A Teacher's Guide to Student Discovery through Inquiry
PROFESSIONAL DEVELOPMENT

A Teacher's Guide to Student Discovery through Inquiry

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Introduction
According to the National Science Education Standards, inquiry is "central to science learning" and "rests on the premise that science is an active process." Students engaged in scientific inquiry are propelled along, making their own discoveries and fueling the desire to learn.

What is Inquiry Teaching? Inquiry is a dynamic teaching method that engages students in "minds-on" as well as "hands-on" activities. Functioning as scientists, students actively generate questions...collect, evaluate and synthesize data...draw conclusions...rely on evidence to support ideas...and contemplate next steps. You facilitate the process by posing questions, managing the learning environment, assessing progress, helping students make sense of what they've learned and providing opportunities for them to investigate, collaborate and explore.

Part I: Why Use Inquiry Teaching?

Take your students to a new level of learning and awareness Inquiry teaching takes children to new levels of awareness and involvement in science. As a student-centered activity, inquiry gives children ownership of the learning process and inspires them to become more independent learners. As students engage in critical thinking and problem solving, questioning, probing and discovering answers, they gain a more meaningful and longer lasting understanding of scientific processes. By questioning and designing systems for gaining knowledge, students become more resourceful, developing self-reliance and a greater under-standing of the life-long learning process.

Why isn't inquiry used in more science classrooms? There are teachers that have concerns about using an inquiry-based approach. They may not feel confident because they lack a solid background in science content. Or, they may see science as a frill or an "add-on," tangential to the essential skills of reading, writing and mathematics. Many hold a number of pedagogical concerns that may prevent them from embracing the inquiry method. Some of these are addressed below in the "Concern Corner."

Concern Corner Here are some of the more common concerns about inquiry teaching as well as answers to some of those concerns and questions.

1. Lesson planning for inquiry takes too much time and it's too difficult to blend an inquiry-based curriculum with the mandated one. As with any new curriculum, inquiry requires an investment of time and energy but the payoffs are significant. By taking the process one step at a time-and when possible-in collaboration, it's much simpler. Here's how you can make it easier:

- Give careful thought up-front to gathering necessary resources and determining the nature and order of the activities.
- Spend time gauging students' levels of content knowledge at the start of the lesson.
- Determine when and how assessment will occur.

2. Inquiry teaching requires you to know so much more science content. It's important to have an understanding of science content, but just as important is knowing how to find information. Attending workshops, taking courses, watching television programs, accessing online information and reading children's books are all excellent ways to build content knowledge. Collaborating with colleagues who have knowledge of science concepts is another way to strengthen your knowledge base.

"Inquiry is not exclusively for our most talented students. Inquiry science, in fact, is of most benefit to our students who are having difficulties with school." -Garnetta Chain, SCIENCELINE Video Teacher, New Brunswick, New Jersey

3. Traditional techniques such as lecturing straight from the text or having students read and memorize reflect tried and true methods-and make it easier to cover the curriculum. Inquiry requires a different set of pedagogical practices that take a lot of time to learn. Many of the pedagogical practices used in the traditional classroom can apply in an inquiry-based environment although they may be used differently: direct teaching, guided practice, modeling, questioning and group discussion among others. During inquiry teaching you guide students instead of lead them, becoming a

facilitator. Instead of tossing away traditional teaching methods, you build and add new ones.

4. Would inquiry teaching cause a loss of control and lead to chaos in the classroom since students suggest the learning direction? No! It's quite the opposite. You still have control and lead the classroom but the difference is that you do not do all of the work or thinking for the students. Strategies such as cooperative grouping, pairing or whole class instruction guide students as they take responsibility for their own learning. What may look like confusion is nothing more than new discoveries and learning taking place!

5. What happens when the materials students need for data collection and investigation are in short supply? Finding materials and resources is essential yet simply requires planning and resourcefulness. Many organizations such as government agencies, universities and businesses are willing to provide books, kits and videos. Some will even send experts to support science programs in the schools. The Internet and e-mail also provide teachers with access to outside resources.

6. Students don't always have the maturity or the social skills necessary to adapt to the freer, more open-ended environment of the inquiry classroom. Isn't this a major hurdle? While inquiry does require a willingness to learn within a different structure, even the youngest of schoolchildren can be successfully engaged. In this unique setting, you have as much freedom to establish ground rules for behavior as in a traditional classroom. When students are given an inquiry structure, they do adapt.

7. Aren't inquiry objectives difficult to assess and link to tests? Actually, like in a traditional classroom, assessment helps drive instruction. It allows teachers to track student progress and needs, while providing a basis for lesson planning, instructional modification, and reflection on teaching strategies. Inquiry objectives are also assessable in various ways such as through observation, one-on-one questioning, science journals, portfolios, and rubrics.

Part II: Main Features of Inquiry Teaching

Enjoy the thrill of interactive discovery When you use the inquiry method, both you and your students embark on a process of exploration and discovery. You both discover the thrill of unexpected outcomes but still use and learn identifiable and specific scientific concepts and principles along the way. See for yourself what teacher Christine Collier, a teacher in Indianapolis, Indiana has to say:

> "My approach has always been a hands-on approach, but it's more than hands-on now...It's about letting kids generate the questions instead of me generating the questions. And then I explore, figure out how they are going to test their ideas, how they are going to explore answers to their questions. And then

I...help them make connections to their lives and make sense of what they have found out."

