# INTRODUCTION

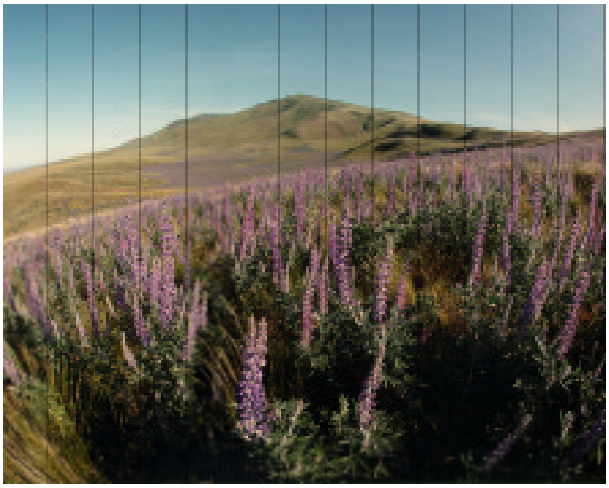
The Partnership for Arid Lands Stewardship (PALS) believes that studying the ecology of the Columbia Basin can help students learn important science knowledge, acquire the skills of science, and develop important scientific habits of mind. Through these ecological learning experiences, students will learn to read with comprehension, write with skill, communicate effectively, and apply mathematics and science knowledge and skills.

The following sections briefly describe PALS' mission related to environmental science education programs and how these programs align with Washington State standards for science and environmental education.

The section also outlines the state Essential Academic Learning Standards (EALRS) and describes how the study of arid lands can help students achieve these standards. Information is provided for teachers on an instructional model, classroom assessment, and approaching arid lands ecology in the classroom.

*"The terms and circumstances of human existence can be expected to change radically during the next human life span. Science, mathematics, and technology will be at the center of that change—causing it, shaping it, responding to it. They will be essential to the education of today's children for tomorrow's world."*

*—American Association for the Advancement of Science*



*"It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others."*

*—American Association for the Advancement of Science*

# SCIENCE Education

PALS supports environmental science education that parallels the way scientists and engineers uncover knowledge and solve problems. Using the Columbia Basin, including the Hanford Site and other natural research areas, PALS seeks to immerse students and teachers in live science experiences that build ecological content/concept knowledge, encourage the use of important science skills, and promote the development of scientific habits of mind.

As part of PALS, learners participate in hands-on/minds-on learning activities that help them meet state EALRs; construct their ecological science knowledge through inquiry and problem-solving activities; understand the interrelationship of science and technology; use cooperative strategies to answer questions and solve problems; and link their ecological science knowledge and skills with other disciplines.

## Linking to Washington State Academic Standards

Washington EALRs are based on four goals. These goals call for students to:

- read with comprehension, write with skill, and communicate effectively
- know and apply the principles of mathematics, sciences, civics, history, geography, the arts, and health and fitness
- think analytically and solve problems
- understand the importance of work and how it relates to academic excellence.

Specific and challenging standards for what students should know and be able to do in the academic areas listed above have been set. Classroom and statewide assessments are being developed to measure student progress toward these standards. Students and schools are being held accountable for results.

Currently, assessments have been or are being developed for reading, writing, communication, mathematics, and science. The Essential Learnings (ELs)—what students are expected to know and be able to do before they leave the K-12 system in Washington State—for these five academic subjects are listed by subject in the box on the next page.

## Classroom Approach

This section provides information on classroom assessment and instruction based on the ELs and describes a continuum of learning experiences you can use in classroom instruction. An example of how you can apply these experiences using arid land ecology also is described at the end of the section.

## Essential Learnings

***Reading***
The student
- understands and uses different skills and strategies to read
- understands the meaning of what is read
- reads different materials for a variety of purposes
- sets goals and evaluates progress to improve reading.

***Writing***
The student
- writes clearly and effectively
- writes in a variety of forms for different audiences and purposes
- understands and uses the steps of the writing process
- analyzes and evaluates the effectiveness of written work.

***Communication***
The student
- uses listening and observation skills to gain understanding
- communicates ideas clearly and effectively
- uses communications strategies and skills to work effectively with others
- analyzes and evaluates the effectiveness of formal and informal communications.

***Mathematics***
The student
- understands and applies the concepts and procedures of mathematics
- uses mathematics to define and solve problems
- uses mathematical reasoning
- communicates knowledge and understanding in both everyday and mathematical language
- understands how mathematical ideas connect to other subject areas and real-life situations.

