learning, instruction must provide students with depth of factual information (not factoids) while at the same time connecting that information to the core ideas or big ideas of science.

What Is a Big Idea?

Jay McTighe and Grant Wiggins in their *Understanding by Design* model use enduring understandings to reach the *big ideas* or *important understandings* of what we want the students to get inside of and retain after they've forgotten many of the details. What this does is help students to connect to a larger idea to provide a cognitive framework that facilitates a greater transfer of learning. In *How People Learn* (NRC 2000), one of the key factors that distinguishes "expert" learners from "novices" is the ability to organize or chunk their thinking around big ideas. It is these big ideas that you will find effective teachers providing for their students.

Some curricular materials will be focused around the big ideas; however, if the resources the teachers are using in their district do not do this, how can this happen? Most of the time it requires district- or grade-level study groups to help flush these out. In some cases districts do provide a road map for their teachers along with the professional development to gain understanding.

One district that has provided a road map for its teachers is Virginia Beach City Public Schools in Virginia:

Voice from the Field

We developed science units of study with the goal of helping students to deepen their understanding of science. To accomplish this goal, each science unit is developed around big ideas or what McTighe and Wiggins call enduring understandings. Students, with the help of teachers, will uncover content and the facts associated with our state standards, through essential questions that get at the heart of the understanding(s). By providing our elementary teachers with this information, teachers can spend the time developing lessons that frame their teaching around the big ideas and essential questions. Activities within the units are aligned to an essential question. By providing teachers with this information, along with professional development, we have been able to move our teachers from just looking at science as a list of factual knowledge to understanding the big idea. For instance, a first-grade student will learn that all animals have certain physical characteristics. Common physical characteristics were used by scientists to form groups. Understanding the physical characteristics of organisms, such as body coverings, leads in later grade levels to the understanding that animals have unique ways to protect themselves in order to survive. In previous years, students would not have gotten to this understanding. They would instead have learned isolated facts about mammals and birds.

—Dr. Jenny Sue Flannagan, Elementary Science Coordinator, Virginia Beach City Public Schools, Virginia

Figure 5–1

BIG Idea Animals, including people, have life needs and special physical features that can be classified according to certain characteristics	
Essential Questions	Knowledge and Skills (from VA State Standards for the First Grade)
■ What terms or words are specific to the work of a zoologist who studies animals? ■ What do animals need to live and grow? ■ What are some characteristics of animals that help them move, protect themselves, and survive? ■ What attributes or characteristics do scientist use to describe and classify animals? ■ What patterns of change emerge as different animals experience the seasons?	Know: 1.4.1 A zoologist uses his or her sense and tools to make observations about animals. 1.4.2 A zoologist classifies animals based on observable features. Do: 1.4.3 Analyze examples of various animal body coverings, body shapes, appendages, method of movement, and the concepts of wild versus tame. 1.4.4 Describe the life-needs of animals: food, water, shelter, and oxygen from air or water. 1.4.5 Infer types of animal homes (water or land) using physical characteristics of the animals. 1.4.6 Classify components of an animal's surroundings as living/non-living (including water, space, and shelter). 1.4.7 Compare and contrast the four seasons and predict how seasonal changes affect animals in terms of when and why animals migrate, hibernate, change their behavior, and change body covering. 1.4.8 Classify animals by where they live (their homes). 1.4.9 Classify and chart simple characteristics of animals. 1.4.10 Make and communicate observations of live animals, including people, about their needs, physical characteristics, and where they live.

Jenny Sue Flannagan, Virginia Beach City Public Schools, Virginia Beach, VA

Looking at animals and humans in this context of a big idea and essential questions instead of isolated facts, the students are able to make important connections—for example, "animals move to meet their needs." Thus movement of animals is seen as something animals and humans do to survive, and how they move can be a way to classify or put them into groups (e.g., two legs, four legs, or no legs; wings or no wings). This way, they begin to see classification as having set characteristics. They then can begin to recognize in later grades the overarching, unifying concept of adaptation.

Science Curriculum Topic Study

Not all districts are fortunate enough to have a person or department to help teachers move in this coherent direction; however, their new tools and resources coming into science education may help. Page Keeley, Senior Program Director for the Maine Mathematics and Science Alliance, has, with funding from the National Science Foundation, developed an effective tool for "unpacking" all of this for teachers and districts. It is called *Science Curriculum Topic Study* (Corwin 2005). This research-based process helps to improve teachers' understanding of science content, identify and clarify the "big ideas," and identify potential learning difficulties and misconceptions associated with a topic.