Inquiry is an evolving process. Students may not always arrive at a complete answer, but the point is they experience things that are new and different, conduct investigations, supply evidence to support ideas, connect with scientists and experts, keep written records of thoughts and conclusions, and continue asking questions.

Highlights of the inquiry-based science classroom:

- **Learning is student-focused with the students determining the lessons' direction.** Inquiry shifts ownership of the learning process from teacher to student, making the process through which students learn concepts and develop skills as important as the science content. In this setting, you act as a facilitator in the process.
- **Students engage in scientific inquiry by asking questions and devising answers.** Inquiry requires students to describe objects and events, ask questions and devise answers, collect and interpret data and test the reliability of the knowledge they've generated. They also identify assumptions, provide evidence for conclusions and justify their work.
- **Teachers ask questions that encourage inquiry and stimulate thinking.** To guide students through inquiry, you engage in open-ended questions such as "How do you know?" and "How does your data support your conclusions?" in order to encourage further probing and discovery.
- **Students are engaged in problem solving, constructing meaningful experiences.** Because students act as scientists, engaging in meaningful problem solving, they can construct meaning out of their experiences. Endeavors include hands-on exercises as well as critical and logical thinking activities.
- **Students gain a greater understanding of the purpose of learning.** Inquiry lets you create a framework where students understand how and why to ask questions. Students reflect on the lesson and explain why it is important-and gain a greater understanding about the inquiry process and how it relates to learning.
- **Inquiry is a creative learning environment using both group and individual discovery techniques.** Inquiry involves setting short- and long-term goals and adapting them to students' interests. Within this framework you might involve students in hands-on activities, whole class instruction, or group collaboration. This learning environment allows students the freedom to explore and investigate while making connections and drawing conclusions.
- **Students interact purposefully with each other and the teacher, leading to effective communications.** Inquiry teaching encourages students to collaborate with one another, communicate ideas and thoughts, ask questions, justify answers and seek advice from others.
- **Assessment is ongoing.** Inquiry takes the focus off memorization and instead promotes assessing students' ability to understand, reason and use their

knowledge. Assessment can be achieved through questioning, observing, using checklists, portfolios and more.

Part III: Procedures for Using Inquiry Teaching

Fourteen proven steps for successful implementation To reach the goals of an inquiry-based science lesson, you should incorporate the following 14 proven procedures:

1. Understand Inquiry Teaching Before you get started you must have a basic understanding of the inquiry approach. Suggestions for:

- lesson planning
- classroom management
- questioning techniques
- assessment and other teaching strategies

Whether you're new to inquiry-or experienced in inquiry teaching-you can gain additional support from the SCIENCELINE online learning communities. These interactive communities are facilitated by experienced elementary science teachers. You can also find helpful tips throughout this print guide-and useful references in the Bibliography section-that you can use to expand your knowledge.

2. Select a Science Topic When starting to teach using inquiry, look at the district standards and the mandated curriculum, which give topical and conceptual direction. Use the KWL method (see Appendix A) to help determine student interests. Weave together their interests with the mandated curriculum to create a conceptual outline. The outline describes the content and the sequence in which it will be taught, so students build knowledge and understanding. This outline will also help determine which resources you should make available for student explorations. *Teacher's Tip:* Start by choosing a familiar topic, perhaps one that was taught previously using a traditional approach, or a portion of a broader topic previously taught. (i.e., if you taught a unit on "water," you may want to focus on buoyancy and have students investigate why objects float.)

3. Prepare Materials and Equipment Since student investigations are the primary activity in an inquiry classroom, it's essential that you have appropriate materials and equipment on-hand to help students build models, collect data, weigh and measure, etc. The following is a possible list of materials that are easily found in school or at home:

aluminum foil	cotton swabs	glue sticks
popsicle sticks	lemon juice	Post-It Notes
rubber bands	paper	clay

paper cups	vinegar	other common resources

Involve your students by having them keep a running list on the board of supplies they need or bring supplies if they have them. *Teacher's Tip:* Ask your grocery store for donations! (See Appendix B for a list of the most commonly used items in an inquiry science classroom.)

4. Locate Outside Resources In addition to ordinary objects, you can tap into technology and community resources to help students connect science to the world in which we live. Some of the outside resources used by the SCIENCELINE video teachers include:

- visiting a pond to discover how plants use water (Jane Morton)
- taking a field trip to a national park (Christine Collier)
- visiting a weather station or art museum (Kathryn Mitchell Pierce)
- using e-mail to communicate with a university scientist (Kathryn Mitchell Pierce)
- accessing a Web site to find information about dolphins (Lisa Nyberg)

Museums, zoos, and local toy stores are also great places to find resources.

5. Explore Science Content If you're unfamiliar with the science content, find information to help strengthen your knowledge. Children's resources are handy because they're written in simpler language that makes it easy to transfer the concepts into lessons. Look for such resources as:

- children's books-Look Closer, Wildlife Fact Files, and Let's Read and Find Out Science
- children's science magazines-Ranger Rick, National Geographic World and ScienceScope
- children's video programs-Bill Nye the Science Guy, Kratts' Creatures and Reading Rainbow
- children's Web sites-PBS Kids! at www.pbs.org/kids/

You can also talk with science-focused colleagues, take classes, and attend workshops. All of these sources help you increase your knowledge of science. *Teacher's Tip:* Make sure to leave yourself open to learning with the students!