***Science***
The student
- understands and uses scientific concepts and principles
- knows and applies the skills and processes of science and technology
- understands the nature and contexts of science and technology.

## Classroom Assessment and Instruction

Because students now are accountable for a particular set of knowledge and skills, planning for instruction should start with assessment. The targets for student learning that will result from the instructional experience should be clearly identified. What is it we want students to know and be able to do? These student learning targets should be directly tied to ELs.

Once the student learning targets are identified, they need to be categorized. Are they a knowledge target? A reasoning target? A skill? A product? An attitude? Categorizing targets is important because the type of evidence of student learning (e.g., observable behavior) you will look for changes with the type of learning target. And, the tool you use to collect the evidence will change, too (e.g., essay, observation, performance task). Table 6.1, the Assessment Planning Matrix (ESD 105 - Feb. 1998), is a useful tool for identifying learning targets, observable behaviors of learning, and assessment tools. Table 6.2, Links Between Learning Targets and Assessments Methods, can help you choose the most appropriate tool for assessing different learning targets.

**Table 6.1**. Relationship of Assessment, Teaching and Learning—Assessment Planning Matrix

| **Student Learning** (tied to the ELs) | **Type of Target** Knowledge, Reasoning, Skills, Product | **Evidences** Observable Behaviors | **Assessment Tools** Essay, Performance, Observation, etc. |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Although the ELs have been set, school districts (e.g., administrators, teachers, and parents) still decide how these ELs can best be achieved. Each district/teacher decides on a program of instruction that will help students meet ELs. Community partners, such as PALS, can assist schools in these efforts by helping them provide powerful learning experiences that are aligned with state academic standards.

## Powerful Learning Experiences

PALS believes a range of learning experiences exists (from less powerful to more powerful). The more powerful the learning experience, the greater the learning. These learning experiences engage the hands and the minds of the learner. Table 6.3 illustrates this range of learning experiences.

When you couple clear learning targets, appropriate assessments, and powerful learning experiences you provide the learner with the greatest opportunity to

**Table 6.2**. Links Between Learning Targets and Assessment Methods

| Target | Selected Response | Essay | Performance Assessment | Personal Communication |
|---|---|---|---|---|
| Knowledge mastery | Strong match: multiple-choice items, true/false items, matching exercises short answer fill-in items | Written answers in paragraph form can show elements of knowledge, but experts advise against using essay here | Not a good choice for this target | A good match but this can be a VERY time-consuming option |
| Reasoning proficiency | Can assess some patterns of reasoning | The real strength of essay assessment through analysis, comparison, drawing interferences, and/or critical thinking | Can watch students solve some problems or infer from their products | This is a strong match; can ask students probing questions about reasoning |
| Skills | Can assess mastery of knowledge but can't rely on this method to tap the skill itself | | Can observe and evaluate skills as they are being performed | Strong match when skill is oral communication |
| Ability to create products | Can assess mastery of knowledge of the ability to create a quality product but not the product itself | | Strong match for proficiency in steps of product development and the product itself | Can probe for procedural knowledge of quality products but not the product quality |
| Dispositions | Can tap into student feelings | Can tap into the attitudes, interest, and levels of motivation | Can only infer dispositions from behavior and products | Strong match; best way to find out from student about their feelings |

(Source: Stiggins, Richard J. (1977). *Student Centered Classroom Assessment.* Columbus, Ohio: Prentice-Hall).

**Table 6.3**. Powerful Learning Experiences

| | |
|---|---|
| Most powerful | First hand (the real thing)<br>Simulation (based on the real thing) |
| ↕ | Hands-on (often out of context—no minds-on) |
| Least powerful | Second hand (interpreted by something or someone)<br>Third hand (symbolic) |

acquire the knowledge or develop the skill called for in the ELs. How something is learned is as important as what is to be learned. PALS believes any program of science instruction should reflect the relationship between science and technology, as shown in Figure 6.1. Once learning targets are identified, PALS supports using the teaching/learning model, recommended by the

