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ABSTRACT

Designed to assist teachers in the improvement of science instruction at the secondary level, this first of a three part series of guidebooks from the Opportunity Systems in Science and Technology Study project focuses on the topic of scientific literacy. Ideas and materials for inservice workshops are provided under the categories of: (1) what is scientific literacy (defining and discussing the five components of scientific literacy); (2) fostering scientific literacy (suggesting instructional methods and pointers for effective use of scientific literacy components); (3) why is scientific literacy important (highlighting the benefits of using scientific literacy components); and (4) training notes (presenting materials that can be used in inservice workshops for high school science teachers). (ML)

Secondary Science and Mathematics Improvement Program

WHAT IS SCIENTIFIC LITERACY?

A Guidebook for High School Science Teachers

Opportunity Systems in Science and Technology Study Series

Volume I

Larry F. Guthrie

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PREFACE

This guidebook is the first of a series of teacher inservice materials produced by the Secondary Science and Mathematics Improvement (SSAMI) Program at the Far West Laboratory for Educational Research and Development. The goal of the SSAMI Program is to study and improve instruction in science and mathematics at the secondary level. During the 1983-1984 school year, one of the ongoing projects of SSAMI was the Opportunity Systems in Science and Technology Study. This guidebook -- and two to follow -- represents an effort to translate the background and findings of that study into a set of materials that provides teachers not only with new knowledge about the goals of science instruction and its current practice, but also with practical recommendations for moving each teacher's current practice closer to these goals. A set of training instructions, to be used in conjunction with each guidebook in workshop meetings, also is provided.

We wish to thank Dr. John Taylor, Teaching and Learning Division, National Institute of Education, for his support in this and other work. His interest in exploring innovative ways of approaching the problems that confront educators is appreciated.

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WHAT IS SCIENTIFIC LITERACY?

BACKGROUND

With today's renewed focus on improving the education of our youth, science instruction is receiving its fair share of attention. Some of this attention is fueled by a concern that the United States maintain a large pool of scientists and, thus, its competitive position worldwide. There also is attention on the need for all citizens to be scientifically literate in our increasingly technological society. But what does being scientifically literate really mean? What can you do to help your students achieve scientific literacy?

Take a few moments now to think about what the term "scientific literacy" means to you.

Scientific literacy is a term used to refer to a set of goals shared by most science education experts. The term was first used in the 1950's as a "rallying symbol" without any clear definition. By now, many science education experts have given their own definition of scientific literacy. Most of these definitions have much in common. Taken together, we can think of scientific literacy as a framework made up of five components.

THE FIVE COMPONENTS OF SCIENTIFIC LITERACY

The scientific literacy framework consists of five components:

1. **Explaining the Content of Science.**

2. **Relating Content to the Social Historical Process of Science.**

3. **Relating Content to the Reasoning Process of Science.**

4. **Relating Content to the Societal Impact of Science.**

5. **Relating Content to the Personal Use of Science.**

As you can see, the first component concerns being able to communicate the content (i.e., terms, facts, and concepts) of science. This is the primary goal of science instruction, both past and present. The remaining components are termed "relating" components. These components represent four different contexts for the content of science. In short, when presenting any particular topic in science, it is possible to refer to one or more of these relating components to provide a larger context of meaning. This notion of providing a context of meaning will become clearer as you read along.

The relationship among the five components of scientific literacy is presented in Figure 1. This figure shows the central role of Explaining the Content of Science. Each of the relating components is portrayed as a potential source for providing a context within which the content of science can be learned and understood.

> Can you think of some occasions when your students have displayed familiarity with one or more of the relating components of scientific literacy?

DEFINING THE FIVE COMPONENTS OF SCIENTIFIC LITERACY

Students' knowledge of the five components of scientific literacy can be fostered through several means. For example, most students probably pick up some understanding of scientific phenomena and the context for these phenomena through experiences outside of school -- whether by their own natural curiosity, visiting science museums, or by watching a science series on televison. When students take science courses in school, there also are numerous ways they may become scientifically literate. They may learn scientific literacy through the textbooks that they read, the assignments they complete, the films they watch, the non-graded activities they participate in, and through what they hear in presentations made by you or guest speakers.

