Effective K-12 Science Instruction

Elements of Research-based Science Education

College of Science
Center for Mathematics and Science Education

Promoting STEM Education

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Research-Based Teaching Strategies for Effective Science Instruction

A major goal of parents and teachers is to produce educated and concerned citizens, and scientific literacy is a critical component of this endeavor. Scientific literacy is more than just knowledge of scientific concepts; it is the ability to apply scientific knowledge to everyday problem-solving situations that impact health, safety, and the environment. During the past quarter-century, education research has provided a deeper understanding of how students learn science and of the knowledge and skills required for academic achievement. This knowledge is invaluable to teachers in guiding instructional decisions, and has implications for science education at all levels.

An effective standards-based science curriculum provides an excellent and equitable science education for all students and provides for a deep understanding of essential science concepts. The *National Science Education Standards* state:

> The *Standards* apply to all students, regardless of age, gender, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science. Different students will achieve understanding in different ways, and different students will achieve different degrees of depth and breadth of understanding depending on interest, ability, and context. But all students can develop the knowledge and skills described in the *Standards*, even as some students go well beyond these levels. (p. 2)

Educators are responsible for ensuring that all students achieve high levels of academic success. Realizing that individuals learn in a variety of ways, it is necessary to provide for student differences through the purposeful use of a variety of teaching strategies that nurture the diverse ways that students learn. Ideally, these strategies enhance student learning by

- Stimulating active participation by all students
- Attending to the different ways students learn
- Providing opportunities for students to experience authentic scientific inquiry
- Providing challenges for all students
- Providing opportunities for students to collaborate with others in diverse groups and settings

While this document presents descriptions of research-based strategies that are effective in teaching K-12 science, it is important to recognize that not every strategy can or should be applied in every teaching situation. Instructional strategies are tools to be used in designing and implementing instruction in a way that supports and nurtures student learning. It is important to note that strategies may be used concurrently; for example, instructional technology strategies may be used to enhance the context for learning. Well-designed laboratory experiences incorporate a number of effective teaching and learning methodologies including inquiry and manipulation strategies. A teacher's task is to determine what preconceptions and knowledge the students bring to the classroom, what concepts and skills they need to learn, and what support structures need to be provided in order for them to meet the learning goals. It is the role of the teacher to judiciously select from a variety of strategies and techniques those which will most effectively enable learners to develop deep understandings of the topics and meet the intended learning targets.

The following teaching strategies have been shown by research to have a positive influence on student achievement. (Note: see Schroeder, et al., 2002 or access original report at http://www3.science.tamu.edu/cmse/tsi/.)These strategies are arranged in order from those which show the greatest effect size to the least effect size. Each strategy is accompanied by a description and examples of how the strategy may be used. It is important to note that the examples are varied and should be used with appropriate grade levels. Remember that a single lesson may utilize a combination of strategies and not every strategy is appropriate for every situation.

It is our hope that you will find this booklet useful as a reference, as inspiration for trying new teaching strategies, and as affirmation of techniques you already use in your classroom.

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1
Enhanced context strategies

The science curriculum must be made relevant to students by framing lessons in contexts that give facts meaning, teach concepts that matter in students' lives, and provide opportunities for solving complex problems. Not only do students need to know the laws of nature, they also must know when to apply these laws in solving problems. Relating learning to students' previous experiences or knowledge and engaging students' interest by linking learning to the students'/school's environment or setting are ways to encourage students to make connections. The more students make connections between what they already know and new learning, the more student achievement will be improved. Teaching concepts in a variety of contexts is more likely to produce flexible learning that can be generalized or used across a broader spectrum of applications. Student-centered classrooms often utilize real-world events in order to create an effective learning environment. Integrating science with other disciplines also supports transfer of knowledge and skills from one setting to another.

Listed below are examples of strategies for enhancing context, some of which are very general and others which are more specific, either in topic or appropriate grade level. They are provided to illustrate enhanced context strategies, though they in no way represent a comprehensive list.

- Look at the big picture – unifying concepts such as systems, form & function, models & their limits
- Use problem-based learning
- Begin and end a lesson or unit with KWL (What I Know, What I Want to Know, and What I Learned) – use to determine students' preconceptions, generate questions for inquiry, and summarize findings
- Incorporate real-life situations/data as contexts for problem solving
- Take students on field trips
- Include field investigations, such as using the schoolyard and/or community for lessons
- Integrate current events, such as using a:
  - Hurricane to illustrate
    - Effects of energy conversions and heat transfer
    - Effects on animal life
    - Weather patterns
    - Effects on water chemistry in affected areas
    - Effects of oceans on land