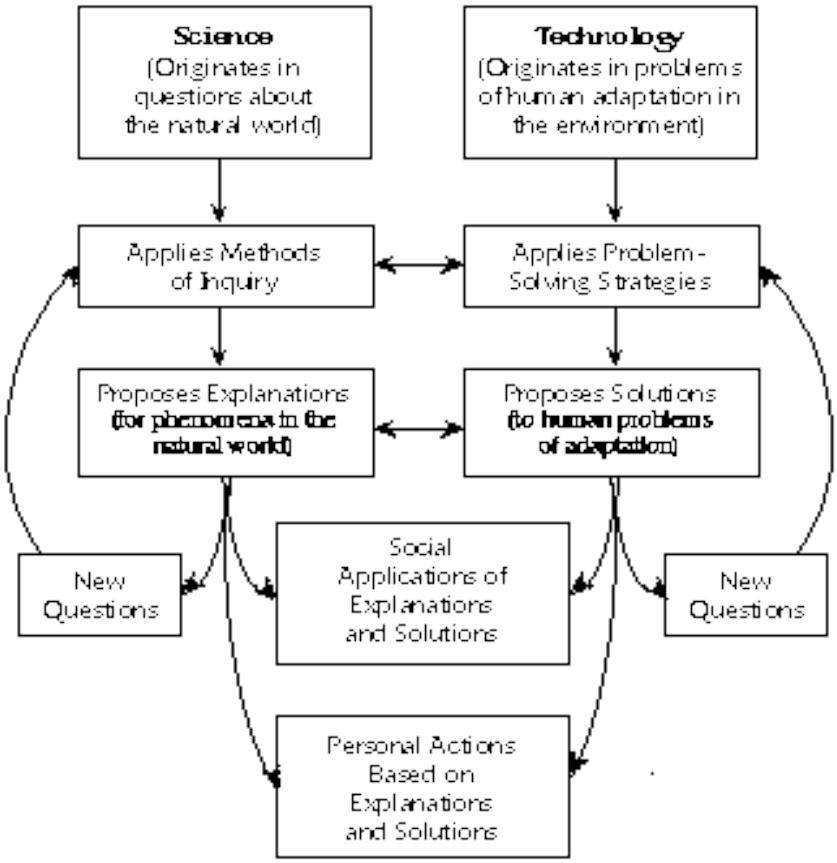



**Figure 6.1**. The Relationship Between Science and Technology and their Connection to Educational Goals

National Center for Improving Science Education (NCISE), to help students achieve these targets. The NCISE model parallels the way scientists and engineers uncover knowledge and solve problems. This teaching model is shown in Figure 6.2. Stages of the teaching/learning model are described in Figure 6.3.

## Using the Teaching/Learning Model

The four stages of the teaching/learning model recommended by NCISE parallel the approach taken by practicing ecologists both in research and in applying science to solve problems.

**Stage 1—Invite** . True learning begins with a question or problem in the mind of the investigator. Teachers can invite students to learn by posing problems or by stimulating questions in students' minds.

**Stage 2—Explore, Discover, Create** . This stage focuses on investigating the research problem scenario. Here, the teacher provides students with the materials, methods, and procedures they need to observe, collect data, and begin organizing information.