Page Keeley was a Presidential Award-winning classroom science teacher before her move to the Alliance. She knows firsthand how difficult and time consuming this can be for teachers and districts. Knowing where to start is an even bigger barrier to this process. Therefore, *Science Curriculum Topic Study* provides a standards-based and research-informed process that builds teachers' content knowledge of the topics they teach, helps them examine instructional implications, unpacks concepts and ideas that are important to teach, identifies misconceptions and potential learning difficulties, and makes coherent connections across and within grade levels (Corwin 2005, 59–60).

> *Unifying Concepts:* Fundamental and comprehensive non-discipline-specific concepts that provide connections between content standards in science (e.g., models, systems, patterns, change).
>
> *Big Ideas:* Generalizations, laws, theories, principles, or broad ideas that show relationships among concepts. Big ideas are the essential understandings that often cut across grade spans and information adult literacy (e.g., organisms depend on other organisms for their needs).
>
> *Concepts:* Mental constructs made up of one to three words that can be broad or topic specific. Even though factual knowledge may evolve and change, concepts remain universal and timeless. Concepts can begin with very basic ideas and culminate in sophisticated understanding. Students refine and enhance their thinking about concepts over the course of their K–12 experience (e.g., motion, adaptation, ecosystems, weathering).

Subconcepts: Concepts broken down into more specific mental constructs (e.g., horizontal motion, behavioral adaptation, lunar eclipse).

Specific Ideas: Scientific statements about a concept or subconcept that give it meaning. Specific ideas provide specificity for a broad local, state, or national learning goals (e.g., a rock is composed of different combinations of minerals).

Facts and Terminology: Definitions, formulas, fragments of specific knowledge, and technical vocabulary. While certain facts and terminology are necessary, when taught and learned in isolation they are less likely to contribute to conceptual understanding (e.g., density equals mass divided by volume; atoms are made up or protons, neutrons, and electrons).

How Can a District Use Curriculum Topic Study (CTS) to Bring Curriculum Coherence and Articulation?

Curriculum Topic Study (CTS) has been gaining in popularity across the science education community. It provides a tool to help districts look at their curricula and standards in a cohesive way. It helps by giving teachers a schema for breaking down ("unpacking") a topic, as well as "building up" into big ideas. By examining the concepts and ideas in a topic and considering recommendations from the standards and research on student learning, teachers can lay out a complete picture of the curriculum. It helps them to think of the flow of ideas to determine:

- The important core set of ideas students should learn, ranging from specific facts, terminology, and ideas to broad concepts, "big ideas," and unifying themes
- The major connections among ideas both within the content domain, across content domains, and across disciplines
- Cross-cutting processes and understandings to inquiry and technological design, the nature and history of science, and personal and social perspectives of science and technology
- Important prerequisites leading to increasing sophistication, by which students eventually come to understand important ideas in science from one grade level to the next and within grade levels (Corwin 2005, 62)

These are actually the pieces to the puzzle that will come together to help teachers see their district's curricula as a whole and not a set of disjointed grade-level expectations.

Voice from the Field

I worked for twenty-six years as an elementary teacher before moving to the Alliance. As a classroom teacher this was the first tool I have ever used to help me unpack the ideas from the standards. It helped me to see what the research said about what misconceptions the children might have and pointed a way to content. I needed to understand so as not to set up these misconceptions. It was a way to drive through the topics and dig deeper. In the long run it made my life easier, but it was time consuming. I feel much more confident about my own teaching and ability to mentor others now that I have done this process.

—Nancy Chesley, Elementary Science and Literacy Specialist, Maine Mathematics and Science Alliance

Effective teachers of science will understand the topics of their grade level. Those who are not effective are looking at the teaching of science as simply teaching ponds, butterflies, or dinosaurs, which are the themes or the stories of science. Effective teachers of science will use them; however, they will use them to develop, practice, and apply the big ideas and skills to get at the necessary content. They might use dinosaurs as the context, but it will not just be to give students facts and vocabulary—it will be to develop interrelated ideas and skills about changes in life forms and environment over time.