6. Develop Lesson Objectives Build on the previous steps by developing lesson objectives that clearly indicate what skills, concepts and vocabulary the students need to acquire. Plus, show how you'll move the students through the inquiry process. Planned activities include hands-on exercises, going beyond memorization and content reading. These types of experiences should occur within the context of broader goals. In addition to determining content objectives, ask yourself:

- What types of inquiry skills should students be developing?
- What kinds of questions do you want students to be asking by certain stages?

- What types of explorations or predictions do you want them to seek out?

7. Assess students' prior knowledge Before you begin the inquiry learning experience, you'll need to determine the student's level of understanding about the selected topic. The following strategies can help you determine their levels:

the KWL technique	concept maps
situational drawings	prediction sheets
diagnostic questions	historical investigations
personally oriented questions	interviews and journals

(See Appendix A for a discussion of these strategies in greater depth.)

8. Handle Classroom Organization and Management Using the inquiry approach requires flexibility and a willingness to follow an evolving lesson rather than a strict outline. This style doesn't mean you lose control. In fact, it may mean infusing more structure into the lesson. Here's how:

- **Classroom Organization** First, decide how best to organize activities-this includes carefully deciding which materials might be needed to address students' interests and help them answer their own questions. Remember, thoughtful resource gathering-bookmarking Web sites, gathering children's books and videos-gives you confidence in responding to students' interests and questions that take the lesson beyond the original outline. *Teacher's Tip:* Teacher Christine Collier puts a "text set" of children's books at each table for children to use during their investigations.
- **Classroom Management** In an inquiry classroom, students are often out of their seats, examining items, collecting data and talking with one another. Maintaining control requires carefully thinking through students' activities and their sequence. *Teacher's Tip:* To effectively manage your classroom, first assess your comfort level with students moving about, noise level, etc. Next, determine where and how students will be engaged and communicate that plan to the children.
- **Establishing Ground Rules** Because students in an inquiry classroom often work in collaborative groups or in pairs, it's important to help them develop effective interaction skills. Some strategies for building these skills include:
    1. having whole-class discussions on working together productively
    2. assigning students different roles (i.e. one collects, one records the data)
    3. posting agreed-upon ground rules
    4. calling timeouts to assess everyone's progress during an investigation When used effectively, such strategies can also help students become a part of the classroom management process. *Teacher's Tip:* Always remember that the very nature of inquiry means even though things may not look organized, there is an underlying order to the learning process.

Learning along with your students helps them understand that science is about finding answers and not about always knowing the right answer from the begining. It also lets them know that teachers do not always have every answer-and that's okay!

To become a skilled facilitator, use a combination of questioning techniques, instructional practices and ongoing assessment strategies to help students build their own connections.

9. Use Time Management Inquiry lessons usually do not have predetermined limits and may stretch over several days, weeks or months. In order for students to get the most from a lesson, you must allow enough time for investigations to occur in their entirety. Careful planning and resource management are the keys! Sometimes student explorations will take a different path than you intended. That's OK! As long as the direction adheres to the lesson's conceptual framework, follow their lead to keep the students interested and engaged. Time is also critical in the questioning process. Be certain there's sufficient "wait time" when asking a question, especially in large group discussions. *Teacher's Tip:* After posing a question, wait eight or nine seconds before calling on a student so that children who deliberate longer have an opportunity to participate.

10. Become a Facilitator To become a skilled facilitator, use a combination of questioning techniques, instructional practices and ongoing assessment strategies to help students build their own connections. As a facilitator, you'll seek answers along with them while at the same time having a sense of the overall objectives. It is important to make yourself available to students in several ways. For example, you could move from group to group and help students gain a better understanding of what they're exploring by focusing their attention on what's happening and posing questions to keep them thinking.

An Exercise in Facilitation Here's a sample exchange between teacher Garnetta Chain and a student to help you better understand the role of a facilitator:

Garnetta: Are there any ways in nature that you have seen rocks get smooth?
Student: If you put rocks under water for a little while they'll get smooth. Some rocks come from mountains and the stream comes down and takes them with them and they get smooth. You could put a rock and some water in a bucket and shake it up for while and then open it and the rock will come out smooth and it will be smaller.
Garnetta: It will be smaller? Why?
Student: Because you shook the water up when the rock was in there and it's just…
Garnetta: How did it become smaller?
Student: Because of the friction.
Garnetta: What did the friction do?
Student: It shook everything up.
Garnetta: And what happened to it (the rock)?
Student: It got smaller and became smoother.

Encourage students to work as scientists and arrive at their own answers through a problem-solving process. However, students should not be limited to specific factual responses (i.e. "Name the different types of leaves." or "Does it sink or float?"). Instead, encourage them to seek an understanding of the connections. Prompt them with a question that challenges them to think deeper. Depending on which stage of the inquiry process you're in, you can ask different types of questions. According to Jos Elstgeest, in "The Right Question at the Right Time," questions should promote activity and reasoning...invite the children to look closer and experiment...but not be too wordy. Here are some of his additional suggestions for questioning that move the inquiry lesson forward, listed in ascending order of sophistication.