In this pamphlet, we want to concentrate on defining scientific literacy in terms of some ways that <u>teachers can foster it with their students</u>. Here, it helps to think in terms of those aspects of your classroom and teaching where you can exercise the most control. For example, you do not have much control over the content of your main textbook and supplementary materials. Thus, if your current textbook does not consistently address at least one of the scientific literacy relating components, your textbook is not an important scientific literacy resource for your students. In contrast, the presentations and work assignments that you give to your entire class are aspects of your instruction that you can shape to your goals. Thus, if you make a point to address the scientific literacy components in your presentations and work assignments, these presentations and assignments become an important avenue through which your students can achieve scientific literacy.

Let us turn, then, to reconsidering each of the five components of scientific literacy. Below we define each component in terms of the kinds of steps you can take as a teacher:

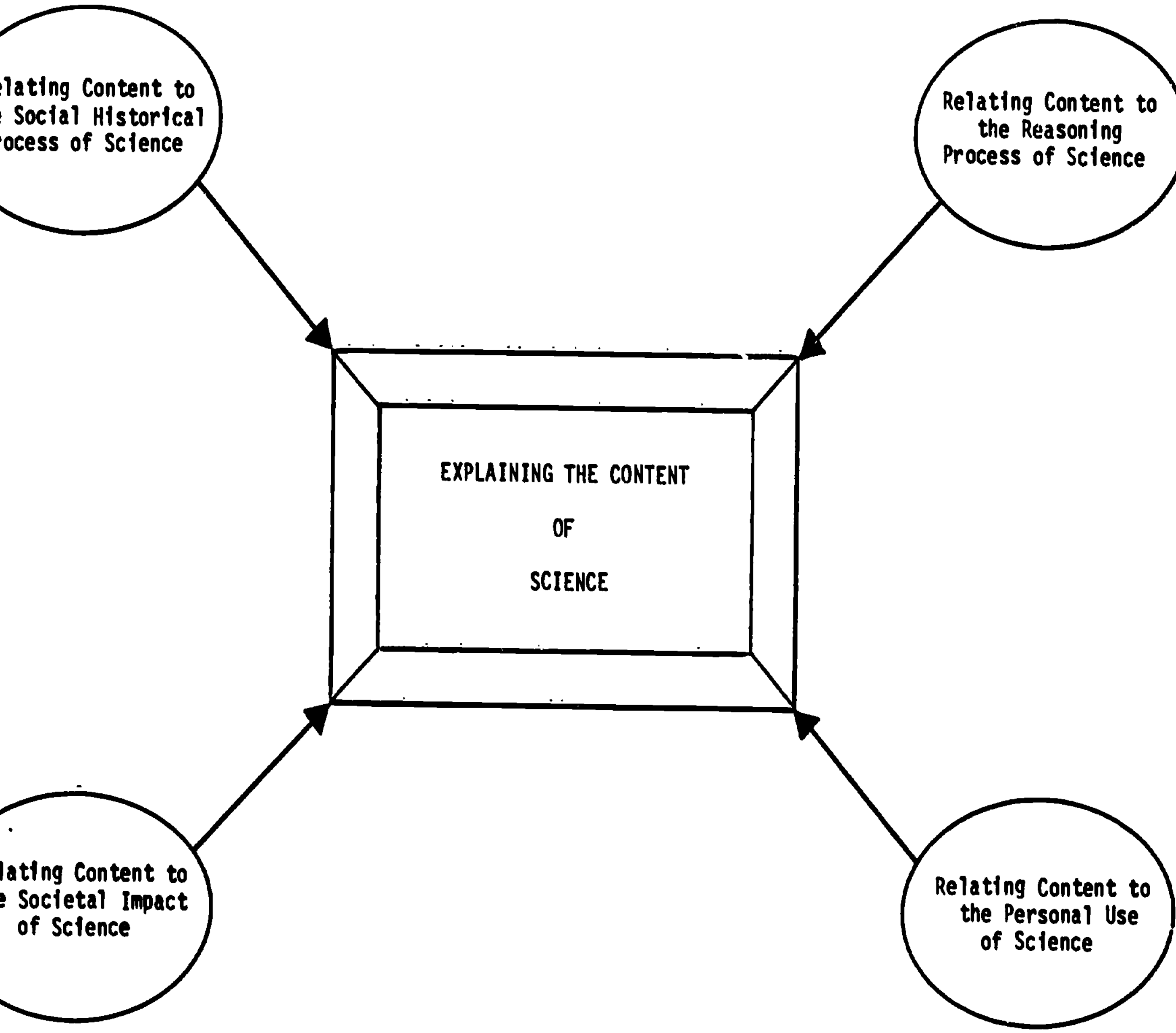

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Figure 1. The Scientific Literacy Framework