- Tsunami to illustrate
  - Wave motion and energy transfer
  - Earthquake causes and effects
  - Effects on animal life
  - Problems from disease and water contamination
- Provide concrete models, metaphors, and analogies to help learners learn abstract concepts
- Connect the learner to content through literature; for example, read a story to introduce a lesson, then ask questions related to the story; show items described in the story or have students bring items (eg., rocks, leaves)
- Model real-world problem solving; for example, have learners solve a specific problem and then provide them with a similar problem to help transfer learning
- Generalize a problem so that students create a solution that applies to a whole class of related problems; for example, instead of mapping out a single trip, students might run a trip planning company that has to advise people on all aspects of travel to different regions of Texas or the U.S. at different times of the year
- Use video clips to create a context for students about an unfamiliar topic

2
Collaborative grouping strategies

Collaborative grouping occurs when teachers arrange students in flexible groups to work on various tasks such as exploring significant problems or creating meaningful projects. The ability to collaborate is a necessary skill for success in the real world and requires *working* with others rather than *competing* with them. In the classroom, collaboration includes the whole process of communication between and among teacher and students. It provides opportunities for students to work in diverse groups and improve social, communication, and problem-solving skills. It can also promote deeper understanding of content and improve student achievement. Collaborative grouping strategies encourage student participation and a shared responsibility for learning that enables the teacher to act as guide, facilitator and at times, even learner. The composition of the group may be random or based on interest, and may be heterogeneous or homogeneous. The size and type of group used for any specific activity depends on the objective of the lesson. In general, small groups of 3-4 are more effective than large groups in positively influencing student achievement. Cooperative learning groups are a type of structured collaborative learning. Collaborative grouping strategies may be used in combination with most other teaching strategies (including inquiry and enhanced context strategies) and may be augmented by the use of information technology strategies. When using collaborative grouping strategies, it is important to have definite goals and objectives. It is also important to set clear expectations at the outset (perhaps through an evaluation rubric) and to resolve conflicts among students as soon as they arise.

Listed below are examples of collaborative grouping strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level. They are provided to illustrate some examples of collaborative grouping strategies. An excellent source of information about collaborative learning is found at http://www.wcer.wisc.edu/archive/CL1/CL/doingcl/DCL1.asp. Another source of free articles about cooperative learning strategies is http://www.kaganonline.com/.

- Laboratory exercises
- Inquiry projects
- Learning/instructional games
- Discussions
    - Paired discussion of new material
    - Whole class discussion of controversial topic, lecture information, or other topic of interest

- Create dramatizations (TV show, weather report) to illustrate a concept or process
- Problem-based learning (PBL) exercises
- School-home projects such as assigning a collaborative project for student and parent(s)
- Kinesthetic activities; for example, small groups modeling a concept such as movement of earth/moon/sun system or behavior of atoms/molecules in the states of matter
- Jigsaw – have small groups of students become experts on a subtopic and teach their findings to others
- Distance learning such as having small groups work with groups from another school over the Internet on a project or problem
- Reciprocal teaching, where small groups of students read a passage, a group leader summarizes and others add to the summary, the leader asks questions and others answer, the leader clarifies or asks others to clarify, and finally the group predicts what will happen
- Collaborative groups study together to master science concepts for benchmarks and other assessments

3
Questioning strategies

The teacher's use of a variety of questioning strategies can facilitate the development of critical thinking, problem solving, and decision making skills in students. The ability to ask good questions is a skill that requires nurturing and practice on the part of both the teacher and the student. Questioning is interactive and engages students by allowing them to share their ideas and thoughts. It is the role of the teacher to create a safe environment where learners' thoughts and ideas are valued and where students feel comfortable challenging each others' ideas. The teacher need not be the expert about everything, but regard student questions as an opportunity for all, including the teacher, to learn. Questioning strategies allow for ongoing assessment of students' understandings so that instruction can be adjusted to meet their needs. Students are often able to answer fact-based questions on tests, but deeper questioning reveals misconceptions in their conceptual understanding. Modeling good question-asking techniques helps students learn to ask good inquiry questions and to solve problems. Questioning strategies may be used to establish relevance, focus attention, encourage creativity, and to have students recall prior knowledge, make connections, and apply knowledge.

Listed below are some examples of questioning strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level.

- Vary timing, positioning, or cognitive levels of questions
- Randomize questioning so ALL students are included
- Respond to student's question with a guiding question in return: "I don't know. How do you think we might find out?" or "What is your evidence?"
- Ask more open-ended questions
    - Closed (only one "right" answer): What tool should be used to measure this table?
    - Open (several possible correct answers): How could we find the length of this table? What units might we use? Which units might be more appropriate than others?
- Increase wait time for student responses and, after incorrect responses, allow time for reprocessing
- Add pauses at key student-response points
- Stop videos at key points and ask questions