- **Attention-focusing questions** Examples: "Have you seen...?" or "Do you notice...?" followed by "What is it?" "What does it do?" "What do you see, feel, hear?" Such questions help learners take note of details easily overlooked.
- **Measuring and Counting Questions** Examples: "How many...?" "How long...?" and "How often...?" These questions allow children to use new skills and new instruments-and are terrific confidence builders since students can easily arrive at exact answers.
- **Comparison Questions** Examples: "In how many ways are these seeds alike and how do they differ?" "Is this longer, stronger, heavier, more ___ than...?" These questions are designed to emphasize the need for keen observation and focus. Such questions also direct students to observe differences in shape, size, color, etc., and recognize these differences as valuable information.
- **Action Questions** Example: "What happens if...?" This question category helps children discover relationships between what they do and the reaction of the materials they are handling. Probing lets students explore the properties of unfamiliar materials, forces at work and small events.
- **Problem-posing Questions** Examples: "Can you find a way to...?" "Can you make a sinking object float?" "Can you make a plant grow sideward?" Such questions build students' abilities to predict, problem-solve and form simple hypotheses that lead to verification.
- **Reasoning Questions** Examples: "Why?" "How?" and other simple questions that call for explanations, build upon natural curiosity, and challenge young minds to think and reason independently. Students discover that there is no one right answer to such questions and that even an outlandish answer can provoke debate which can lead to correction-if it's based on sound evidence. Further probing with questions like "What do you think about___?" or "Why do you think ___?" helps students understand that they can apply their own reasoning. These questions shouldn't be posed before children have had the necessary experience, so they can reason from evidence.

12. Address Student Misconceptions Since so much of an inquiry lesson involves students working on their own or in groups, they may at times draw incorrect conclusions or misinterpret information.A good facilitator will provide experiences that help learners confront misconceptions through such strategies as:

- questioning to redirect the students to a more accurate path of inquiry
- calling for a reexamination of specific stages of the process that lead to erroneous conclusions
- teaching or reteaching a concept explicitly
- various others

In addition, skilled facilitators help students challenge assumptions that may be based on a weak premise. If an investigation is based on faulty assumptions, it's not productive to continue it.

An Exercise in Managing Misconception The following exchange between teacher Lisa Nyberg and a student during a KWL exercise offers you helpful thought for how to deal with a misconception:

Lisa: "[What are some] other things we know about sound?"
Student: "Well, Mackenzie said that to make sound, things have to vibrate. Not everything has to vibrate."
Lisa: "Not everything has to vibrate to make sounds?"
Student: "Yes."
Lisa: "Can you give me an example of something that makes a sound that doesn't vibrate?" **Student**: "Like when you stomp your feet, your foot doesn't vibrate."
Lisa: "So, what you're saying is, you think when you stomp your feet there's no vibration in your foot? Let's look at that. So you think there are some times when sounds are made like stomping your feet when there isn't vibration. Am I understanding you right? [Lisa writes the student's idea on the flip chart along with the other ideas about sound suggested by the class.] Okay more ideas about what we know about sound. Naomi?"
Naomi: "Adding on to what Brittany just said, when you stomp your foot the floor is kind of like vibrating."
Lisa: "So you disagree with what Brittany is saying. You think that there is vibration. Maybe you don't feel the vibration in your foot, but you think there's some vibration in the floor itself?"
Naomi: "And in the foot. You can't really feel it though. You can't really tell, but there is a vibration between the floor and your foot."
Lisa: "So you're suggesting that perhaps sometimes the vibration is so subtle, it's so little that maybe we can't always feel it. But you think that there's a vibration even like with a foot stomp. So you disagree, but it's okay to disagree."

13. Integrate Subject Matter Once you've mastered inquiry planning, take it one step further by integrating it with 16 other disciplines. For example, in the classroom of teacher Kathryn Mitchell Pierce, students not only designed, built and tested their instruments, they also painted weather systems and wrote poems about the weather.

14. Perform Assessments Assessment provides students with feedback on how well they're meeting expectations...and gives you feedback on how well your lessons are going. Start by assessing students at the beginning of a lesson by determining how

much they know about the lesson's topic. Next, weave assessments through the entire lesson using a variety of strategies-often called "authentic assessments"-including:

student journals	student work samples
observations	interviews
performance-based testing	hands-on assessments
portfolios	scoring rubrics

(See Appendix A for an in-depth discussion of these strategies.) Through ongoing assessment, you can use student feedback to:

- modify your instruction
- assist students around learning "roadblocks"

In any case, set high and specific expectations for the type and quality of work students will produce-and clearly communicate them to students. Because children's expertise and skills differ, you must consider both the class as a whole and the individual learner during assessment. For example, if reading or writing is challenging for some students, you might also let them show or tell the answer. Such activities let them demonstrate what they know.

Part IV: Exploring a Sample Inquiry Lesson

Inquiry offers countless fun and productive approaches to teaching! Inquiry takes on many forms. Some classrooms may look structural, with inquiry being more like a research project where you provide the framework for investigations. Still others may be more open-ended, with students suggesting more of the structure.

The following example of an inquiry lesson, based on teacher Lisa Nyberg's approach, demonstrates how an inquiry-based lesson could be structured and conducted. In this scenario, she's teaching students the concept of sound, one of the major science topics she is required to teach during the year. See how she creates the lesson framework to get your own ideas.