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Explaining the Content of Science

Terms, facts, and concepts are fundamental to specific science topics. This basic content is the foundation for understanding many of the essential phenomena of earth's life systems. For example, if you are teaching students about the digestive system of mammals, the names and functions of several organs as well as the role of digestion are basic content you need to explain.

Relating Content to the Social Historical Process of Science

Scientific knowledge is not acquired through the discovery of sets of preexisting facts; rather, it accumulates as the work of individual scientists is recognized and accepted by other scientists and the public at large. Both, the scientific community and the lay public are often slow to recognize and assimilate new discoveries. You can communicate the social historical process of science in specific or general terms. In specific terms, you can refer to the contributions of particular individuals in history and the way that these contributions took hold. For example, you could organize a topic on genetics using the history of the work of Mendel and his scientific community. In general terms, you can indicate that some aspects of scientific knowledge are the collective work of many individuals addressing similar problems, without mentioning specific scientists.

Relating Content to the Reasoning Process of Science

Scientific knowledge is accumulated through a set of agreed upon methods and standards, and not in an arbitrary fashion. You are relating to this component when you take a particular topic and illustrate how you can learn about the topic by observing natural events and formulating and testing hypotheses. In the course of such a presentation, you may also have occasion to cover the concepts of deductive and inductive reasoning, randomness and probability, as well as the tools and methods of measurement.

Relating Content to the Societal Impact of Science

Scientific knowledge in a particular topic area has led to technologies that, in turn, influence society. Often, you can make a direct link between a technological product (e.g., a new fertilizer) and its social consequences (e.g., more productive farming, increased land use, more pollution). You also will find that this component lends itself especially well to the presentation of more than one point of view (e.g., the advantages and disadvantages of organ transplants), thus modeling aspects of a decision-making process that students may apply in their role as citizens.

Relating Content to the Personal Use of Science

Science has implications for students' everyday lives. Here, it is possible to illustrate that scientific knowledge in particular topic areas can help students make informed decisions about their own health and their selection of food, household goods, and sources of energy.

> Can you think of an instance where you used one of the relating components to help organize your presentation of one science topic?

In the next section, we will suggest some fruitful approaches for using the scientific literacy framework with your students. Then, we will present some important reasons for using scientific literacy in the high school science curriculum.

FOSTERING SCIENTIFIC LITERACY

INSTRUCTIONAL METHODS

There are several instructional methods you can use to foster your students' understanding of the five scientific literacy components. First, you can address any of the five components in your verbal presentations to students through either short statements or longer "lecture-like" talks. A second way to develop students' understanding of scientific literacy is to write key points on the board and ask students to answer questions. A third technique is to get a discussion started among students about the connection between lesson content and the relating components. Finally, you can give your students assignments that tap their memory and understanding of the five scientific literacy components.

But helping your students to become scientifically literate requires **more** than just **referring** to the five components. You will become a more effective communicator of scientific literacy if you make scientific literacy one of your major instructional goals and systematically plan for how to include scientific literacy in each of your course topics. Below are several pointers for how you can be most effective in using scientific literacy.

POINTERS FOR USING SCIENTIFIC LITERACY

- <u>Introduce your students to the scientific literacy framework at the beginning of the school year.</u> By familiarizing your students with the structure and meaning of the scientific literacy framework, you are increasing the likelihood that they will recognize and comprehend the connections you make between science content to the relating components. At the same time, you may be encouraging students to make their own connections to the relating components as they proceed through the course content.

- <u>Build up your own scientific literacy resource folder.</u> An analysis of today's most popular science textbooks indicates that they are devoted almost entirely to explaining science content, rarely making reference to any of the relating components. Thus, it probably will be necessary for you to compile your own set of scientific literacy resources. Here, the easiest approach is to set aside a special folder or notebook where you can place materials and ideas that are potentially relevant to the topics you already teach. If you place these materials and ideas in the folder as you come across them, you will have valuable help when you sit down to plan your topics.