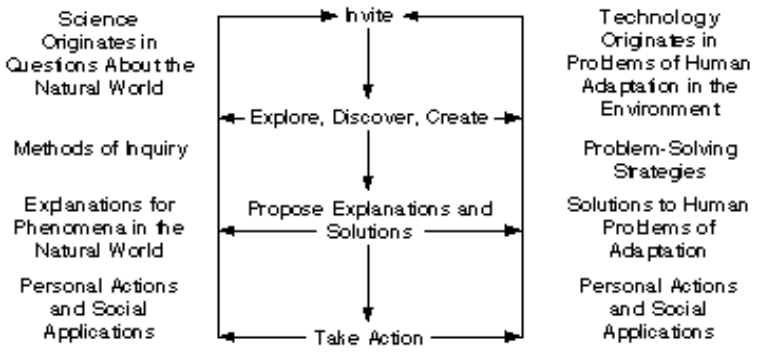



**Figure 6.2**. The Teaching/Learning Model

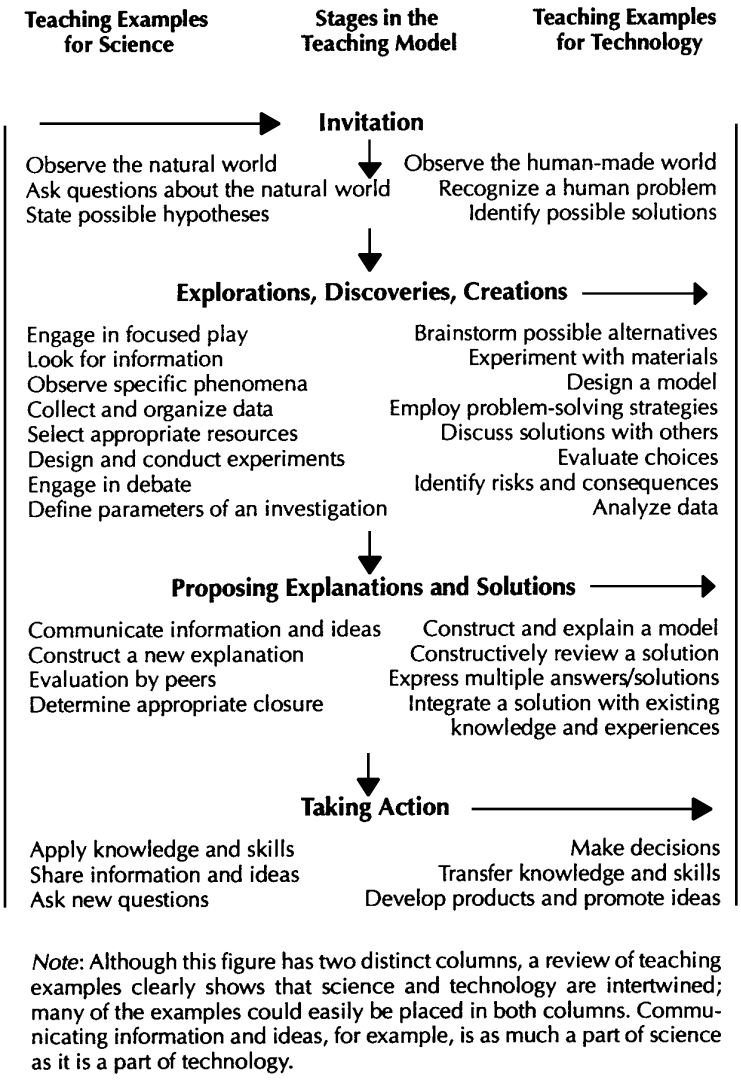



**Figure 6.3**. Stages of the Teaching/Learning Model

**Stage 3—Propose Explanations and Solutions** . In this stage, teachers help students refine their understanding of the data they collected. Through group discussions, students learn to propose, evaluate, and accept alternative viewpoints, to listen and question, and to persist in seeking satisfying explanations for the data they collected.

**Stage 4—Take Action** . In stage 4, students apply new knowledge acquired to the problem scenario. Students determine the uncertainty and ambiguity associated with their results and recommend further research to be conducted or identify additional questions. The student research group prepares a product (e.g., oral or written presentation) that demonstrates their knowledge/skills.

## The Laboratory Journal

*(The following section was written by Dr. Irene D. Hays. It was excerpted from Hays, Irene D. 1982. "Teaching Writing in the World of Science and Technology." National Education Association Washington, D.C.)*

"If a child is to keep alive his inborn sense of wonder...he needs the companionship of at least one adult who can share it, rediscovering with him the joy, excitement, and mystery of the world we live in."

—Rachel Carson

Scientists, engineers, and technologists use a laboratory journal as a tool for written communications. The journal becomes a permanent record of collected data, experimental results, and conclusions. Scientists also use the laboratory journal to help them in the process of thinking-out a problem, for asking questions, making speculations on paper, and clarifying hazy issues or concepts.

For students, a laboratory journal is a place to accurately record what they see and do; a place to record what they THINK about what they see and do; and a place to ask questions about the experiences. Students' use of the laboratory journal can be a novel experience for them. It also can become a symbol of scientific discovery and learning, a way students can relate to and identify with scientists. After using the laboratory journal, some students may be motivated to take the scientific concepts they have learned with them and continue the data collection, information gathering, and application process on their own.

### Convergent and Divergent Writing

The heart of the scientific process is observation and analysis of data or phenomena. Reporting the five senses is the basis for any science. Every sophisticated instrument, whether a microscope, telescope, or oscilloscope is but an extension of the five senses. Thus, training students in the objective reporting of data is basic science.

Convergent writing is related to this objective reporting of data. It is precise and provides procedural descriptions of an event. It is the kind of writing used to record, verify, document, and inform.

Divergent writing is free, flexible, fluent, and inquiring. It may contain emotional content because scientific discovery is an emotional as well as intellectual experience. Take the example of Archimedes. When he discovered what has come to be known as the Law of Floating Bodies, he reportedly ran into the street naked (they say) and shouted EUREKA!

True scientists seek not only to accurately describe an experience, but also to answer the "so what?" in relation to it—exploring alternatives, discovering new relationships, pushing out the limits of understanding. Divergent thinking/writing is related to this process of discovery, of answering the "so what?"

Divergent writing is vital to success in the scientific and technical world; it prepares the mind for discovery. Serendipity (the happy or lucky accident) can arise from a mind prepared by such thinking (prepared by such writing). Many scientists have actually "discovered" something while recording their thinking/speculations about their work in their journal.