Step One: Lisa creates a foundation using the KWL method (see Appendix A) to learn what students know (K), what they want to know (W), and to find out what they've learned by the end of the lesson (L). To accomplish this task, she uses guided inquiry-getting them to ask questions and challenge their own ideas. She asks such questions as, "What do we know about sound?" and "What's the first thing you want to know?" As students give answers, she records them on the board, asking for clarification as needed. When she encounters misconceptions or conflicting statements she writes them down as well.

Step Two: To begin exploring student-generated statements, her class uses a homemade oscilloscope, shouting into one end to create a light pattern on a screen that shows energy vibrations. Probing why certain results occurred, she follows up with "What if...?" questions, such as "Would it work better if I made (the drum) tighter?" Her questions prompt a student to suggest bouncing the laser off a mirror attached to a vibrating speaker to see what kind of light pattern it would create. Since this suggestion follows the lesson's conceptual framework, Lisa decides to follow his lead and redirects the lesson.

Step Three: Seeing that vibration transmits sound, the class makes sound amplifiers using paper cups and string. Along the way, Lisa lets the children use different materials to change the quality of the sound. Next she begins asking more "What if...?" types of questions, such as "What could we do differently to change the sound?" in order to encourage them to experiment and participate. The activity also provides a springboard for homework where students make different sounds using household materials.

Step Four: The next day, Lisa brings in guitars for the students to compare sounds and determine why they're different. She has them compare their previous day's findings with the sounds the guitars are producing. Lisa asks, "So what was the actual thing you were feeling with your hand near the speaker-air or sound?"

Step Five: Finally, on another day, her students go to the music room to apply what they've learned to different situations. Students compare the sounds in different sized bells and, through questioning, discover that "the bigger the bell, the lower the sound." She has them test the idea:

Lisa: "The smaller you get, why does it make a higher-pitched sound?
Student: "Because it vibrates more."
Lisa: "Because it vibrates more? Hmmm...How would you check to see if that's true?"

To test this hypothesis, she has them strum the guitar strings to determine which makes the lowest sound. The student accurately predicts that the thickest string makes the lowest tone. When she asks, "How can you change the sound?" the students tighten the guitar knob and put their fingers on the string to create higher and lower pitches of sound. Through this process, students make the connection between different tones made by the bells based on size and the different tones made by guitar strings based on their diameter. Ultimately, the students connected concepts through multiple exposures, and their conceptual understanding was solidified.

Appendices

Appendix A: Assessing Students' Prior Knowledge

The following strategies help determine a student's grasp of content at the beginning of a lesson. Most of them are adapted from Children and Science by Dr. Bonnie B. Barr. (Used with permission.)

A. The KWL Technique Using the board, write down information drawn from students during a class discussion to gauge where they are before starting the lesson.

1. Write down what the students know (K) to obtain baseline data on their levels of understanding and initiate the assessment process.
2. Determine what the students want to know (W) to suggest areas of focus. (For example, teacher Michael Beason asked what his students wanted to learn about worms. Answers ranged from knowing about their mouths, to how they get wet, walk and dig holes.)
3. At the end of the lesson, refer back to the chart to see what students have learned (L).

The KWL chart can also be used to:

- remind students of their questions
- correct prior misconceptions
- enable them to compare previous levels of understanding with newly acquired information

B. Concept Maps In a concept map, labels for concepts are interconnected to give a visual representation of how the learner views the relationships among the concepts. From previous experiences, students come to the classroom with some understanding of the concepts that will be presented. However, the students' views may be quite different than the views held by scientists-or they may have similar views but see the concept relationships differently. Often, the understandings held by the student are incomplete and inadequate to cognitively build links with other related concepts. Based on the conceptual change model, it is important for both the student and the teacher to identify what initial concepts are held. The concept map can do this. One method of constructing a concept map:

1. Present each student with a list of related concepts-the most usable ones have fewer than 10 concept labels.
2. Provide each student with Post-It Notes (or small pieces of paper) -one for each of the concept labels-and ask each student to write one concept on each note.
3. Ask students to place the labels on a blank sheet of paper and arrange them to show the best relationship between the concepts. Students should connect related concepts with arrows, and label the arrow with a description of the relationship.
4. Once the "maps" are created, let students share them in order to articulate their ideas in their own words and recognize any gaps in their understanding. Ask students to share their maps with other students in a small group, with the entire class or on a one-on-one basis with you.

Why concept maps?

- to help students reflect on their own ideas
- to help you prepare for a unit of instruction
- to reflect changes in student understanding during instruction or detect persistent naive conceptions

For example, during a unit on photosynthesis each student in a ninth grade class constructed a concept map using the concept labels. During this exercise, it was discovered that eighty-five percent of the students indicated oxygen was a product that only animals required. Seventy-five percent associated food production with animals as well as plants. More than half associated food production with small plants but not trees. None of the students yet understood that during photosynthesis, energy was trapped in the food. Concept maps alone won't bring about conceptual change, but they enable both student and teacher to focus on concepts held prior to instruction.

C. Situational Drawings Help students focus their ideas by allowing them to reflect on the possible outcome of a given natural event. For example, you could supply them with a picture of a closed flask and tell them that it contains gas. Then ask students to note the following predictions on their pictures:

1. If you could see the gas in the flask, draw what you think you would see.
2. The stopper has been removed from the flask. Draw what you think will happen to the gas.