- <u>Before you begin, plan what parts of the scientific literacy framework you will use and how you will use them.</u> Deciding how to make the connection between science content and the relating components requires some careful planning before you introduce your students to a new topic. For example, if you are planning to incorporate scientific literacy into the topic for the first time, you may have to locate some resources in addition to your standard set of materials (e.g., other textbooks, magazine articles, the encyclopedia). These resources should be used to help you decide which relating components you want to emphasize and which specific examples you want to use with your students. After you have decided on your emphasis and examples, you should outline your topic activities, indicating how you will use the relating components.

- <u>For each topic, focus on explaining content in the context of no more than two of the relating components.</u> It is possible to have too much of a good thing. If you plan a topic so that you make repeated connections to all four of the relating components, you risk overwhelming and confusing your students. Thus, it is preferable to select one or two of the relating components as the primary theme(s) for organizing your topic content. While this does not mean that you should avoid making connections to other relating components, it does mean that one or two relating components will receive more attention than the rest. If you are gearing your year's curriculum to the scientific literacy relating components for the first time, it may be best to limit yourself to one relating theme for a topic; furthermore, it may be best to select only a subset of your topics for revision. Clearly, it is preferable to address a few carefully planned topics rather than many poorly planned topics.

- <u>When you use a relating component, be explicit.</u> In other words, cue your students when you are using one of the relating components. This can be done by referring the students back to the scientific literacy framework. Also, it is important to consistently use the <u>language</u> of the components as a cue (e.g., "Now, let's stop and consider what this may mean for our current <u>society</u>.").

- <u>When you use a relating component, be consistent.</u> Once you select relating component(s) as your primary theme(s), it is important to carry the theme through the entire topic. This does not mean that you have to devote a large block of time to the relating component each day; rather, it means that you should not let your students lose sight of the significance of the relating component as an organizing context for the topic content. Thus, on some days, you may provide longer examples based on the relating topic, while on other days you may simply refer back to these examples or give short ones. This approach contrasts with the technique of giving occasional anecdotes during a topic. The sporadic use of anecdotes may actually confuse students rather than help them.

- <u>When you refer to the scientific literacy components in your presentations, reinforce students' understanding by asking them to think about the same components in their assignments.</u> To students, the assignments you give are the clearest indicators of what you actually value as a teacher. Performance on assignments usually accounts for most of their grades. Thus, while you may give attention to the scientific literacy relating components in your presentations, your students will pay little attention to these components in the long run unless your assignments reflect the same components. Thus, you should design or revise your laboratory, worksheet, and exam materials to include items that ask for students' understanding and interpretation of your chosen scientific literacy theme(s).

AN EXAMPLE

Teacher X teaches biology. Her next topic is on bacteria, viruses, and disease. When Teacher X sits down to plan this topic, she notes that the relevant chapter in her textbook makes brief mention of Pasteur for his work supporting the theory that bacteria affects fermentation and can cause disease. This leads Teacher X to consider the possibility of presenting the topic content on bacteria, viruses, and disease in terms of the work of several individual scientists (i.e. relating content to the social historical process of science). When Teacher X then turns to her scientific literacy resource folder and a few supplementary books, she finds that there are a number of historical events that can be used to give context to knowledge about bacteria, viruses, and disease. After some consideration, Teacher X sketches the following outline for herself:

(1) Introduce the topic with an overview of the beliefs past societies have held about contagious diseases (e.g., ancient Greece, Middle Ages, early 19th century). Emphasize that human diseases, particularly the outbreak of various epidemics, were a major impetus for scientists to begin looking for the agents of diseases. These agents turned out to be microorganisms. Two major categories of microorganisms are bacteria and viruses.

(2) Introduce and contrast the basic structure of bacteria and viruses. Compare both with the typical cell structure.

(3) Indicate that the current understanding of bacteria and viruses is the result of the work of many individuals, beginning in the 19th century. Take four individuals as examples and describe their work.

(a) John Snow's work (1850s) in determining the manner in cholera is spread. He theorized that this disease was caused by microorganisms, but his work did not confirm it.