In the final analysis, learning to write is learning to think. How students think about science and technology and feel about them are important, and they should be encouraged to express their feelings in the laboratory journal. Often times, journal writing is both convergent and divergent, even on the same page or in the same paragraph.

The "Egg Demonstration" activity on the following page shows one example of how two students responded to the same demonstration. It should help you understand the difference between convergent and divergent writing.

## Activity: Egg Demonstration

Imagine the following demonstration:

I stand before you with two oversized glass goblets each filled with clear liquid, and as you watch I sip from one glass and then the other, returning each to the table. I then pick up an egg from a carton to my right, I spin it carefully on the table to demonstrate its freshness. I then lift it and place it carefully into the first goblet. There it slowly sinks to the bottom. I pick up another fresh egg. I also spin it. It behaves much the same as the first. When it stops spinning I pick it up. I place it gently into the goblet of clear liquid. This egg bobs slightly and remains afloat.

Now if I should ask a group of you to write, describing what you have observed, your descriptions would fall generally into two categories. The first is represented by this excerpt of a student's writing in response to the egg demonstration.

*The teacher sipped liquid from each of two glass containers on the table. Each glass container had a 5-inch stem and a bowl-like top piece about 4 inches across at the mouth. The liquid was clear. Then the teacher picked up an oval-shaped whitish object, spun it clock-wise on the smooth tabletop, picked it up with his thumb and first two fingers on his right hand and dropped it into one glass container. The object sank to the bottom of the glass container, displacing an amount of water upward toward the top of the glass. He then repeated the procedure using a similar white object, placing it in the second glass container In the second case, the object floated near the mouth of the container. He then smiled and asked us to write down what we saw.*

The student's response to the egg demonstration is almost like a precise, procedural description of the event. It is focused, it is accurate, or tries to be. It is the kind of writing used to record, to verify, to document, to inform.

Other students would respond in a different, but equally valid way. I'll illustrate this second kind of writing by reading what another student wrote in response to the egg demonstration.

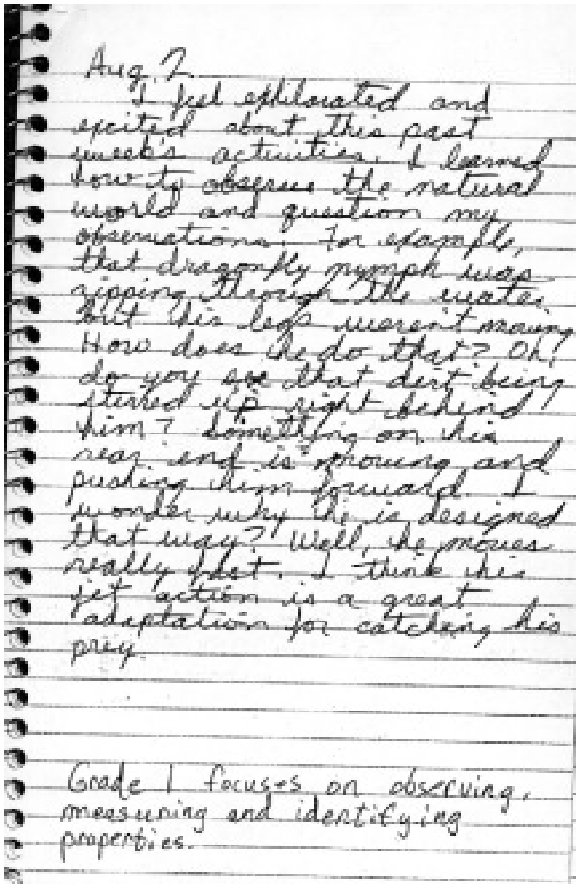
*It was a totally bizarre thing to see. In one cup an egg sank, in the other the egg floated. Incredible! I am stumped. Let's see, what do I know about eggs? Hard or soft, heavy or light. What makes the difference? The evidence of softness is in the spin. The spin of the egg before he dropped it, placed it in the cup, in each cup. Was one egg solid, real, the other weighted in some way, a visual replica of the first? Not likely. The liquid must be water or else the experimenter would not have dared to drink it, or would he? What do I know about floating? Heavy water, light water. Oh, an answer, a hypothesis. If both eggs are the same then there has to be something different about the liquid. If they are both the same liquid then the two objects, though alike as I see them must be made of different material. The water density must be different. What does this mean? What does this say about objects or humans floating in water, salted or fresh? What about ships? The design of them. Is the displacement different for different densities or the same? Only what this makes me feel is like a kid watching a magic show, the water scintillating, clear in lovely goblets.*

This student's response to the egg demonstration is freewheeling and exploratory. It's the kind of writing used to probe, to question, to learn. The essence of the scientific process is the ability to explore alternatives, to discover new relationships, to push out the limits of understanding. True scientists seek not only to accurately describe the experience, but to answer the question "so what?" in relation to it.