D. Prediction Sheets Similar to Situational Drawing, this technique takes the student and the task further in the learning process. Here's what to do: Have students make a prediction based on their current conceptions of a natural event-then participate in an activity to test their predictions. Afterwards, they complete another diagram detailing what occurred.

Prediction Sheet Exercise: Distribute two identical diagrams of a vial-one labeled, "I think," and the other, "I know." Ask students to imagine a vial, mouthside down, held in an upright position and lowered over a cork floating on top of water in a cup until the vial reaches the bottom of the cup. Next, direct your students to take the picture of the vial labeled, "I think," and put an X where they think the cork will be when the vial reaches the bottom of the cup. Once students make their predictions, they can try the experiment and note the actual results in the picture labeled, "I know."

E. Diagnostic Questions This method provides a surefire way to gain insight into the validity and level of confidence a student has in his or her answers to a series of multiple choice questions-and a handy way to assess each student's level of understanding and reasoning so you know where to begin related lessons. Examples of diagnostic questions include:

1. I filled a cup and a jug with water heated to the same temperature.
a. What would I find if I returned one hour later?
1. The water in the jug was hotter.
2. The water in the cup was hotter.
3. The water was the same temperature in both containers.

b. How sure are you of your answer?
_ Just a guess
_ Not too sure
_ Pretty sure
_ I'm right

c. Explain your answer.

2. I took a small ice cube and a large ice cube out of the freezer.
a. Which one will melt first?

b. If I put a thermometer in each ice cube, what would it show me?
1. The small ice cube is colder.
2. The large ice cube is colder.
3. The two are the same temperature.

c. How sure are you of your answer?
_ Just a guess
_ Not too sure
_ Pretty sure
_ I'm right

d. Explain your answer.

3) I added an ice cube to a cup of water.
a. What will happen to the temperature of the water?
b. Why?

To begin the process of conceptual change, students' ideas need to be probed. Encourage them to clarify their theories to classmates, you, and most importantly, themselves. You'll soon discover that students begin to focus on differences between their own ideas and those of their peers. Once that happens, the recognition of conceptual conflict sets the stage for cognitive restructuring and/or conceptual change.

F. Historical Investigations One of the more fascinating aspects of inquiry is the fact that the conceptual change that occurs in the students' minds is similar to the evolution in thinking held by today's scientists. Examining historical investigations is an excellent way for students to demonstrate their knowledge and connect themselves to the scientific process. First, describe for students a historical science investigation. Then, ask students to interpret the data obtained and record their interpretations. Finally, share the scientist's interpretation so they can compare them. Putting ideas on paper simply enhances the focusing process. Here are some sample historical experiments you might share with students:

Van Helmont's Experiment on Plant Growth: In the late 1500s, Jan Baptista van Helmont planted a willow branch weighing 2.2 kg in a tub of soil weighing 90 kg. After five years, the plant increased in weight by 73 kg. The weight of the soil remained the same. Sample questions: How would you explain the results of van Helmont's investigation?

Galileo's Experiment: Aristotle believed an object that weighs 10 times as much as another object would fall 10 times faster than the lighter object. Galileo believed objects accelerate equally regardless of mass. To demonstrate his theory, it is said that he dropped two objects of different masses from the rim of the Leaning Tower of Pisa in Italy at the same time. Sample questions: Do you support the idea of Aristotle or Galileo? Will the objects hit at the same time or will one hit the ground sooner than the other will? Explain.

G. Personally Oriented Questions Students are often most effective at demonstrating their scientific knowledge when concepts are formed in real-world situations in which they have a personal stake. Whenever possible, students should have the opportunity to share their solutions to the question by either writing about it in a journal or by sharing ideas in a cooperative group. Following are some examples of personally oriented questions:

- Your best friend has challenged you to a bicycle race. How can you make your bike go faster?
- You're on a camping trip and are told not to go near the water. You disobey and fall in. How can you dry your clothes before anyone finds out?
- Your mom sends you to the store to buy peanut butter and wants the best buy. How do you know which is the best buy?

H. Interviews and Journals Much of the research on the misconceptions students have about science concepts has been done in clinical interviews. Since one-to-one clinical interviews are time-consuming they're less suited to teachers. But, you can gain some of the insights gathered from such interviews by having students write their ideas about a natural event in a journal.

For maximum effectiveness, ask students to respond in their journals before instructing on a new concept. Make certain they know these entries are not graded, but instead are used to help them focus. Afterwards, have the entries read, reflected on and probed by another person. This is a skill that needs be nurtured.

Teacher's Tip: Have students discuss the content of their journals with a partner or in a cooperative group. Or, collect the journals and read them at periodic intervals. Following are samples of journal entries that you might use as focus activities:

- List five things known about evaporation.

- Describe your adventures as a predator.
- Explain why predators tend to have eyes facing forward.
- Explain how one object might have two shadows.

Children already hold concepts about many aspects of the world-explanations that to them are meaningful and logical. These ideas may, however, be quite different from those held by scientists and are often resistant to change. If conceptual change in their thinking is to occur it's critical that you take the time to identify students' existing knowledge and ensure that their thinking is sufficiently challenged during their investigations.