- Pose comprehension questions to students at the start of a unit, lesson or assignment to determine prior knowledge or misconceptions
- Allow students to take risks and be wrong without feeling censured
- Ask students for a rationale for their answers or justification for their beliefs
- Include questions that target unifying concepts in science
- Increase the number of higher-cognitive-level questions (Web sites with good explanations of Bloom's taxonomy of the cognitive domain include: http://www.coun.uvic.ca/learning/exams/blooms-taxonomy.html, http://www.nwlink.com/~donclark/hrd/bloom.html, and http://web.uct.ac.za/projects/cbe/mcqman/mcqappc.html)

4
Inquiry strategies

Although there are various interpretations of what inquiry means, most science teachers would agree that it involves exploration, asking questions and constructing explanations about natural phenomena. According to the *National Science Education Standards*, "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities in which [students] develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (p. 23). The Inquiry Synthesis Project (2006) defined inquiry as containing 1) science content, 2) student engagement in experiencing the science content, and 3) components of instruction that include a question, designing an investigation, data gathering or structuring, drawing conclusions or explanations, and communication of the results of the investigation. It is important for students to have "an adequate knowledge base to support the investigation and help develop scientific explanations" (NSES, 1996).

Inquiry provides opportunities for students to experience the nature of science by engaging them in the practices of scientists. Scientists use a variety of scientific research designs that range from descriptive to comparative to experimental and students should experience using different types of designs. Descriptive research involves describing natural phenomena whereas experimental research is used to determine causation. Through inquiry, students learn how to obtain and make sense of data and how to generate their own knowledge and understandings. Students may make decisions, contribute to group knowledge, have opportunities for creativity and risk-taking, and link prior knowledge to new ideas. The involvement generated during inquiry encourages deep understanding. *It is important to not confuse "hands-on" or manipulation strategies with inquiry strategies.*

Inquiry requires students to answer scientific research questions by analyzing data. (Data may include student-collected data or authentic data from other sources such as the Internet. It does not include simulated or made-up data.) There is a broad continuum of levels of inquiry through which students assume more or less responsibility for each of the components depending on the subject matter, student maturity and cognitive development, available resources, and time constraints. All levels are important; ideally, as students mature and/or become more experienced in inquiry, the amount of direction from the teacher decreases and the amount of learner self-direction increases.

Students should move from traditional prescriptive laboratory and field exercises to various types of student led investigations. The move to inquiry progresses students from a model of structured inquiry where the teacher identifies the research question and procedures to student-directed inquiry.

Below is a continuum of inquiry levels from the lowest, which includes no true inquiry, to the highest, which is student-directed, authentic inquiry. Skills needed for successful inquiry and the types inquiry with examples of each for K-12 classrooms are also given.

- Inquiry continuum (from lowest to highest)
    - Illustration/confirmation (no inquiry)
        - Teacher directs all parts
        - Results are known prior to the activity
    - Structured inquiry
        - Teacher chooses question and specifies procedures
        - Students collect data and analyze results
    - Guided inquiry
        - Teachers chooses question
        - Students design procedures with teacher input
    - Student directed/open inquiry
        - Students develop question to be investigated
        - Students design procedures to be used

- Skills needed for inquiry:
    - Identifying appropriate questions for inquiry
    - Acquiring information (library, Internet, scientists, etc.)
    - Designing investigations
    - Identifying independent and dependent variables
    - Predicting results
    - Collecting and analyzing data
        - Observing carefully
        - Using various tools and units of measure
        - Recording and organizing data in charts or tables
        - Using quantitative or mathematical and statistical methods for data analysis
    - Interpreting data
    - Drawing conclusions and making predictions based on evidence
    - Making evidence-based arguments or justifications
    - Communicating through written, oral, and graphical means
    - Collaborating with others

- Types of scientific inquiry for K-12 students
  - Descriptive research design or descriptive study
    - Used to describe a natural phenomenon that not much is known about
    - Uses descriptive statistics: frequency, mean, median, mode, range; display of data in frequency table and bar chart or graphs(as appropriate for grade level/student skills)
    - Examples of research questions:
      - Elementary – What kinds and how many of each kind of trees are in our schoolyard?
      - Secondary – What kinds and how many of each kind of plants are in a 1 m^2 representative sample in a given site?
  - Comparative research design (or comparative data analysis study)
    - Used to identify statistically significant linkages between factors (e.g., health issues)
    - Statistics – descriptive and various types of linkages, for example, correlations; scatterplot graphical display illustrating the correlation (as appropriate for grade level/student skills)
    - Example
      - Elementary – Does exercise cause heart rate to increase?
      - Secondary – Does blood pressure increase as a person ages?
  - Experimental research design or experimental study
    - Used to determine causation
    - Statistics: descriptive, ANOVA, regression (as appropriate for grade level/student skills)
    - Examples:
      - Elementary – How does the height of a ramp affect the distance a ball will roll?
      - Secondary – At what salinity do lettuce seeds germinate the fastest?