## Using the Laboratory Journal

When students keep detailed notes, the teacher, or specialist can step in, look at the notes and perhaps help access the process the student is following, and look for areas that may be causing problems in a classroom or field research project. The journal also gives the teacher a tool for evaluating the unit of study.

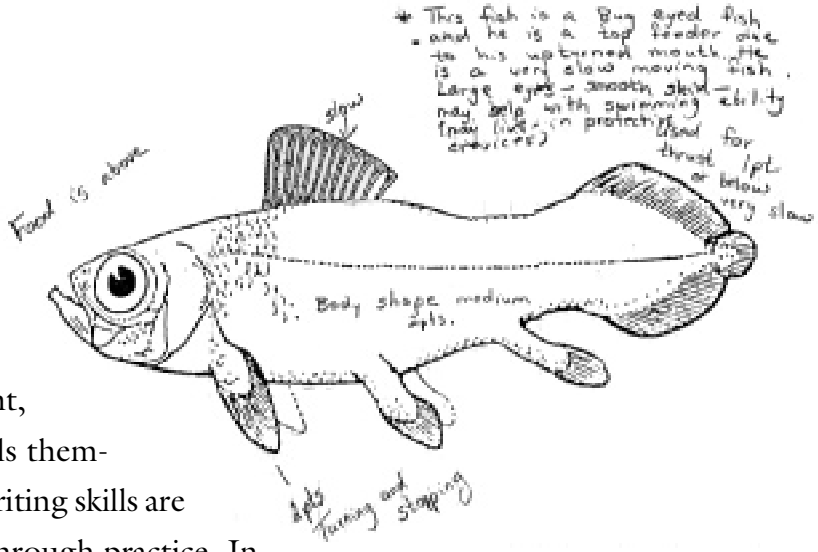
Specific rules for writing in a laboratory journal are not important. The main task is to motivate students to write what they are thinking, observing, or need to remember—information that will be useful for the future. Students can use the journal, as scientists do, to think out a problem, ask questions, or clarify concepts. The important task is to get them to write, draw, think, and collect data in a notebook. The illustrations included on the following pages show two student laboratory journal entries.


Aug. 7
I feel exhilerated and
excited about this past
week's activities. I learned
how to observe the natural
world and question my
observations. For example,
that dragonfly nymph was
zipping through the water,
but his legs weren't moving.
How does he do that? Oh!
do you see that dart being
shoved up right behind
him? Something on his
rear end is moving and
pushing him forward. I
wonder why he is designed
that way? Well, he moves
really fast. I think this
jet action is a great
adaptation for catching his
prey.

Grade 1 focuses on observing,
measuring and identifying
properties.

Journals used in research are bound so the numbered pages do not come out. Written items cannot be erased, and generally, any corrections are done with a single line drawn through the deleted word or words. For practical experience, a loose-leaf three-ring binder may be useful in learning to write in a science journal. With a binder, students can add extra pages and classroom handouts, or they can take out a specific page and turn it in to the teacher to read.

Keep in mind that the purpose of the journal is as a learning tool. Clear writing promotes




clear thinking. The emphasis of writing to learn is on learning content, not on writing skills themselves, although, writing skills are likely to improve through practice. In reading student journals, you should not dwell on grammar, spelling, or other technical aspects of language. The general rule should be: "If it does not interfere with clarity of meaning, ignore it."

As students become more familiar with their ability to use their journal, and as they observe other students organizing, writing, drawing, and outlining, they will develop an intrinsic sense for the usefulness of their writing and their ability to clearly present what they have learned. The journal will then become for them a reference for following a procedure and for showing other students and the teacher what's been taking place in the classroom, laboratory, and in the field. Successful student journals are an accountable indication of accomplishment when students have finished a classroom activity or research project.

It is essential that you check student journals a minimum of once every week or two. Make sure you provide them with written feedback, comments, or advice on their thinking/learning process.

**Journal Write Prompts**

1. If you had one question to ask the author, what would it be and why?
2. What did you read that you didn't understand?
3. Write down what is bugging you.
4. What did the article make you think of?
5. What did you learn from this article that you didn't know before?
6. Do you agree or disagree with the article?
7. What was the most useful thing you heard in the last 30 minutes?
8. What puzzles you about this article?
9. What makes sense to you about this article?