Appendix B: Sample Items Most Needed in a Science Inquiry Classroom

Aluminum foil Assorted containers (clear ones make materials visible) Baking soda Balloons Batteries Books (primarily nonfiction science trade books) Clay Coffee filters Computers with Internet access Cotton swabs and cotton balls Dish detergent Eye droppers and small spoons Flashlights Food coloring Funnels Glue and glue sticks Hand lenses Lemon juice Magnets and magnet items Marking pens Measuring tools: measuring spoons, cups, graduated cylinders, rulers, tape measures, etc. Oatmeal Oil (vegetable, olive, etc.) Paper (all types) Paper bags Paper plates and cups of all sizes Paper towels Pipe cleaners Plastic zip lock bags Polaroid camera Q-Tips Raisins Rubber bands Rubber gloves (be careful, some children are allergic to latex) Salt Sand, soil, gravel Scales Scissors Seeds Spools Straws Sugar and sugar cubes Thermometers Tongue depressors or popsicle sticks Toothpicks Vinegar Waxed paper Wire

Appendix C: Assessment Strategies

Following is a list of assessment strategies taken from Children and Science, by Dr. Bonnie B. Barr. (Used with permission.)

A. Performance-Based Testing Performance-based testing involves placing students in a laboratory setting, giving them a novel problem, and asking them to solve it. This strategy assesses students' higher-order thinking skills and allows you to determine which learning activities have been the most effective. Take a look at this process in the following instructional scenario from a classroom studying density.

Assessing student understanding of density A class of students was asked to explain why an egg floats in salt water but sinks in fresh water. To explore this question, they first determined the density of various objects by finding each object's mass per given volume. They also determined the density of water and put each object in water to see if it would sink or float. Next, they compared the density of the objects that sank with the density of water. For an application task, students were asked to determine the density of four salt solutions of different concentrations, and to predict the order in which they could be layered.

Student understanding of density was measured by a pencil and paper, short-answer instrument and a performance assessment. The following questions appeared on the short-answer quiz.

1. A difference between ocean water and fresh water is:
a. ocean water is more salty.
b. fresh water is more salty.
c. fresh water is a darker blue.
d. fresh water is heavier.

2. Objects float more easily in:
a. salt water.
b. fresh water.
c. either salt water or fresh water.
d. fresh water mixed with salt water.

3. What happens to a layer of fresh water on top of a layer of salt water?
a. The two kinds of water mix together.
b. The fresh water floats on the salt water.
c. The salty water floats on the fresh water.
d. The two kinds of water do not mix at all.

Eighty eight percent of the students answered all three questions correctly. For the performance assessment measure, the students were shown two balloons filled to the same size with liquid. Unknown to them one balloon contained water and the other a salt solution. Both were placed in a container of water. The students were then asked to record their explanations for why one balloon sank and the other floated. Forty six percent of the students gave the correct response. However, forty three percent gave the opposite answer, stating that salt water, "makes things float."

The pencil and paper test was inadequate in detecting a persistent naive conception. Only when students were put in a situation in which they had to demonstrate understanding was the misconception revealed. With the results from the pencil and paper test, you might believe that an understanding had been achieved and move on to something new, leaving many students with no better conceptual understanding than they started with at the beginning. The performance assessment, however, indicated that further instruction on density was necessary and was more effective in evaluating students' understanding.

B. Hands-On, Practical Assessments Recognized as the most appropriate method to assess science process skills, practical assessment requires a child (or group) to read sample instructions, perform a task involving the materials and respond in writing to relevant questions. Following is an example of this assessment method taken from the National Assessment of Educational Progress Pilot Study of Higher Order Thinking Skills (NAEP, 1987).

Classifying: What is the Same About the Bones in Each Group?

1. Look at the collection of labeled bones. These bones are from the backbones of different animals.
2. Put the bones into three groups. Make sure there is something the same about all the bones in each group. You must use all of the bones.
3. Write the letters of the bones in your three groups.

- Group A:
- Group B:
- Group C:

4. What is the same about the bones in each of your three groups ?

- Group A:
- Group B:
- Group C:

The information gathered from hands-on practical assessments helps the student, teacher and parents make judgments on how well the student uses the tools of science-both manipulative and thinking skills. However, this type of assessment is not used to collect data on conceptual change.

C. Portfolio A portfolio is a collection of pertinent student products that must be evaluated with an established criterion to determine conceptual change and growth in problem-solving abilities. When used with other assessment tools, a portfolio can be a powerful instrument in encouraging students to accept responsibility for their learning.

You should collaborate with your students on the items to include in the portfolio. Either of you can submit entries, and both should be able to present a rationale for each inclusion. The portfolio should reflect what is valued and illustrate growth and progress toward the goals in the instructional program. Entries should also reflect growth in conceptual understanding and the ability to use content and process skills to solve problems.

Portfolio Management Note the entry date of each document placed in the portfolio. If a document is a product of group work, list the names of all group members. The portfolio might include the following:

- concept maps
- lab reports
- analysis of problem situations
- analysis of articles
- examples of student work
- student-developed exams with expected answers
- interpretation of data from historical investigations

Make certain the portfolio is housed in the classroom for maximum accessibility. Documents in a portfolio can provide some evidence of a student's risk taking, decision making, creativity, and value judgments of their own performance skills-all of which are needed for students to become independent, self-directed learners. You can protect your portfolio against unreliability or inconsistency by:

- engaging in discussions about the goals and priorities for instruction and assessment-in order to build a common understanding of expectations and criteria for success
- assessing in an ongoing capacity and collecting several indicators for any particular goal

The more measures you have in place, the greater the reliability of the conclusions you make.