5
Manipulation strategies

Manipulation strategies permit students to work directly with materials and manipulate physical objects in order to experience science. They allow students of all ages to learn using concrete, tangible things that are accessible to their senses. Auditory, visual, tactile, and kinesthetic learners all benefit from manipulating the things they are studying. Using scientific instruments (everything from rulers to microscopes to computers) allows learners to experience authentic scientific activity while developing necessary skills. Interacting and engaging in investigations with the materials and objects of science also allows students to draw meaning from their experiences. Manipulation strategies require students to become active learners who participate in building their own understanding; students remember content better when they experience it for themselves.

Listed below are examples of manipulation strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level. They are provided to illustrate the strategies, but do not represent a comprehensive list.

- Develop skills (e.g., measure length, volume, mass, temperature, etc. with precision; use compass)
- Operate apparatus (e.g., balance, microscope, calculator, computer probes) to collect data
- Create a drawing or diagram to illustrate a process, including arrows and labels (e.g. food web illustrating energy sources and transfer)
- Make a map (e.g., show migration of bird species & draw the bird)
- Create a model (e.g., how an earthquake occurs, structure of a compound)
- Create a graphic organizer such as a concept map
- Move through learning stations with various materials relating to a concept
- Build and maintain a terrarium
- Create a mobile illustrating a concept
- Analyze the effects of a chemical reaction
- Build electrical circuits
- Make and use simple machines to perform work and collect data
- Manipulate computer simulations
- Care for living organisms in the classroom

6
Assessment strategies

The role of assessment in effective teaching has broadened from primarily evaluating student achievement to include diagnosing student needs, advising instructional decisions, and auditing student progress. Assessment should be ongoing and integrated into the instructional process. Prompt, effective feedback from assessment is critical to student achievement.

It is important to use formative assessment to guide instructional decisions and to change the frequency, purpose, and cognitive levels of summative testing. Alternative assessment strategies can take the focus off grades, put more emphasis on learning with understanding, and reduce test anxiety and stress on struggling learners. Providing for student self-assessment through reflective journaling and student goal setting may encourage students to become more responsible for their own learning while still providing evidence for the teacher to assess progress. Appropriate assessment techniques should be chosen to conform to instructional needs.

Listed below are examples of assessment strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level. They are provided to illustrate the strategies, but are not a comprehensive list.

- Diagnostic assessments – before instruction to inform unit and lesson planning; enable teacher to build on students' prior knowledge and identify misconceptions
  - KWL (What I know, What I want to know, What I learned)
  - Pretests
  - Science journals (entries guided by questions about upcoming lessons)
  - Interviewing/questioning
- Formative assessments – during instruction, enable prompt individual feedback to guide learners and inform instruction
  - Checks for understanding
    - Slates
    - Think-pair-share (think about question, discuss with partner, share with group/class)
    - Electronic response devices
    - Minute papers (write about question for 1 minute, turn in) or exit cards (students answer brief question) used at end of lesson to probe student understanding
  - Homework

    - Self-assessment
        - Science journal entries
        - Rubrics
        - Checklists
        - Graphic organizers
    - Review games such as Bingo or Jeopardy
    - Quizzes
    - Science journals
    - Interviewing/questioning
- Summative assessments – after instruction of lesson or unit, used to measure student understanding for scoring or grading, generally not used for instructional purposes
    - Traditional paper & pencil posttests
    - Performance tasks
        - Teacher provides rubric to communicate criteria at beginning of task
        - May provide opportunities for solving complex problems and designing inquiry projects
        - Student groups may create their own demonstrations/experiments to illustrate a specific law, theory or lesson, then other groups critique

7
Instructional technology strategies

Instructional technology (IT) provides numerous ways to help teachers meet the challenge of providing effective instruction and conducting inquiry in the classroom. IT includes a broad spectrum of tools including – but not limited to – computer hardware and software, electronic measuring and data collection devices, digital cameras and video recorders, and scientific calculators as well as the more traditional videos and overhead projectors. Technology can enable simplified calculation, information access, and data collection. Interweaving technology throughout the curriculum can provide meaningful ways for teachers to present information and for students to learn technology skills. Computer simulations enable students to manipulate variables and quickly see the results of changing the values of variables. Developing a web site for a class creates a place to post assignments and worksheets, link to relevant information and data sources, and communicate with parents and students. The use of IT enables teachers to facilitate communication, collaboration, critical thinking, data interpretation and problem solving skills and to promote student responsibility for learning.

Listed below are several examples of instructional technology strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level.