Whatever method a district uses to look closer at their curricula for coherence and alignment, they must not look at it through the lens of a "check-off" list of their state and district standards. Standards are important, but to get at the heart of developing scientifically literate students, teachers need to weave an interconnected web of understanding. For more reading and information about CTS, visit: www.curriculumtopicstudy.org

Deepening Teacher Content Knowledge

While visiting with a district curriculum superintendent she ask me what are some ways to help with the overarching problem of elementary teachers not having enough content knowledge to feel comfortable teaching science. It was not a simple question to answer. Therefore I said, "First of all, you have to provide purposeful, efficient, and effective professional development to deepen both your teachers' content and pedagogical knowledge. Not the one-time workshop after school, but sustained efforts giving teachers time to learn this new knowledge. Then provide mentoring and coaching to help them transform their classroom practice reflecting this new knowledge."

In *Taking Science to School* (NRC 2006), one of the key recommendations is that teachers deepen their science content knowledge. "Professional development should be rooted in the science that teachers teach and should include opportunities to learn about science, about current research on how children learn science, and about how to teach science" (NRC 2006, ES-5). *Looking Inside the Classroom* backs up this recommendation (Weiss et al. 2003) by explaining what transpires in the nation's classrooms, and the factors that shape instruction in mathematics and science. The study points out that without question, teachers need to have sufficient knowledge of the mathematics/science content they are responsible for teaching. However, teacher content knowledge is not sufficient preparation for high-quality instruction. Teachers also need expertise in helping students develop an understanding of that content, including knowing how to determine what a particular student or group of students is thinking about those ideas, and how the available instruction materials can be used to help students deepen their understanding.

We now know (and research and studies are telling us) there is a national shift toward looking at the content knowledge that elementary teachers need. The NRC research in *How People Learn* (Bransford, Brown, and Cocking 1999) has helped to raise this awareness among educators and policy makers. They point out that the difference between novice and expert teachers is that the former:

- Know the structure of the knowledge in their disciplines.
- Know the conceptual barriers that are likely to hinder learning.
- Have well-organized knowledge of concepts and inquiry procedures and problem-solving strategies (based on pedagogical content knowledge).

If you are a classroom teacher or a professional development provider and you want to dig deeper into the content, there are some tools available to help (however, this does not replace formal science content coursework):

- *Curriculum Topic Study* (CTS) provides avenues and reading references to help teachers gain content knowledge. It does this by providing a systematic way for teachers to identify relevant grade-level content and increase their knowledge of the science ideas as well as understand how the knowledge is structured. Many district elementary science programs are using CTS to help enhance and identify what they don't know. By using the CTS guide and the optional content reading supplements on the CTS website (www.curriculumtopicstudy.org) teachers will be well on their way to helping to solve the problem.

- National Science Teachers Association (NSTA), the largest professional science teachers' organization, has recognized this as a growing concern. They offer many excellent resources to help elementary teachers deepen their content knowledge, one of which is a set of very popular books called *Stop Faking It! Finally Understanding Science So You Can Teach It* (Robertson, W. NSTA). Each book focuses on a particular concept, such as air, water, and weather; force and motion; light; etc. Although they are listed as for grades 5–12, they can be used effectively in professional development experiences or study groups.
- These and other books published by NSTA are connected to the website called SciLinks. This central location helps teachers avoid searching hundreds of science websites to locate the best sources for more information on a given topic. You simply go into the URL (www.scilinks.org) and type the keyword code that is found by the logo on the book's page. You will then receive an annotated listing of as many as fifteen Web pages, all of which have gone through an extensive review process that will help you understand the content. Try it with the concept of light and the topic of refraction; go to the website and type in the code SFL02 to view examples of content articles.
- Another effort by the National Science Teachers Association is their Learning Center. NSTA is creating a scalable e-Professional Development (e-PD) portal that will allow educators to utilize a comprehensive systems-based approach to their professional development. They have developed 26–30 comprehensive online learning experiences for K–12 science teachers focusing on fun, interactive science content learning experiences delivered through a state-of-the-art e-Professional Development portal.
- The Learning Center will be home base for science teachers and school systems in search of high-quality science content specifically addressing their individual needs and their system's professional development requirements. Educators are able to diagnose their needs and gain access to a variety of professional development resources and opportunities aligned to standards and the grade bands they teach. Personalized tools within the Learning Center, such as *My PD Plan and Portfolio, My Library, My Calendar,* and *My Transcript,* will allow educators to manage, track, document, and certify their professional development growth over a period of time. The beta launch of the NSTA Learning Center and all the resources below are available at http://learningcenter.nsta.org. You may view a

7-minute multimedia overview of the NSTA Learning Center by going to: http://institute.nsta.org/learningcenter/flashdemo/index.html.