## Journal Writing Activities

You will need to promote using the laboratory journal because many students have learned to think of writing as a difficult task. Daily writing is essential in the science class for students. A number of activities follow that can be used to stimulate student writing.

**Journal Write** : *The purpose of this exercise is to get as much information and as many questions onto paper as quickly as possible. Some information may be facts students want to remember, or questions students would like to have answered because an article they read had insufficient information, or the student didn't have sufficient background to understand it.*

- Distribute a short article (1-2 pages depending on grade level) from a current periodical to each student. Give students a specified period of time (i.e., 5 minutes) to read the article. At the end of the time period, tell students to stop reading even if they all haven't finished the article. As they begin to write, give them some writing prompts (see box above for examples). You can use an overhead projector, the white board, or hand out the prompts on paper. When time is up, have students count the number of words they wrote, and record them at the bottom of the page.
- After a journal write, have students exchange notebooks with a partner. Partners read each other's journals and make comments on the page about the writing (i.e., "Looks great!" or "I wish I could organize my thoughts as well as you did," or "I found the answer to your question a little later in the article.").

- Have partners discuss the article or their writing for a short time. These partner activities allow students to learn from other students' strengths and insights as to how they accomplished the task.
- Have a whole class discuss the article and writing experience. The article could inspire students, and learning about a scientific concept would be a group motivator.
- Use questions evolving from the journal write for student research. Have students find a resource in the community to answer a particular question, or invite a local "expert" to come to class and talk about the question.
- To vary the journal write activity, have students jot down what they already think they know about a topic or article they will read. They can also write questions they hope the article will answer or predict the author's major points. After reading the article, students can then respond to what they wrote.

**Student Benefits of Using the Laboratory Journal**

The journal

- enlarges student understanding of science and technology
- encourages participation through a success-oriented activity
- helps develop clear thinking
- encourages and illustrates importance of writing across the curriculum
- provides open and risk-free communication with the teacher
- provides acceptability to teacher for work done
- emphasizes importance of writing now and in the real world
- can be used as a resource in an open-journal test
- gives students a reason to write.

**Daily Write** : *The purpose of this activity is to get students to write their thoughts and ideas in the journal. It is also an activity for teaching "thinking on paper," so students become aware of thoughts that occur to them day to day and the thought patterns that might be forming.*

- Ask students to answer the following questions: 1) What did I do in class the last time we met? 2) What did I see or learn about science or arid lands

### Teacher Benefits of Using the Laboratory Journal

The journal

- provides insight into students as individuals and their understanding of scientific content/skills
- provides optimum teaching opportunity (if students can write about and clearly explain something, teachers know they have taught beyond memorization for a test)
- promotes "active" teaching; forces teachers to examine course work and their efforts more closely
- builds rapport between teacher and student; makes learning a joint effort
- provides a future resource for teacher, students, and classmates
- provides an effective communication source to encourage students
- provides accountability for teacher assessment of individual students and the entire class.

ecology since the last time we met? 3) If I could ask only one question related to arid land ecology, what would it be? Challenge students to find answers to their questions by talking to a local expert, consulting a resource book, or doing a search on the World Wide Web. When the question is sufficiently answered, have students write this information in their journal.

**Weekly Summary** : *During these weekly reviews, students may discover what learning is taking place over time or what concepts continue to be a problem. They can sort out some variables of a recurring problem on a specific answer to a problem. (i.e., my sagebrush starts continue to die. I need to learn more about how much light they need and how much water.) These summaries can also zero in on specific item(s) that may warrant teacher attention.*

- Have students spend 10 minutes each week summarizing their week's work. Use the following journal prompts:

  *What did you do this week?*

  *How did it go, good or bad, and why?*

  *Who did you work with, and what was the result?*

  *What did you learn from your work?*

  *What are your next steps?*

  *What are your frustrations and your successes and why?*

## Writing in the Field

This kind of writing involves recording the information gathered while on a field trip and/or conducting research in the field. A field journal or field notebook is an important tool for scientists whose research is based in the out-of-doors. Many scientists who do field research have two journals—a small journal they carry with them to record notes in the field (weather, drawings of plants and animals, temperature) and a second journal that is used to elaborate on their field notes. The office or laboratory journal is the final record of observations; data; and specific information recorded about plants, animals, or geology (the color a bird, the number of deer observed, flowers in bloom at a specific site).