- Connect with other students and with scientists via the Internet and/or e-mail
- Use podcasts for instruction
- Bring real-world data and current events in science into the classroom via the Internet
- Take virtual field trips
- Promote critical thinking by having students compare and evaluate several Web sites on the same topic but from different sources
- Use computers for visualizations, simulations, and modeling abstract concepts
- At higher grades, use computer algebra systems to aid student learning of mathematical concepts and understanding of mathematical models
- Show videos or use pictures, photographs, or diagrams to introduce, illustrate, or reinforce a concept
- Provide opportunities for receiving immediate feedback (software programs, classroom response devices)
- Collect, record and graph data using probes and graphing calculators or computers
- Publish student work on a teacher-created Web site

- Reflect on learning through electronic journaling
- Create reports, PowerPoint® slide shows, or video projects to communicate information
- Use a computer simulation before/after dissection to prepare or review
- Use geographic information systems (GIS) and remote sensing data for maps, models, and analysis
- Conduct WebQuests (inquiry-oriented activities where most or all the information used by the learners is found on the Web)
- Organize information or create graphic organizers using software such as Kidspiration® or Inspiration®
- Create an animation to illustrate concepts (water cycle, phases of the moon) using software such as PowerPoint® or Flash®
- Use discussion lists for peer-to-peer interaction and for instruction and feedback
- Create a class blog
- Use online science resources such as the GLOBE project (Global Learning and Observations to Benefit the Environment) and Project WISE (Web-based Inquiry Science Environment)

8
Enhanced material strategies

The ability to teach science well depends on strong content knowledge combined with knowledge of the methods and strategies that have been proven to work. Effective science teachers have a large array of instructional strategies and methods available to produce successful learning. Recognition of suitable methods for teaching certain concepts or skills in different situations enables the teacher to provide appropriate instruction. Instructional materials purchased to support science often do not meet the needs of the classroom or students and must be modified before they can be used. The teacher can modify or enhance instructional materials in a variety of ways to increase student learning.

Listed below are examples of enhanced material strategies, some of which are very general and others which are more specific, either in topic or appropriate grade level. They are provided to illustrate some strategies, but do not represent a comprehensive list.

- Modify a laboratory exercise to increase the level of inquiry and make it less prescriptive. Provide opportunities for students to:
    - Ask testable questions
    - Generate and test hypotheses
    - Create and justify explanations for phenomena based on evidence
- Rewrite or annotate text materials
- Use graphic organizers to clarify concepts
- Resequence lessons to align with the 5E Instructional Model
- Provide opportunities for students to make actual observations of objects or events or to use representative computer simulations
- Provide oral and/or written instructions (tape-record directions)
- Simplify or substitute laboratory apparatus to make it age-appropriate
- Modify an activity to use readily available materials
- Change an exercise to include questions that require higher order thinking skills
- Create integrated units to combine concepts from different disciplines
- Resequence content to clarify content structure and establish interrelationships among major concepts
- Integrate a structured video series into a course

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Recommended Readings

Atkin, J. M. & Coffey, J. E. (Eds.). (2003). *Everyday Assessment in the Science Classroom*. Arlington, VA: NSTA Press.

The authors of the 10 essays included in this book offer suggestions on how to embed assessments in classroom routine. Topics discussed include the importance of assessment, how questioning can be used for assessment, and how assessment can improve student learning and thinking. A wide variety of specific assessment methods are described and explained.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school* (Expanded ed.). Washington, D.C.: National Academy Press.

This book from the National Research Council presents findings from research on how people learn and examines the implications for the classroom and for schools in general. The relationship between classroom learning and the community is discussed, and the book takes a realistic look at the role of technology in education. Many examples in the book are from science teaching. The book is available free in its entirety at http://www.nap.edu/books/0309070368/html/.

Donovan, M. S., & Bransford, J. D. (Eds.). (2005). *How students learn: History, mathematics, and science in the classroom*. Washington, D.C.: The National Academies Press.

This sequel builds on the discoveries introduced in *How People Learn*, presenting them in a way that teachers can use immediately to provide for more effective teaching and learning at elementary, middle and high school levels. It discusses how to produce student understanding of scientific principles through science experiments and has suggestions for classroom activities. The science portion of the book is available online at http://www.nap.edu/books/0309089506/html/.

Kagan, S. (1997). *Cooperative Learning*. San Clemente, CA: Kagan Cooperative Learning.

Dr. Kagan's comprehensive book presents many "structures" or strategies for effectively implementing cooperative learning in the classroom for all grade levels and content areas. Suggestions are included for classroom setup and management and lesson planning. It includes teambuilding and classbuilding activities as well as tables, graphics, and reproducibles.

Marzano, R. J., Pickering, D. J, & Pollock, J. E. (2001). *Classroom instruction that works: Research-based strategies for increasing student achievement*. Alexandria, VA: ASCD.
The authors present research-based teaching strategies that have positive effects on student learning. These strategies are described and examples and models are provided for each to help teachers plan lessons and implement the strategies. Although this book is not specifically for the science classroom, good teaching strategies are useful to all teachers.

