

Supporting Goals–Based Learning with STEM Outreach

Sofia Kesidou, Ph.D.

Program Director
AAAS Project 2061

Mary Koppal

Communications Director
AAAS Project 2061

In its latest update on the state of U.S. science and engineering, the National Science Board reports that nearly all Americans agree on the importance and value of science literacy in understanding and dealing with the issues of the day (1). However, performance by the nation's K-12 students in mathematics and science as measured by the National Assessment of Educational Progress (NAEP) tests continues to be disappointing (2). Without basic literacy in science, mathematics, and technology, these young people will not be prepared for tomorrow's jobs or for making decisions about health care, national security, the environment, and a range of other issues in which science and technology play a key role. While reforms in science, mathematics, and technology education are underway to address these problems, a great deal more needs to be done throughout the education system before significant improvements in student achievement can be realized.

As an important part of the system, the scientific and technological community has a vital role to play in reaching out to education reform efforts and encouraging young people to study and pursue careers in science, technology, engineering, and mathematics (STEM). One such reform effort is Project 2061, a long-term nationwide education reform initiative of the American Association for the Advancement of Science (AAAS). Project 2061 began its work in 1985, the year Halley's Comet was last visible from Earth. Children just starting school now will see the return of the Comet in 2061—a reminder that today's education will shape the quality of their lives as they come of age in the 21st century amid profound scientific and technological change. Project 2061 has focused its work on understanding what it takes to help all students become literate in science, mathematics, and technology and on developing tools to help all those engaged in this important endeavor.

In this article, our goal is to share with *JSTEM Education* readers some ideas and resources drawn from our work at Project 2061 that can help them develop outreach efforts that are more relevant, effective, and rewarding. In particular, we focus on identifying resources and strategies that can be used to enrich outreach efforts that aim to supplement or enhance STEM content for students

in kindergarten through 6th grade, rather than on efforts related to STEM careers. Our recommendations below are drawn from the standards- and research-based practices that are driving reforms in today's science and mathematics classrooms.

AAAS's Project 2061 and Science Literacy

With its first publication *Science for All Americans* (3), Project 2061 called attention to the knowledge and skills that all citizens need so that they can live productive and rewarding lives in a society that is increasingly shaped by science and technology. Drawing on the work of expert panels representing the major scientific and technical disciplines, *Science for All Americans* describes a science literate person as one who:

- is familiar with the natural world.
- understands some of the key concepts and principles of science.
- has a capacity for scientific ways of thinking.
- is aware of some of the important ways in which mathematics, technology, and science depend upon one another.
- knows that science, mathematics, and technology are human enterprises and what that implies about their strengths and limitations.
- is able to use scientific knowledge and ways of thinking for personal and social purposes.

This vision of science literacy emphasizes the connections among ideas in the natural and social sciences, mathematics, and technology and avoids the artificial boundaries that separate the traditional curriculum into individual disciplines. *Science for All Americans* has laid the groundwork for Project 2061's ongoing research and development efforts and for the nationwide science standards movement of the 1990s.

To help students make progress toward science literacy, Project 2061 next published *Benchmarks for Science Literacy* (*Benchmarks*), which proposes learning goals for students at the end of grades 2, 5, 8, and 12 (4). Developed in collaboration with teams of educators in six diverse school districts and with scientists and experts on learning and curriculum design, *Benchmarks* reflects the input of

Abstract

Drawing on knowledge and experience gained through the study of K-12 science, mathematics, and technology education practices and efforts to reform them, this article suggests several ways to strengthen outreach efforts aimed at students in the elementary grades. The article begins with a description of Project 2061, an education reform initiative of the American Association for the Advancement of Science that promotes the goal of science literacy for all students and the importance of coherent and specific content standards to guide K-12 teaching and learning. The authors then recommend several strategies and a number of resources that can help those in the scientific and technological community to develop outreach efforts and materials that are aligned with and support the goals that today's students and teachers are striving to achieve.

more than 1,300 individuals. *Benchmarks* provides educators with sequences of specific learning goals that they can use to design a core curriculum, guiding decisions about what content to include (or exclude), when to teach it, and why. To help educators as they rethink their curriculum, *Benchmarks*:

- describes levels of understanding and ability that all students are expected to reach on the way to becoming science literate;
- concentrates on the common core of learning that contributes to the science literacy of all students while acknowledging that most students have interests and abilities that go beyond that common core, and some have learning difficulties that must be considered;
- avoids technical language used for its own sake, in part to reduce sheer burden, and in part to prevent vocabulary from being mistaken for understanding;
- is informed by research on how students learn, particularly as it relates to the selection and grade placement of the learning goals;
- encourages educators to recognize the interconnectedness of knowledge and to build these important connections into their curriculum units and materials; and
- includes knowledge of the nature and history of science, mathematics, and technology, an understanding of common themes that cut across disciplines, and the development of scientific habits of mind as essential aspects of science literacy.

Both *Science for All Americans* and *Benchmarks* have been influential in national and state education reform efforts. The National Research Council's *National Science Education Standards*, for example, acknowledges "its indebtedness to the seminal work by the American Association for the Advancement of Science's Project 2061" (5). A study by SRI International found that Project 2061's work had an impact on the day-to-day work of most state education leaders and influenced the development of nearly every state science curriculum framework or standards-type document (6). Along with Project 2061, other national organizations have developed content standards for other subject areas, including the publication in 2000 of *Principles and Standards for School Mathematics* produced by the National Council of Teachers of Mathematics (7) and *Standards for Technological Literacy: Content for the Study of Technology* produced by the International Technology Education Association (8).

In its current work, Project 2061 has focused on helping educators and others make use of learning goals (a general term for benchmarks or standards that specify the content that students are to learn) in their efforts to improve curriculum materi-

als, teacher education, assessments, and other elements of the K-12 education system. Project 2061 also works closely with the informal science education community through partnerships with science centers and museums around the country.

Of particular interest to Project 2061 has been the role of curriculum materials—including traditional textbooks, stand-alone or supplemental units, computer-based activities and programs, and so on—as tools that can support both teachers and students. To gather baseline data on the extent to which currently available science and mathematics textbooks could be useful in helping a wide range of students learn some of the key ideas recommended in national and state content standards, Project 2061 conducted evaluative studies of 44 middle and high school textbooks. The studies looked at the most widely used textbooks and at some non-traditional textbooks that were fairly new to the market. With the exception of a handful of promising mathematics textbooks, nearly all of the textbooks had many weaknesses, including a lack of coherence and focus on key learning goals, an overemphasis on trivial details and terminology at the expense of more in-depth content, failure to develop students' thinking and reasoning skills, and inadequate support for teachers in identifying and correcting students' misconceptions. In science not a single textbook received a satisfactory overall rating (9, 10, 11).

Drawing on the findings from these and other studies and from the available research on teaching and learning, we've distilled three key recommendations that we think will help the readers of *JSTEM Education* place their outreach efforts within the broader context of education reform in science, mathematics, and technology. At the same time, we identify some useful resources—both online and in print—that can help put these recommendations into practice. As a result, outreach efforts can be designed to engage young audiences more effectively and help them make progress toward achieving important learning goals. We've tried to recommend steps that will provide the most lasting benefit to developers of outreach activities and materials and to the classrooms that will be using them.

Recommendation #1: Align Your Outreach Efforts to Relevant Content Standards

By specifying what students should know and be able to do in each content area and grade level, the standards movement has been a major influence on the reform of STEM education. With the introduction of the No Child Left Behind Act of 2002 (12), schools, teachers, and students must now meet stringent accountability measures that are tied to those standards.