D. Projects Typically the culminating activity of an instructional unit, projects serve a dual purpose of being both instruction and assessment. For example, students might construct a "Rube Goldberg Apparatus" at the end of a unit on simple machines. Completing such a project requires students to apply specific concepts and skills, giving them additional exploration and providing you with useful assessment data on their abilities. If you expect to uncover what a student really knows, you must have a checklist of fair and reasonable expectations and outcomes.

E. Observations and Interviews An easy, quick record keeping system is needed prior to using observation and/or interviews as assessment tools. Both observation and interview assessment most frequently occur during the normal course of hands-on conceptual change instruction. Make a point of observing specific behaviors and asking the learner to reflect on the science situation in which he or she is engaged. Simply record students' progress on a checklist developed before instruction. Through probing questions, you can explore the depth and breadth of student understanding. To do so correctly, you must have a firm grasp of the subject matter and of the students' entering constructs.

F. Journals Once rare, writing in science is now considered vital. The need for internalizing understandings through language can easily be facilitated with a student journal. That journal becomes an assessment tool with evidence of student progress. Both you or your students may initiate entries in the journal.

Be certain to engage a peer partner in the journal reading. In this role, the partner engages the author in written or verbal dialogue which causes reflection. If discrepancies or inconsistencies appear, they're targets for discussion. Ask the reviewers to concur or disagree with the views of the writer and justify-in writing-their stance. This dialogue will force reflective thinking.

Periodically, you should collect and read the journals. If journals are being used for assessment, be sure students have a description of what indicates "success" before they begin. The California Mathematics Council and Project EQUALS have developed the following rubric for scoring journal entries that are responses to open-ended problem solving questions. Similar scoring rubrics are necessary for other forms of journal entries.

Sample General Scoring Rubric for Open-ended Questions PLEASE NOTE: For each individual open-ended question, a rubric should be created to reflect the important elements of that problem. The following example will help you think about which factors to consider. *Teacher's Tip:* Sort papers first into three stacks: good responses (5 or 6 points), adequate responses (3 or 4 points), and inadequate responses (1 or 0 points). Each of those three stacks then can be resorted into two stacks and marked with point values.

Helpful ways to perform assessment Assessment can take several forms. Some of the more common forms include:

- encouraging students to communicate their findings and engage in peer review
- writing in journals
- presenting to the class or to small groups
- making a group presentation

Try them out in your classroom, helping students learn to accurately explain and defend their findings and their conceptual understanding.

Benchmarks to Demonstrate Competence

Strong Response
Exemplary Response: Rating = 6 Gives a complete response with a clear, coherent, unambiguous, and elegant explanation; includes a clear and simplified diagram; communicates effectively to the audience; shows understanding of open-ended problem's mathematical ideas and processes; identifies all the important elements of the problem; may include examples and counter examples; presents strong supporting arguments.
Competent Response: Rating = 5 Gives a fairly complete response with reasonably clear explanations; may include an appropriate diagram; communicates effectively to the identified audience; shows understanding of problem's mathematical ideas and processes; identifies the most important elements of the problems; presents solid supporting arguments.

Satisfactory Response
Minor Flaws but Satisfactory: Rating = 4 Completes the problem satisfactorily, but the explanation may be muddled; argumentation may be incomplete; diagram may be inappropriate or unclear; understands the underlying mathematical ideas; uses mathematical ideas effectively.
Serious Flaws but Not Nearly Satisfactory: Rating = 3 Begins the problem

appropriately but may fail to complete or may omit significant parts of the problem; may fail to show full understanding of mathematical terms; response may reflect an inappropriate strategy for solving the problem.

Inadequate Response
Begins, but Fails to Complete Problem: Rating = 2 Explanation is not understandable; diagram may be unclear; shows no understanding of the problem situation; may make major computational errors.
Unable to Begin Effectively: Rating = 1 Words do not reflect the problem; drawings misrepresent the problem situation; copies parts of the problem but without attempting a solution; fails to indicate which information is appropriate to problem.
No Attempt: Rating = 0

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This guide was produced by PBS. Project Advisors: William Badders, Cleveland Public Schools Bonnie Barr, State University of New York at Cortland Rodger Bybee, National Research Council Joseph Carter, Draper Elementary School Sheila Dunston, New York City Public Schools Irene Eckstrand, National Institutes of Health Gerald Foster, DePaul University Douglas Lapp, Smithsonian Institution Lawrence Lowery, University of California at Berkeley Joan McShane, Jefferson Elementary School Lisa Nyberg, Brattain Elementary School Dennis Schatz, Pacific

Science Center Gloria Tucker, Beers Elementary School JoAnne Vasquez, Mesa Public Schools Gerald Wheeler, National Science Teachers Association Special thanks to the following persons for their advice in the development of this guide: Barbara Bourne, University of Maryland Larry Flick, Oregon State University William McDonald, Montgomery County Public Schools Writer: Stephanie Dailey Copy Editors: Jennifer Johnson Beth Van-Spanje

The SCIENCELINE video series was produced by Thirteen/WNET. Funding for PBS SCIENCELINE was provided in part by the Carnegie Corporation of New York. For more information on PBS SCIENCELINE, visit http://www.pbs.org/scienceline/