Essential information to include in a field journal:

- date, day, time, location
- weather
- description of the area
- description of what you are observing
- number and names of the plants or animals that are observed
- description of what an animal is doing
- drawings or photographs of animals and plants observed.

You can develop data sheets for students that will assist them in taking good notes in the field. If hard-cover journals are not available, you can have students attach their data sheets to a clipboard. Back in the classroom, students can add additional information to their field notes. You may want to have students use a loose-leaf journal; that way it is easy for them to add completed data sheets, drawings, photographs, and additional information they find on the subject they were learning about in the field. Sample journal writing activities for the field and classroom follow.

## Activity: Sustained Writing

**Purpose:** To improve students' observation skills.

**Materials:** Journal or paper on clipboard, pen or pencil, 1/2-meter length of string per student (ends tied to form circle.)

**Procedure:**

1. In an outdoor school site area, instruct the students to place a string in a circle on the ground. (Be sure students are separated by enough area so they will not be distracted.)
2. Students will write for a minimum of 10 minutes, describing everything within the circle.
3. Have the students go over their own (or another student's) writing, and underline the observations that are detailed and specific.
4. Discuss the observations with the class.

**Discussion Questions:**

- How did you feel about the assignment before you began? Did you think it would be easy, difficult, boring?
- Was the timed writing an easy task? Why or why not?
- Compare your observations to those you made at the end of the 10-minute assignment. Which are more detailed? Why?
- How might this exercise help you in observing the shrub-steppe?

**Extension:** Repeat the activity at different times of the year with the same students in the same space. How has the area they are studying changed?

(Source: *Particles and Prairies: The Fermilab Prairie Savannah Curriculum*, Fermi National Laboratory, Batavia, Illinois.)

## Activity: Candle Eating

**Purpose:** To improve students' observation skills.

**Materials:** One potato, one paring knife, several hazelnuts (filberts not dry roasted), matches.

**Procedure:**

1. Before class, prepare "candle." Pare potato into candle shape (dip in "Fruit Fresh" or lemon juice to retain color. Wrap in plastic or place in Ziplock bag until ready to use.) Carve a "wick" out of a hazelnut. Place on "candle."
2. Display "candle" to class. Light wick and have students record in their journal what they observe, or ask for oral observations (Hazelnut has enough oil to support a flame.)
3. If you had the students write, after 1 minute ask them to share their observations.
4. Bite off the top of the candle and eat. (You probably won't want a BIG bite.)
5. Discuss.

**Discussion Questions:** These can be discussed orally or the answers written in the students' journal.

1. Why were students giving "candle" characteristics to a potato and a hazelnut?
2. Think about some occurrences in nature that are not what they seem to be. Name two.
3. Define a good observer.
4. Why is it important for a researcher to be a good observer?

(Source: *Particles and Prairies: The Fermilab Prairie Savannah Curriculum*, Fermi National Laboratory, Batavia, Illinois.)

## Journal Resources

Do The Write Thing, Elizabeth Everett, October 1994, *The Science Teacher*, National Science Teachers Association, Washington, D.C.

Guidelines for Writing Assignments in Content Areas, Allan Dittmer, April 1996, *English Journal*, pp. 56-63.

Leaders for Writing Know the Whys, Hows, and Dos, R.N. Fortenberry, 1987, *Clearing House*, Vol. 61, pp. 60-62.

*Materials Science and Technology Teacher Handbook*, 1995, Pacific Northwest Laboratory, Richland, Washington.

*Particles and Prairies: The Fermilab Prairie Savannah Curriculum*, Fermi National Laboratory, 1992, Batavia, Illinois.

*The Amateur Naturalist*, Gerald Durrell, 1988, Alfred E. Knopf, New York.

The Learning Power of Writing, R. Walsh, 1987, *English Journal*, pp. 22-27.

*The Nature Company Guides—Birding*, Joseph Forsha, Steve Howell, Terence Lindsey and Rich Stallcup, 1994, Time Life Books, New York.

*Writing the Laboratory Notebook*, H. Kanare, 1985, American Chemical Society, Washington, D.C.

Writing as a Learning Device in Calculus, C.L. Mett, 1987, *Mathematics Teacher*, pp. 534-537.

*Writing to Learn Across the Curriculum*, J. Myers, 1984, (Fastback #209), Phi Delta Kappa Educational Foundation.

Writing: Gaining Emphasis in Science and Math Classes, R. Rothman, 1987, *Education Week*, May 13, 1987, p. 6.

Special thanks to Dr. Irene Hays, Associate Director, Science Education Programs, Pacific Northwest National Laboratory for the work she has done on writing and the scientific process.