In this new environment, it is more important than ever that outreach efforts be well aligned with the relevant science and mathematics learning goals. Achieving this alignment is not as easy as it might seem; many standards documents are little more than checklists of concepts and skills to be “covered.” To be meaningful, alignment needs to go beyond a key word or topic match. For this reason, *Benchmarks* spells out quite specifically the ideas that students are expected to know and expresses the ideas in language that is appropriate to each grade band. Although written to be as precise as possible, the learning goals in *Benchmarks* still need to be interpreted and clarified before they can effectively guide the design of an activity, experiment, demonstration, lesson, or unit. To help think through what this kind of alignment would look like when applied to a particular outreach activity or material (as well as to textbooks and a wide variety of other curriculum materials), here are some questions to keep in mind:

Does the activity or material address the actual substance of the learning goal or just the topic? As an example, consider the following learning goal for students in grades 3-5 that relates to understanding the nature of science and how scientists work:

Clear communication is an essential part of doing science. It enables scientists to inform others about their work, expose their ideas to criticism by other scientists, and stay informed about scientific discoveries around the world. (4)

At first glance, it might seem that any outreach activity that addresses the topic of communication by providing opportunities for students to work together or to share information would be aligned with this learning goal. Instead, the goal actually expects students to understand the essential role that clear communication plays in scientific discovery. More on-target activities might bring students together as a team to investigate a science question and then to reflect on how sharing their data and information helped their work along. To demonstrate how much clear communication contributes to their work, activities might even include deliberate blocking of communication so that students can see how their work suffers as a result.

Does the activity or material focus on the “big ideas” specified in the learning goal rather than on less important details? Consider this learning goal for students in grades 3 through 5:

The patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons. (4)

Here students are expected to understand that when any group of stars is observed at different

times over the course of one night or on different nights, the stars always have the same arrangement—they always have the same relative positions to one another. This arrangement is consistent night after night, year after year, and century after century even though there may be times when parts (or all) of the arrangement may not be visible. Outreach activities or materials that give students opportunities to observe that stars within a group maintain their relative positions and that groups of stars maintain their positions relative to other groups, even as they all appear to move across the sky during the night, are likely to be well aligned with this learning goal. Efforts aimed at having students know the names of constellations or how many there are would not be aligned.

Does the activity or material reflect the level of sophistication of the learning goal? Consider this learning goal for students in kindergarten through 2nd grade:

Water left in an open container disappears, but water in a closed container does not disappear. (4)

In this example, K-2 students are not expected to understand the mechanism of evaporation, including molecules, invisible vapor, or even the term “evaporation” itself; it is enough to observe what happens to the water in a sufficient variety of contexts to see the pattern described in the benchmark. Students are expected to build on their observations in grades 3-5 to understand that when liquid water disappears, it turns into a gas (vapor) in the air, and in grades 6-8 to explain evaporation in terms of invisibly small molecules. In Project 2061’s *Benchmarks*, decisions about the placement of learning goals at particular grade levels are based on cognitive and domain-specific research and on teachers’ experience. Useful summaries of much of this research are included in a special chapter of *Benchmarks*.

Recommendation #2: Pay Attention to What Students Are Thinking

Extensive research has shown that even very young children have their own ideas about almost every topic they are likely to encounter. For example, on the topic of “light,” some children may identify light only with its source or with its effects rather than thinking of light as an entity that travels in space. Rather than dismissing these as merely “erroneous” beliefs that can be easily corrected, it’s important to understand that these are powerful ways of thinking that affect the way children are likely to interpret and respond to the outreach activities or materials being planned.

By being aware of these ideas and beliefs and taking them into account in their planning, outreach developers will be able to ask better questions and

to provide more convincing evidence about the validity and plausibility of a scientific explanation. For example, if students associate light only with its source or effects, they are unlikely to explain the direction and formation of shadows in terms of an obstacle blocking the *passage* of light but will merely notice similarity of shape between object and shadow, or say that the object hides the light. Questions such as “what is the path of light?” or “does light move?” are not likely to make sense to these students (13).

Benchmarks (4) is one of several helpful sources of information about the ideas that many students have in specific topic areas: other resources include *Children’s Ideas in Science* (14) and *Making Sense of Secondary Science* (15). Project 2061 is currently developing comprehensive summaries of findings from learning research on student thinking. They include descriptions of learners’ common ideas and likely sources of these ideas, as well as lists of questions or tasks that can be used to elicit students’ thinking and track their understanding. In some cases, the research summaries include not only descriptions of conceptual but also of relevant cultural, epistemological, or ontological prior knowledge that may influence student learning. (See Figure 1 for an example of a research summary dealing with one of the ideas that students often have related to light. Additional examples can be found on the Project 2061 Web site at <http://test.p2061.org/curriculum/welcome.htm>.)