National Research Council. (1996). *National science education standards*. Washington, D.C.: National Academy Press.
National Science Education Standards presents standards for science teaching, professional development of science teachers, assessment in science education, science content, science education programs, and science education systems. The goal of the *Standards* is to move the nation toward science literacy for everyone and it is available at http://www.nap.edu/openbook/0309053269/html/

National Research Council. (2000). *Inquiry and the National Science Education Standards: A guide for teaching and learning*. Washington, D.C.: National Academy Press.
An addendum to the *Standards*, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, aids teachers and teacher educators in gaining a deeper understanding of the meaning of inquiry and provides substantive examples showing what it looks like in practice. It is available online at http://www.nap.edu/books/0309064767/html/

Singer, S. R., Hilton, M. L., & Schweingruber, H. A. (Eds.). (2005). *America's lab report: Investigations in high school science*. Washington, D.C.: National Academies Press.
The role of laboratory experiences as a part of the high school science curricula is examined and their contributions to science learning is discussed in this new book from the National Research Council. It looks at what research tells us about learning in labs, what constitutes effective laboratory teaching, how assessment of student learning in laboratory experiences should be done, and how laboratory experiences for high school students can be improved. The complete book can be accessed on line at http://www.nap.edu/books/0309096715/html/ at no charge.

Walsh, J. A. & Sattes, B. D. (2005). *Quality questioning: Research based practice to engage every learner*. Thousand Oaks, CA: Corwin Press.

The authors present effective questioning strategies that engage all learners in the teacher's questions and encourage students to ask questions of their own. It includes a complete framework for preparing and presenting questions, prompting and processing student responses, and teaching students to generate questions, as well as stimulating reflective questioning practice. It contains checklists for classroom applications, reproducibles, rubrics, resources, and evaluation tools.

Rubric for Analyzing Science Products

This rubric for evaluating and analyzing products for use in science classrooms was created primarily by Anna McClane of the Region IV Educational Service Center and based on the eight teaching strategies discussed earlier in this booklet. However, there are other important components of teaching products that must be evaluated, including science content, organization and structure of the materials, assessment, equity, and practicality. An earlier draft of the rubric was field tested by a group of experienced science teachers and supervisors after discussion and comments. Agreement on definitions of terms and meanings of criteria is paramount to successful use of the rubric by more than one person evaluating the same product; therefore scoring notes were created (see pp. 34-35). The weight given to each cell reflects the input of the field testers, but can be easily modified to suit different situations.

Electronic versions of the rubric, scoring notes, and score sheet can be accessed at http://www3.science.tamu.edu/cmse/tsi/.

Component	Criteria	Highly Recommended
Science Content	Accuracy and Alignment	❹ Reflects **accurate** scientific information **aligned** to the content and rigor of the grade appropriate standards; clearly demonstrates the **vertical articulation** of the concepts
	Safety	❹ Includes activities based on **safe** practices **with** appropriate and clearly-stated safety precautions for all procedures and materials
Organization and Structure	Format of Materials	❹ Provides **comprehensive** information and guidance for successful implementation such as content overview, materials lists, facilitation questions, standards correlations, and background information
	Coherency	❹ Provides a **well-connected** sequence of **rich** activities specifically designed to **build conceptual understanding**

Science Products

Recommended	Not Recommended
❸ Reflects **accurate** scientific information **aligned** to the content and rigor of the grade appropriate standards	⓿ Reflects **inaccurate** scientific information and/or **poor alignment** to the content and rigor of the grade appropriate standards
❸ Includes activities based on **safe** practices yet **lacks** clearly-stated safety precautions for some procedures and materials	⓿ Includes **unsafe** practices
❸ Provides **adequate** information and guidance for successful implementation such as content overview, materials lists, facilitation questions, correlations to standards, and background information	⓿ Provides **little or no** information and guidance for successful implementation
❸ Provides a **somewhat-connected** sequence of activities that **build toward conceptual understanding**	⓿ Provides a collection of **unconnected** activities that lead toward **little conceptual understanding**

Component	Criteria	Highly Recommended
Effective Instructional Practices	Enhanced Context Strategies	❽ Includes **frequent opportunities** for all learners to engage in activities **such as**: ■ Relating learning to previous experiences ■ Experiencing learning in settings outside the classroom ■ Using real world contexts that are engaging to the learner ■ Applying science concepts to new situations ■ Approaching a new concept by sharing in a common experience with peers
	Inquiry Strategies	❹ Provides **frequent opportunities** to: ■ Foster learners' questioning & curiosity ■ Engage in learner-centered investigations ■ Utilize science inquiry to solve problems ■ Formulate explanations from evidence ■ Justify & communicate explanations
	Instructional Technology Strategies	❹ Incorporates **frequent use** of **applicable** standards-based technology including calculators, computers, and probeware