- As of spring 2007 there are more than 1,400 professional development resources and opportunities available within the Learning Center, with 35 percent available for free or less than $1.00. You do not need to be a member of NSTA to access the NSTA Learning Center, but members receive member discounts and/or free access to many resources. Professional development resources such as NSTA e-Books, e-Book Chapters, Journal Articles, Web Seminars, Symposia, SciGuides, Science Objects, and SciPacks are all available within the NSTA Learning Center.

- NSTA SciPacks are 5–10 hour-long, discrete, online learning experiences to assist educators in understanding the science content they teach. SciPacks are based on the national science standards and are accessible anytime, anywhere. The basic feature common to all SciPacks is a set of three to five Science Objects, each with embedded simulations and related follow-up questions. In addition to the free Science Objects, each SciPack contains a pedagogical section that provides the teaching context of the content. This part of the SciPack will be designed to help them recognize the level of sophistication appropriate for their students, identify or diagnose students' misconceptions, and employ strategies that are most effective for the particular ideas they teach. Each SciPack also provides individualized email support from a Content Wizard and concludes with a graded assessment that if passed, allows a teacher to print a "certificate" demonstrating mastery understanding of the content addressed.

Other efforts to improve and deepen teachers' content knowledge and add just-in-time resources right at their fingertips are:

- **NSTA SciGuides** are online, thematically based packages of pre-evaluated and standards-aligned Web-accessible classroom resources for science teachers to use in their classroom. Each SciGuide consists of a library of approximately 100 Web pages vetted against eight educational rubrics. Each SciGuide provides a brief content background description for the educator and links to the Web-based resources. Each SciGuide has a set of tools to assist educators in implementing the Web-based resources into their classroom with lesson plans, media vignettes, and samples of student work illustrating lesson outcomes.
- **NSTA Symposia** experiences are face-to-face workshops that provide follow-up online learning opportunities, such as live web seminars and asynchronous threaded discussion. The content of Symposia is delivered in partnership with

NASA, NOAA, FDA, NSF, and NSTA Press authors, with offerings in STEM-related content areas.

- **NSTA Web Seminars** are live, professional development experiences that allow participants to interact with nationally acclaimed experts, scientists, engineers, and education specialists from NSTA government partners such as NASA, NOAA, NSF, FDA—all from the convenience of a desktop computer! Educators use their browser to mark up and annotate presenter's slides or share desktop applications, in addition to engaging in chat with others and answering poll questions. Seminars are archived and available for viewing after the live event. Agency-sponsored Web seminars are free and create learning opportunities for those unable to attend face-to-face opportunities.
- The National Science Digital Library (NSDL at www.nsdl.org), funded by NSF, provides research-based content to teachers for free. This same site can also be used for student research. NSDL lists resources and articles by reputable sources that are organized under broad umbrellas. There are also Web seminars for teachers to attend around topics to help broaden their content knowledge.

Managing Inquiry-Based Learning

Mr. Hallock points out in Voices from the Field many of the elements we have been discussing, but two of which we have not focused on are materials management and cooperative learning strategies, both of which go together to support inquiry-based science instruction.

You Need the Stuff to Teach Hands-on Science

Mr. Hallock's district and others around the country provide materials for their elementary science programs. This district has made elementary science a priority and the materials kits are delivered to every teacher from a central distribution center. These material resource centers can be found in some large districts across the country. To learn more about these resource centers, visit the Association of Materials Centers website www.kitsupport.org.