Recommendation #3: Take Advantage of Instructional Strategies That Work

Just as there are established methods for making a presentation compelling, persuasive, and memorable for professional and other adult audiences, so too are there strategies—supported by research—for engaging young students with ideas and helping them to understand and retain the most important concepts. In conducting our textbook evaluation studies (4), we developed a set of criteria for judging the quality of each textbook’s instructional design. Derived from research on effective teaching and learning, these criteria can also provide some insights on the kinds of activities and materials being developing for outreach in elementary level classrooms. Although there are more than 20 criteria (Figure 2) that were applied to the textbooks covered by our studies, we’ve streamlined the process and provided some questions below that highlight the essence of the criteria that are likely to be the most relevant to outreach efforts designed for K-6 students. By answering these questions in the context of specific outreach activities and materials—and modifying them as needed—outreach developers can add significant educational value to their efforts.

If an activity involves a demonstration or hands-on activity, does it use a relevant phenomenon to help make an important scientific idea plausible to students? Will the activity be comprehensible to students, given their grade level and prior experiences? Can students make the connection between the phenomenon and the main idea in a small number of steps and using reasoning skills that are appropriate for their age? Does the activity require complicated and time-consuming set-up, calculations, or other procedures that might distract students from the most important ideas? (See Figure 3 for an example of a phenomenon that is often used to help students understand the grades K-2 learning goal that the sun appears to move slowly across the sky (4). The example also includes commentary from Project 2061 on strengths and weaknesses of this phenomenon when used with students at different grade levels.)

If an activity or material includes representations of real-world objects or events (for example, drawings, diagrams, graphs, images, analogies and metaphors, models and simulations, or role-playing), are they accurate and likely to be comprehensible to the student audience? Will students be able to distinguish between real-world objects or events and symbolic entities? Does the activity or material make clear which aspects of an object or event are represented and which are not?

Does the activity or material include questions that can help students make sense of what they have experienced or read about? Are there questions that can help introduce students to the important scientific, mathematical, or technical ideas or issues and relate those to the scientific phenomena or representations they have experienced through the activity or material? Are there questions that ask students to explain their own ideas about the real-world objects or events they’ve just seen or experienced? Are the questions likely to make sense to students who have never studied a particular topic and are not familiar with the scientific vocabulary? For example, asking “What do you think will happen if we let go of this ball? Why do you think this will happen?” is more comprehensible to students who have not studied gravity than asking “What is the effect of gravity on this ball?” Are there questions that encourage students to relate their own ideas to the scientific ideas?

Conclusions

The challenge for teachers and for scientists and engineers who want to support them is finding effective resources that are well aligned with learning goals. To help meet that need, Project 2061 is identifying, developing, and making available a collection of resources that can be used to create outreach activities and materials that focus on ideas

that are important for science literacy and that meet Project 2061's criteria for instructional quality. Made possible by a grant from the National Science Foundation (NSF), the collection includes reference tools (e.g., summaries of research on how students think about natural phenomena and ideas in science) that inform the work of curriculum materials developers and teachers, and building blocks (e.g., activities, photographs, diagrams, sets of questions, and examples of phenomena that demonstrate particular scientific ideas) that can be incorporated into outreach activities and materials. Available online, the collection will allow users to click on the text of a learning goal and access the various resources that are linked to it. Extensive hyperlinks will relate resources to each other.

Information about this and other Project 2061 activities can be found on our Web site at www.project2061.org (see our home page in Figure 4). The site includes the full text of Project 2061's *Science for All Americans* and *Benchmarks for Science Literacy* (along with many other Project 2061 publications). The chapters on historical perspectives and common themes may be especially fruitful sources of ideas and inspiration for planning outreach. For those who would like more details on Project 2061's approach to the analysis of science and mathematics curriculum materials, the Web site also includes extensive explanations of the analysis criteria and examples drawn from a variety of materials showing instances of meeting and not meeting the criteria. Other standards documents and a wealth of additional background information on science literacy, along with links to the Web sites of more than 400 science centers worldwide can be found at www.ScienceEverywhere.org, a site developed in partnership with TryScience.org.