Recommended	Not Recommended
❻ Includes **some opportunities** for all learners to engage in activities **such as**: ■ Relating learning to previous experiences ■ Experiencing learning in settings outside the classroom ■ Using real world contexts that are engaging to the learner ■ Applying science concepts to new situations ■ Approaching a new concept by sharing in a common experience with peers	⓿ Includes **few or no opportunities** for all learners to engage in activities **such as**: ■ Relating learning to previous experiences ■ Experiencing learning in settings outside the classroom ■ Using real world contexts that are engaging to the learner ■ Applying science concepts to new situations ■ Approaching a new concept by sharing in a common experience with peers
❸ Provides **some opportunities** to: ■ Foster learners' questioning and curiosity ■ Engage in learner-centered investigations ■ Utilize science inquiry to solve problems ■ Formulate explanations from evidence ■ Justify and communicate explanations	⓿ Provides **few or no opportunities** to: ■ Foster learners' questioning and curiosity ■ Engage in learner-centered investigations ■ Utilize science inquiry to solve problems ■ Formulate explanations from evidence ■ Justify and communicate explanations
❸ Incorporates **some use** of **applicable** standards-based technology including calculators, computers, and probeware	⓿ Incorporates **no use** of **applicable** standards-based technology including calculators, computers, and probeware

Component	Criteria	Highly Recommended
Effective Instructional Practices (Continued)	Collaborative Learning Strategies	❹ Provides **frequent opportunities** for learners to interact in various large and small group settings that: ■ Foster collaboration within the classroom ■ Require learners to interact with others to complete tasks ■ Engage learners in sharing and discussing their observations, ideas, and work
	Manipulation Strategies	❹ Provides learners with **frequent** opportunities to: ▪ Have hands-on experiences with both scientific tools and everyday materials ▪ Use two and three dimensional physical models to explore and/or explain scientific concepts
	Questioning Strategies	❹ Models an **extensive use** of **high-level** questioning to: ■ Motivate and focus learners ■ Help learners identify what they already know ■ Identify misconceptions ■ Help learners connect ideas to reach a greater depth of understanding

<table>
<tr><th>Recommended</th><th>Not Recommended</th></tr>
<tr><td>❸ Provides some opportunities for learners to interact in various large and small group settings that:
Foster collaboration within the classroom
Require learners to interact with others to complete tasks
Engage learners in sharing and discussing their observations, ideas, and work</td><td>⓿ Provides few or no opportunities for learners to interact in various large and small group settings that:
Foster collaboration within the classroom
Require learners to interact with others to complete tasks
Engage learners in sharing and discussing their observations, ideas, and work</td></tr>
<tr><td>❸ Provides learners with some opportunities to:
Have hands-on experiences with both scientific tools and everyday materials
Use two and three dimensional physical models to explore and/or explain scientific concepts</td><td>⓿ Provides learners with few or no opportunities to:
Have hands-on experiences with both scientific tools and everyday materials
Use two and three dimensional physical models to explore and/or explain scientific concepts</td></tr>
<tr><td>❸ Models some use of high-level questioning to:
Motivate and focus learners
Help learners identify what they already know
Identify misconceptions
Help learners connect ideas to reach a greater depth of understanding</td><td>⓿ Models little or no use of high-level questioning to:
Motivate and focus learners
Help learners identify what they already know
Identify misconceptions
Help learners connect ideas to reach a greater depth of understanding</td></tr>
</table>

Component	**Criteria**	**Highly Recommended**
Meaningful Assessment	Alignment	❹ Reflects **comprehensive alignment** among the assessment, the standards, and the instructional process
	Formative	❹ **Routinely embeds** a variety of formative assessments to inform and guide future instruction
	Summative	❹ Uses a **wide variety** of methods for summative assessment such as selected responses, constructed responses, and performance tasks
	Metacognition	❹ **Routinely engages** learners in actively monitoring their own learning through reflective practices such as journaling or interactive notebooks

Recommended	Not Recommended
❸ Reflects **adequate alignment** among the assessment, the standards, and the instructional process	⓿ Reflects **poor alignment** among the assessment, the standards, and the instructional process
❸ **Occasionally embeds** a variety of formative assessments to inform and guide future instruction	⓿ **Does not embed** formative assessments to inform and guide future instruction
❸ Uses **some variety** of methods for summative assessment such as selected responses, constructed responses, and performance tasks	⓿ Uses **only one** method of summative assessment
❸ **Occasionally provides opportunities** for learners to actively monitor their own learning through reflective practices such as journaling or interactive notebooks	⓿ **Provides few or no opportunities** for learners to actively monitor their own learning through reflective practices such as journaling or interactive notebooks