(b) Robert Koch's work (1870s) (also carried out elsewhere) in isolating the bacteria causing anthrax and tuberculosis. Koch was able to observe the bacteria under the microscope (unlike Snow). Koch's unique contribution was to develop methods for studying bacterial growth in the laboratory.

(c) Louis Pasteur's work (1860s-1880s) on germ theory (refer back to topic when spontaneous generation covered) and immunization. Pasteur took Koch's work further by developing a vaccine for anthrax. Also, he developed a vaccine for rabies, which is a virus. However, Pasteur did not realize that he was dealing with an organism distinct from bacteria.

(d) Viruses were not actually identified until the work of Frederick Twort. Twort was growing colonies of bacteria and found that something was destroying these colonies; thus, the first viruses discovered were those that attack bacteria.

(4) Go back and review the structure of bacteria and viruses, adding information about how they work to create disease, and what makes them good disease agents in terms of resisting the body's defenses.

(5) Indicate that while some bacteria cause disease, many bacteria serve beneficial purposes. Cite examples. In contrast, viruses cannot be considered beneficial because they inevitably cause the destruction of cells. Nonetheless, viruses have greatly helped scientists to understand the operation of genes.

With this outline sketched out, Teacher X goes on to think about the kind of activities she can use to convey the above information and engage students in it. Teacher X decides to present the information initially in several recitations spaced throughout the week. Teacher X makes a point to think of the kinds of questions she can ask to get students involved in the recitations. She writes down some potential questions that will tap students' comprehension of the material and their own knowledge of various diseases and their transmission.

In terms of assignments, Teacher X has several thoughts. First, she thinks of using last year's worksheet that asks students to identify and label the structure of bacteria and viruses. She plans to add a couple of questions to the worksheet that asks students to consider the tools scientists needed to study these organisms and what led them to view these organisms as distinct from cells. Teacher X then considers developing an entirely new worksheet that will give students a set of factual data about a hypothetical disease and asks them to indicate what methods they would use to track and identify the disease agent. Teacher X notes that this is an opportunity to reinforce the social historical process of science if she also asks students to contrast their methods with those used by Snow and Koch. Teacher X thinks of designing her final exam in a similar fashion. Finally, Teacher X considers the possibility of having students do individual research reports on a bacteriologist or disease that interests them. She decides to leave this open as an option, depending on the level of interest her students display.

WHY IS SCIENTIFIC LITERACY IMPORTANT?

Scientific literacy is often talked about as if it were a self-evident goal for science instruction. Simply saying that scientific literacy is a "good goal," however, is not enough to convince most teachers to go beyond teaching content and incorporate the relating components of scientific literacy into their curriculum. Improving students' understanding of scientific literacy is going to require extra planning, time, and resources; this may be a significant drawback to teachers as they feel increased pressure to be accountable for their students learning the "basic facts" of science. However, we take the position that fostering scientific literacy has several benefits that far outweigh any drawbacks. These benefits are as follows:

- The scientific literacy framework is an important organizational tool for the teacher. Scientific literacy is not just a goal for students. It also provides a conceptual framework within which teachers can define and organize their instructional objectives and activities. The scientific literacy framework gives teachers an "organizer" that is at a higher level than a list of, say, 20 life science topics. It also gives teachers the opportunity to decide, for each topic, the major reasons why the topic content is worth teaching to students (i.e. where it fits in the broader scheme of human endeavors). Thus, the framework lays the basis for a coherent and rational presentation of the topic content

- The scientific literacy framework is an important learning tool for students. It is known that in the natural learning process, both children and adults develop sets of different "mental schemas" based on their knowledge and experiences in the world. As people encounter new information throughout their lives, they place this information in existing schemas or else develop new schemes to accommodate it. Placing the information in schemes greatly increases the likelihood that the information will be retained in memory for a long period of time. The process of formal schooling is often at odds with this natural process; students are called upon to memorize information for which they have no existing schemas. By presenting students with the scientific literacy framework, teachers are giving students a schema that may help students "place" the topic content, thus increasing students' ability to memorize and recall the material.