Taking advantage of the knowledge and experience that already exists can help make outreach efforts—whether they involve classroom demonstrations, experiments, and hands-on activities or lesson plans, kits, booklets, software, or other instructional materials—more effective for the developer, for teachers, and, most important, for the students.

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Sofia Kesidou is program director for Project 2061 of the American Association for the Advancement of Science. She oversees the project's National Science Foundation-funded initiative to create tools to support the development of goals-based K-12 curriculum materials in science and mathematics. Kesidou has contributed to Project 2061's research and development efforts for the past ten years. Most recently, she was involved in developing procedures to analyze curriculum materials that align with important learning goals and conducting evaluations of middle grades science textbooks. As a postdoctoral fellow for the Learning Research and Development Center at the University of Pittsburgh and as a postdoctoral scholar for the Institute for Science Education at the University of Kiel, Germany, her research was on student learning.



Kesidou holds a Ph.D. in physics education from the University of Kiel, Germany, and a B.S. in physics from the Aristotle University of Thessaloniki, Greece. She has served as a reviewer for *Science Education* since 1992 and has published numerous articles on science education in books and journals.

Mary Koppal is the communications director for Project 2061 of the American Association for the Advancement of Science. She is responsible for the project's publishing and outreach programs. Previously, Koppal was the publisher for the National Academy of Sciences' *Issues in Science and Technology*, where she began her work as the associate publisher/circulation manager. She was responsible for the overall business and administrative operation of this award-winning national science and technology policy journal.



Koppal was the marketing director for the National Academy Press, which publishes a wide range of trade, scholarly, and professional titles in all areas of science, technology, health, and public policy. In earlier positions, Koppal was a writer for the Congressional Information Service, Inc., and a marketing specialist for the Printing and Publishing Office of the National Academy of Sciences.

She received a B.A. in English from the University of Maryland and is pursuing graduate studies in Communication in Contemporary Society at Johns Hopkins University.

Research Summary: Ideas Students Have about Light

Students may think that light helps us see a shadow that is always there, or that light causes an object to produce, cast, or push a shadow out of an object

Shadows are formed when an object blocks the path of traveling light. In contrast, students may speak of shadows as if they were the presence of something that has material characteristics (as opposed to the absence of light), or may describe shadows as “images,” “pictures,” or “reflections” that are the same shape as and look like the object (13, 16). As a result, students may not accept that a shadow is formed behind an object if a light source is placed directly in front of the object. If students count shadows as dark images that look like the object, then an amorphous black spot does not count as a shadow (17).

Students may have alternative explanations for how shadows are formed:

- a. They may think that shadows are always present but that light is needed to see them (“It’s there at night. You just can’t see it”) or
- b. They may think that light causes an object to produce/cast a shadow or that light pushes the shadow out. Students describe shadows as shot out by objects when triggered by light (“When light hits an object, the object reflects the shadow”), or even as actively pushed by light (“Light pushes the shadow like a wave pushes a ball in water”) (16).

Use of the terms “reflection” and “reflect” in students’ descriptions and explanations of shadows does not necessarily mean that students think that shadows form by light bouncing off objects. Students often use the term “reflection” loosely to describe the similarity of form between the object and the shadow. Similarly, students often appear to use the verb “reflect” synonymously with “hit,” “move,” and “project” without any reference to light bouncing off or changing direction. Students’ statements such as “the sun reflects your shadow on the ground,” “when light hits an object, the object reflects the shadow,” or even “the light reflects off you and bounces down there to make the shadow” need to be probed further to ascertain whether the idea “shadows are formed by light hitting the object and changing direction” is underlying these responses. Students may correctly predict the relative location of the light source, object, and shadow but account for the formation of shadows using one of the alternative explanations. For example, some students predict the correct location of a shadow but believe that light pushes the shadow out of the object. Furthermore, some students refer to objects blocking light and causing shadows, but their use of the term “blocking” indicates a belief that when light is blocked by an object, a shadow is forced out (17).