Many districts provide materials kits that are intended to last for the entire year, with a teacher or a school leader responsible for turning in the replenishment list at the end of the year. Whichever way the materials are delivered or supplied to the teacher, the main point is that to be an effective teacher of science you have to have the materials to do the hands-on

Voice from the Field

I want to see teachers being organized and having clear lesson objectives. I want teachers to have their materials out and ready for the groups to pick up. They need to be able to set up the lesson in a way that motivates the students to want to learn and then let them get on their way. We use cooperative group strategies, so the group members all have roles. The teacher then becomes the facilitator of the lesson and helps the group members as they work on their investigation. I want teachers to have the students clean up and provide a lesson wrap-up.

—Principal Michael Hallock, Spectrum Elementary School, Gilbert Public Schools, Gilbert, Arizona

investigations. You might find pockets of teachers who gather their own materials and are still very effective, but most of the time the teachers who rise to the top are those who have a strong support system.

Whether the district chooses to go with curriculum kits or modules that contain the materials, or uses textbooks combined with kits of materials, the materials are a must. We have discussed the importance of a coherent curriculum; however, this curriculum must be combined with the resources and materials for successful classroom implementation.

Just Putting the Students into Groups Does Not Guarantee Effectiveness

Frankie Troutman (see Voices from the Field) is a highly effective kindergarten teacher who is passionate and knowledgeable about the teaching of primary science. She is asked to deliver professional development seminars all over the country and knows that materials are not enough to be effective in executing an inquiry-based investigation. She therefore stresses cooperative learning. Science educators, because they encourage teachers to have students work in groups for their investigations and projects, have embraced cooperative learning techniques.

VOICE FROM THE FIELD

When I am presenting teacher workshops or seminars I always model cooperative learning techniques. I am amazed at the number of experienced elementary teachers who have never heard of these strategies. I wonder how they ever get their students into groups to do their activities. It seems to me it would just be chaos without some sort of structure to the grouping.

I guess I was lucky because many years ago our entire school was given a series of sessions about how to use cooperative learning strategies. Not all teachers still use them; however, many of us do, and my students leave my kindergarten class knowing at least the basics of working together in a group situation.

—*Frankie Troutman, Kindergarten teacher, Sirrine Elementary School, Mesa Public Schools, Mesa, Arizona*

What Is Cooperative Learning?

Cooperation is working together to accomplish shared goals. Within cooperative activities, individuals seek outcomes that are beneficial to themselves and beneficial to all other group members. *Cooperative learning* is the instructional use of small groups so that students work together to maximize their own and each other's learning. It is a successful teaching strategy in which small teams, each with students of different levels of ability, use a variety of learning activities to improve their understanding of a subject. Each member of a team is responsible not only for learning what is taught but also for helping teammates learn, thus creating an atmosphere of achievement. Students work through the activity until all group members successfully understand and complete it.

These cooperative efforts result in participants striving for mutual benefit so that all group members:

- Gain from each other's efforts. (Your success benefits me and my success benefits you.)
- Recognize that all group members share a common fate. (We all sink or swim together here.)

- Know that one's performance is mutually caused by oneself and one's team members. (We cannot do it without you.)
- Feel proud and jointly celebrate when a group member is recognized for achievement. (We all congratulate you on your accomplishment!).

There are a number of key elements that set cooperative learning apart from other grouping techniques (Cochran 1989, Johnson and Johnson 1999). These elements include the following:

- Heterogeneous grouping (mixing levels of student abilities especially ELLs)
- Positive interdependence (sinking or swimming together)
- Face-to-face supportive interaction
- Individual accountability (requiring each group member to contribute to the group's achievement of its goals; typically each member is assigned a specific role to perform in the group)
- Interpersonal and small group skills (communication, trust, leadership, decision making, and conflict resolution)
- Group processing (reflecting on how well the team is functioning and how it can function even better)

In a classroom of an effective teacher you will find these strategies employed, particularly during investigations. However, these same cooperative-learning strategies can be used throughout all subject areas and are not just for science instruction.

Summary Thoughts

Designing and delivering effective science instruction takes a coherent and aligned curriculum designed around the big ideas of science. This curriculum must be strategically built in order not to teach lots of pieces of science knowledge. To deliver this curriculum effectively teachers need to deepen their content and pedagogical knowledge. And for this curriculum to be effectively delivered in the classroom it needs to be supported with the appropriate tools and materials. Teachers cannot just put students into groups to have them complete activities and think they will be successful. Grouping and group skills must be specially taught by the teacher to guarantee success of all the group members.

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