- The scientific literacy framework helps students understand in what ways science content is meaningful. Students sometimes have difficulty understanding why a subject matter is worth learning, particularly if they view the subject matter as a string of unconnected facts. The scientific literacy framework addresses this problem by providing students with a set of concepts that are likely to add meaning to topic content. For example, the use of the relating components makes it more likely that they will see how science links to other academic subjects (e.g., history, mathematics) and to their own observations about their personal lives, current events, and society.

- The scientific literacy framework helps to motivate students in science. While student learning and motivation clearly interact with one another, most research evidence indicates that learning precedes motivation rather than follows it. Thus, if students' meaningful learning of science topic content is increased (as indicated by 2 and 3 above), one can anticipate that their motivation in science also will increase. This increased motivation will then feed into repeated cycles where students will make more of an effort to learn in the first place.

- The scientific literacy framework gives students practice in their roles as informed citizens. As students gain experience in relating content to the societal impact of science, they are learning how to make reasonable decisions about the types of issues they will face as adults. Increasingly, citizens will be called upon to make critical choices on issues with a potential social impact, such as the operation of nuclear power plants, methods of toxic waste disposal, and strip mining. Teachers who provide students with opportunities to debate similar topics and guide them in the use of valid scientific and technological information, are helping to prepare them for their roles as adults.

- The scientific literacy framework gives students information that is useful for their current and future lives. The component which relates content to the personal use of science, for example, may provide students with information about the effects of diet, smoking, drugs, or aging. Knowledge in these areas can influence students' personal choices for years to come as they consider the use of chemical additives in the food they buy, the effectiveness of megavitamins, the potential harm of smoking or alcohol consumption, or the benefits of exercise. Scientific literacy, therefore, can help students to be successful consumers and to maintain healthy bodies.

TRAINING NOTES

WHAT IS SCIENTIFIC LITERACY?

A GUIDEBOOK FOR HIGH SCHOOL SCIENCE TEACHERS

The accompanying materials are intended for use with high school science teachers. They provide an overview of the concept of scientific literacy and encourage the discussion of how this concept is an effective framework for teaching and curriculum planning. The materials can be used in an inservice workshop held after school. Within such a format the trainer should strive to make sure that teachers understand the main points contained in the material and leave the workshop with explicit ideas for using the scientific literacy framework in their own classes. The materials also lend themselves to longer discussions during an entire inservice day or over the course of several shorter inservice workshops. When more time is available, the trainer has the opportunity to work individually with teachers in recognizing potential links between their science curriculum and the scientific literacy components.

However these materials are used, it must be remembered that they present ideas that may be new to some teachers and which, as a consequence, may be somewhat confusing. The role of the trainer is to facilitate discussion that demystifies the scientific literacy components, and provides concrete examples of the use of these components in regular science lessons. In so doing, the trainer must maintain a balance between uncritically accepting the ideas of the participants, and appearing as a dictatorial authority. Often, this balance can be set if the trainer:

1) Listens carefully to the confusions of the participants and allows them to express fully their own ideas--no matter how erroneous;

2) Responds to these confusions in a matter of fact way that focuses on participants' incorrect ideas rather than on the participants (e.g., "I don't think that's what the packet means here." rather than "I think you are confused."); and

3) Allows participants to reject the ideas expressed in the packet, should they wish.

We believe this workshop can be conducted most successfully with teachers who teach the same science courses (e.g., 10th grade biology and 12th grade advanced placement physics) and who use the same science textbook. The trainer should be familiar with the curriculum of the courses taught by the teachers attending the workshop and the content of the textbook they use.

Try to establish a warm, relaxed atmosphere so that teachers will feel comfortable discussing new ideas. If possible, seat the participants in such a way that they are able to see each other. Begin the workshop by giving the participants an opportunity to introduce themselves and say something about their teaching. You might want to ask the participants to tell the group what the words "scientific literacy" mean to them, or ask them what they like most about teaching science. Then present a brief overview of what will be discussed. Use the overhead provided to present a visual image of the scientific literacy components. Do not expect that teachers will have read the materials before coming to the workshop. Structure your own presentation so that teachers have a chance to read the booklet, discuss as a group the questions that are posed in boxes, and then hear your own summation and discussion of the ideas. Frequently ask the participants if they have questions in order to clear up misunderstandings as they occur.

At the end of the workshop, ask teachers to complete the workshop evaluation form. Also complete one of the forms yourself so you can check your own impressions against those of the participants.