Likely Sources of Student Ideas

The shadows we see under usual circumstances when we stand on the pavement in the sun are caused by objects that are far from the light source and close to the screen (the surface on which the shadow forms). In these cases, the shape of the shadow is indeed the same as the shape of the object. Probably for this reason we ascribe the shadow to the object; we speak of “its” shadow or “our” shadow in the possessive. Furthermore, we say the object casts its shadow as if it were throwing out something previously held within it. Children’s literature reinforces this view: Peter Pan’s shadow has Peter Pan’s shape, it moves around with him constantly, and is material enough that Wendy can sew it back on when it accidentally becomes detached (16).

Figure 1.

Project 2061 Criteria for Evaluating the Quality of Instructional Support in Textbooks

The criteria are organized in seven categories, each of which focuses on a specific aspect of instructional support.

I. Providing a Sense of Purpose

This category consists of criteria for determining whether the curriculum material attempts to make its purposes explicit and meaningful to students, either in the student text itself or through suggestions made to the teacher. The sequence of lessons or activities is also important in accomplishing the stated purpose, since ideas often build on each other.

Conveying unit purpose. Does the material convey an overall sense of purpose and direction that is understandable and motivating to students?

Conveying lesson/activity purpose. Does the material convey the purpose of each lesson or activity and its relationship to others?

Justifying lesson/activity sequence. Does the material involve students in a logical or strategic sequence of lessons or activities (versus being just a collection of lessons or activities)?

II. Taking Account of Student Ideas

Fostering understanding in students requires taking time to attend to the ideas they already have, both ideas that are incorrect and ideas that can serve as a foundation for subsequent learning. This category consists of criteria for determining whether the curriculum material contains specific suggestions for identifying and addressing students' ideas.

Attending to prerequisite knowledge and skills. Does the material specify prerequisite knowledge/skills that are necessary to the learning of the key ideas?

Alerting teachers to commonly held student ideas. Does the material alert teachers to commonly held student ideas (both troublesome and helpful), such as those described in *Benchmarks for Science Literacy, Chapter 15: The Research Base* (4)?

Assisting teachers in identifying their students' ideas. Does the material include suggestions for teachers to find out what their students think about familiar phenomena related to the key ideas before the scientific ideas are introduced?

Addressing commonly held ideas. Does the material attempt to address commonly held student ideas?

III. Engaging Students with Relevant Phenomena

Much of the point of science is to explain phenomena in terms of a small number of principles or ideas. For students to appreciate this explanatory power, they need to have a sense of the range of phenomena that science can explain. The criteria in this category examine whether the curriculum material relates important scientific ideas to a range of relevant phenomena and provides either firsthand experiences with the phenomena or a vicarious sense of phenomena that are not presented firsthand.

Providing variety of phenomena. Does the material provide multiple and varied phenomena to support the key ideas?

Providing vivid experiences. Does the material include activities that provide firsthand experiences with phenomena when practical or provide students with a vicarious sense of the phenomena when not practical?

IV. Developing and Using Scientific Ideas

Figure 2.

Science literacy requires that students understand the link between scientific ideas and the phenomena that they can explain. Furthermore, they should see the ideas as useful and become skillful at applying them. This category consists of criteria for determining whether the curriculum material expresses and develops the key ideas in ways that are accessible and intelligible to students, and that demonstrate the usefulness of the key ideas and provide practice in varied contexts.

Introducing terms meaningfully. Does the material introduce technical terms only in conjunction with experience with the idea or process and only as needed to facilitate thinking and promote effective communication?

Representing ideas effectively. Does the material include accurate and comprehensible representations of the key ideas?

Demonstrating use of knowledge. Does the material demonstrate/model or include suggestions for teachers on how to demonstrate/model skills or the use of knowledge?

Providing practice. Does the material provide tasks/questions for students to practice skills or to use knowledge in a variety of situations?