Component	Criteria	Highly Recommended
Equity and Practicality	Equity	❹ Materials and experiences: ■ Reflect the diversity of our society when appropriate ■ Are free of ethnic, cultural, racial, economic, political, age, and gender bias ■ Accommodate a range of abilities and learning styles
	Practicality	❹ Experiences are: ■ Transferable to teaching practices ■ **Not dependent upon** specialized equipment or materials that are costly or difficult to obtain when suggested for classroom use ■ **Not dependent upon** specialized facilities that go beyond the standards-based norm for science labs, classrooms, and field experiences

Recommended	Not Recommended
❸ Materials and experiences **for the most part:** ■ Reflect the diversity of our society when appropriate ■ Are free of ethnic, cultural, racial, economic, political, age, and gender bias ■ Accommodate a range of abilities and learning styles	⓿ Materials and experiences **for the most part**: ■ Do **not** reflect the diversity of our society when appropriate ■ Are **not** free of ethnic, cultural, racial, economic, political, age, and/or gender bias ■ Do **not** accommodate a range of abilities and learning styles
❸ Experiences for the most part are: ■ Transferable to teaching practices ■ **Not dependent upon** specialized equipment or materials that are costly or difficult to obtain when suggested for classroom use ■ **Not dependent upon** specialized facilities that go beyond the standards-based norm for science labs, classrooms, and field experiences	⓿ Experiences for the **most part are**: ■ **Not** transferable to teaching practices ■ **Dependent upon** specialized equipment or materials that are costly or difficult to obtain when suggested for classroom use ■ **Dependent upon** specialized facilities that go beyond the standards-based norm for science labs, classrooms, and field experiences

Rubric for Analyzing Science Products

Scoring Notes

Science Content

- Accuracy and Alignment:
  - Score 0 if **either** accuracy or alignment are weak
  - Difference between a 4 and 3 is the inclusion of vertical articulation
- Safety
  - Score 0 if unsafe
  - Difference between a 4 and 3 is the clarity and completeness of safety precautions

Organization and Structure

- Format of Materials
  - Little or no information for implementation *versus* adequate information for implementation v*ersus* comprehensive information for implementation
- Coherency
  - Score 0 if activities are unconnected
  - Score 3 if somewhat-connected activities build toward understanding
  - Score 4 if well-connected activities build understanding

Effective Instructional Practices

- Enhanced Context Strategies
  - Few or no opportunities *versus* some opportunities *versus* frequent opportunities
  - List following the "such as" is given as examples; does **not** mean all items in list must be "included"
- Inquiry Strategies
  - Few or no opportunities *versus* some opportunities *versus* frequent opportunities
- Instructional Technology Strategies
  - No use *versus* some use *versus* frequent use
  - "applicable" is stressed
- Collaborative Learning Strategies
  - Few or no opportunities *versus* some opportunities *versus* frequent opportunities

- Manipulation Strategies
  - Few or no opportunities *versus* some opportunities *versus* frequent opportunities
- Questioning Strategies
  - Little or no use of high-level *versus* some use of high level *versus* extensive use of high-level

Meaningful Assessment

- Alignment
  - Poor alignment *versus* adequate alignment *versus* comprehensive alignment
- Formative
  - Does not embed *versus* occasionally embeds *versus* routinely embeds
- Summative
  - Only one *versus* some variety *versus* wide variety
  - List following the "such as" is given as examples; does not mean all items in list must be "included"
- Metacognition
  - Provides few or no opportunities *versus* occasionally provided opportunities *versus* routinely engages

Equity and Practicality

- Equity
  - Difference between 3 and 4 is "for the most part"
  - Emphasize the word "appropriate" on first bulleted item
- Practicality
  - Difference between 3 and 4 is "for the most part"
  - Emphasize "when suggested for classroom use"

Score Sheet
Rubric for Analyzing Science Products

Name of Product ____

Name of Reviewer ____

Component	Criteria	Score		
Science Content	Accuracy & Alignment	❹	❸	⓿
	Safety	❹	❸	⓿
Organization & Structure	Format of Materials	❹	❸	⓿
	Coherency	❹	❸	⓿
Effective Instructional Practices	Enhanced Context Strategies	❽	❻	⓿
	Inquiry Strategies	❹	❸	⓿
	Instructional Technology Strategies	❹	❸	⓿
	Collaborative Learning Strategies	❹	❸	⓿
	Manipulation Strategies	❹	❸	⓿
	Questioning Strategies	❹	❸	⓿
Meaningful Assessment	Alignment	❹	❸	⓿
	Formative	❹	❸	⓿
	Summative	❹	❸	⓿
	Metacognition	❹	❸	⓿
Equity & Practicality	Equity	❹	❸	⓿
	Practicality	❹	❸	⓿
	TOTAL			

☐ Highly Recommended (68-64) ☐ Recommended (63-48) ☐ Not Recommended (47-0)

Comments:

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