V. Promoting Students' Thinking about Phenomena, Experiences, and Knowledge

Engaging students in experiences with phenomena (category III) and presenting them with scientific ideas (category IV) will not lead to effective learning unless students are given time, opportunities, and guidance to make sense of the experiences and ideas. This category consists of criteria for determining whether the curriculum material provides students with opportunities to express, think about, and reshape their ideas, as well as guidance on developing an understanding of what they experience.

Encouraging students to explain their ideas. Does the material routinely include suggestions for having each student express, clarify, justify, and represent his or her ideas? Are suggestions made for when and how students will get feedback from peers and the teacher?

Guiding student interpretation and reasoning. Does the material include tasks and/or question sequences to guide student interpretation and reasoning about experiences with phenomena and readings?

Encouraging students to think about what they have learned. Does the material suggest ways to have students check and reflect on their own progress?

VI. Assessing Progress

This category consists of criteria for evaluating whether the curriculum material includes a variety of aligned assessments that apply the key ideas taught in the material.

Aligning assessment to goals. Assuming a content match between the curriculum material and a key idea, are assessment items included that match the same key idea?

Testing for understanding. Does the material include assessment tasks that require application of ideas and avoid allowing students a trivial way out, like using a formula or repeating a memorized term without understanding it?

Using assessment to inform instruction. Are some assessments embedded in the curriculum along the way, with advice to teachers as to how they might use the results to choose or modify activities?

Figure 2 (cont.).

VII. Enhancing the Science Learning Environment

The criteria in this category provide analysts with the opportunity to comment on features that enhance the use and implementation of the curriculum material by all students. For this category, the reviewers used criterion-specific ratings in lieu of the general ratings used for categories I through VI.

Providing teacher content support. Does the material help teachers improve their understanding of science, mathematics, and technology as is necessary for teaching the material?

Encouraging curiosity and questioning. Does the material help teachers to create a classroom environment that welcomes student curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids dogmatism?

Supporting all students. Does the material help teachers to create a classroom community that encourages high expectations for all students, that enables all students to experience success, and that provides all different kinds of students with a feeling of belonging in the science classroom?

Figure 2 (cont.).

Curriculum Components - Microsoft Internet Explorer

Expand All | Collapse All

Phenomena/Activities

A variety of phenomena are included for each key idea. Phenomena can be used in numerous ways for instruction and assessment to make the key ideas plausible.

Brief Descriptions

Brief descriptions and purposes are included for all phenomena. These entries may be elaborated by curriculum developers, teachers, and researchers into student activities, interview questions, assessment items, and full lesson plans. In addition to the brief descriptions, detailed descriptions of selected phenomena are included. (See example at right).

Critiques of Popular Phenomena

Some popular phenomena are critiqued using the Project 2061 criteria for the analysis of curriculum materials. The critiques illustrate why one phenomenon may be more efficient or effective than another.

Phenomena/Activities

Shadows from Fixed Pole in Sunlight

Brief Description: Over the course of a day, the direction and length of a shadow cast by a fixed pole changes. On several consecutive days, the shadows cast by a fixed pole will be in approximately the same places at the same times.

Purpose: The purpose is to infer the generalization that the sun changes position across the sky and does so in the same manner every day by relating the positions of the shadows to the changing position of the sun.

This phenomenon supports the key idea through the following chain of inferences. From the changing position and length of the shadows cast during the day, we infer the changing positions of the sun across the sky. The same pattern of changing shadows cast by a fixed pole occurs every day. From this, we infer that the sun changes position across the sky every day.

To infer the position of the sun in the sky from the shadows cast by a fixed pole, students may need to know that light travels in a straight line, that a shadow occurs when an object blocks the path of the traveling light from the sun, and how the relative position of a light source and an object determines where the object's shadow will form. These ideas are quite sophisticated for grades K-2 students. *Benchmarks for Science Literacy* does not expect that students will know these ideas until grades 3-5 (see key idea that Light travels). *Therefore, this phenomenon is complex for students due to the amount of time and additional knowledge required. Other phenomena may be more efficient and effective.*



Figure 3.

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Figure 4.