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Critical Thinking in Elementary Science Instruction Using Portfolios and Cooperative Learning

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CRITICAL THINKING IN ELEMENTARY SCIENCE INSTRUCTION USING PORTFOLIOS AND COOPERATIVE LEARNING

A Thesis Presented

by

LISA A. HAYES

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ABSTRACT

CRITICAL THINKING IN ELEMENTARY SCIENCE INSTRUCTION

USING PORTFOLIOS AND COOPERATIVE LEARNING

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Elementary science education often does not reflect the processes used in professional science. Students are instructed in a recipe-oriented way to follow predetermined procedures in order to come to predetermined results. The embedding of critical thinking skills instruction into science curriculum makes it possible for science instruction to more closely resemble professional science.

This curriculum development thesis utilizes critical thinking skills and instructional strategies as a basis for embedding critical thinking skills instruction into a series of lessons on the topic of sound. Each lesson includes objectives for science content and thinking skills, a motivational activity, the activation of prior knowledge, central activities, use of portfolios for metacognition, and an activity to promote the transfer of the targeted thinking skills. Students work in cooperative learning groups to which they belong during the entire lesson series.

A trial implementation of the lessons was conducted in a suburban, heterogeneous, self-contained, third grade classroom. It became clear that this method of teaching requires more student and teacher input and greater effort than traditional methods. The role of the teacher shifts from director to facilitator, and the students become much more involved in the direction their learning takes. Based on constant observation, the teacher must design activities and ask questions which motivate students to continually reshape and modify their thinking.

Students demonstrated an improved ability to accept science as a work in progress, developed questioning skills, and learned to transfer knowledge to new situations. They also began to recognize discrepancies between past and present thinking. Yet some students held on to misconceptions and showed resistance to change in light of opposing evidence. One example of these misconceptions is the belief that sound always passes through transparent objects. This thesis not only provides sample lessons for other teachers, but also serves as a stepping stone for further investigation of students' misconceptions about sound.

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CHAPTER I

INTRODUCTION

> Science is a field in which trial-and-error, experimentation, and hypothesis testing are fundamental; yet we teach students how to memorize a set of, say, 10 neat steps that summarize the scientific process, without letting them experience this process. In teaching science, we should keep in mind . . . critical thinking in science involves a set of skills, and like skills in other areas, it is best developed through frequent practice and good coaching. Developing critical thinking skills in science requires active learning. (Narode, Heiman, Lochhead, and Slomianko 1987, 5)

The topic of this thesis is the embedding of critical thinking skills instruction into the elementary science curriculum. Specifically, I will deal with the topic of sound and how it can be used as a vehicle for instruction in critical thinking skills related to professional science processes. I chose the subject of sound because it was recently included in my science curriculum. However, the science subject I have chosen is actually secondary in importance to its use in conjunction with thinking skills instruction. The techniques and skills are applicable to any science topic.

This thesis takes the form of curriculum development. I am a full-time teacher of third grade students in a self-contained, heterogeneous, suburban classroom. As such, I find that developing curriculum is a means for me to demonstrate theory in my daily work. This thesis includes two sample lessons, the first and last, from a series of four which were implemented in my classroom. These sample lessons are meant to be flexible examples which can serve as a starting point for the reader in developing curriculum.

The intended audience for this thesis consists of my colleagues who teach upper elementary grades. The sample lesson plans can be scaled up or down to accommodate students in grades two through six.

The purpose of this thesis is to demonstrate and explain an approach to science instruction which can, at the same time, effectively teach students thinking skills rather than merely giving them the opportunity to use thinking skills. The results of the trial implementation of this approach are explored for the benefit of those who will utilize it in the future.

Now that the intended form, audience, and purpose of this thesis have been mentioned, I will give a general overview of the central theme of each chapter to follow. Chapter II defines and discusses the specific critical thinking skills and instructional strategies on which the sample science lessons are based. Science is a subject for which most elementary students have total enthusiasm, though much science instruction at this level is very "recipe" oriented. Students are instructed to proceed through various predetermined steps in activities or experiments with little time given for reflection or true emphasis on thinking about the processes involved.

Knowledge is treated as though it can be simply added and subtracted from a student's mind like interchangeable parts of a machine. When scientifically invalid beliefs are demonstrated, the teacher gives the scientifically valid knowledge to "replace" them. Students often experience this replacement passively, without encouragement to become actively involved in the process. Each activity or experiment is often used as merely a means to an end, the gain of predetermined ideas by the student, rather than an important end in itself.

Embedding thinking skills instruction into the science curriculum not only facilitates the gain of specific thinking skills but also makes the science curriculum more meaningful. Rather than passive exercises in following directions, the science activities and experiments become active processes of which students, their thoughts and conclusions, become integral parts. The gain in quality for the science curriculum and thinking skills curriculum is mutual. Science becomes more student centered, and thinking skills instruction no longer occurs in isolation.

This chapter includes my definition of critical thinking based on the work of Richard Paul (1992). Within this definition is embedded the concept of metacognition. A diagram of critical thinking skills by S. L. Winocur (1981) is utilized in delineating the critical thinking skills targeted in the lesson series. The instructional strategies of Paul are discussed and those which pertain to the lesson series are delineated.

Chapter III gives background information about the instructional and assessment approaches I used in the lesson series. Based on the work of David W. Johnson and Roger T. Johnson (1991), I give my definition of cooperative learning and use it as the instructional framework on which the lesson series is built. Johnson and Johnson cite reasons as to how cooperative learning promotes the use of thinking skills and metacognition. These reasons are explained. The specific cooperative learning strategies I utilize in the lesson series are explained in detail.

I propose a portfolio model of assessment as an effective approach for continuous evaluation of student concept formation and as an effective tool for nurturing metacognitive activity within the student. The "portfolio culture" model of Richard Duschl and Drew Gitomer (1991, 848) is described, and the modifications I have made to this model for implementation in the lesson series are explained. Advantages of portfolios over conventional assessment tools for this purpose are delineated. Suggested contents for the portfolios are discussed.

Chapter IV is a discussion of the sample lessons on sound, which embed thinking skills instruction into content instruction. I explain the factors which I considered when placing students into cooperative learning groups. A comparison is made between that which might be considered a comprehensive unit on sound and those concepts which are appropriate for third grade students. The specific aspects of sound and the specific targeted thinking skills within each lesson are delineated. The first lesson in the series, focusing upon sound as vibration, and the last lesson, on the conduction of sound, are presented with fully developed plans to serve as samples for other teachers.

The format of each lesson includes five steps: 1) motivation, 2) prior knowledge, 3) activity, 4) portfolio and metacognition, and 5) transfer. Motivation is a demonstration by the teacher which encourages questioning by and curiosity of the student regarding the given aspect of sound. Prior knowledge begins with student-directed manipulation of materials. The cooperative learning groups discuss that which they believe to be true about the given aspect of sound and record any questions they may have in their portfolios. The activity involves directed manipulation of materials and recording of observations and processes utilized by the cooperative learning group. This step is distinctly different from a "recipe" format of science instruction in that, though the activity is predetermined, the student observations, conclusions, and thoughts are not. The portfolio and metacognition step requires the re-examination of prior work in the portfolio and a metacognitive exercise in order to record comments about thought processes and new conclusions. Transfer requires the independent demonstration of the targeted thinking skills. The student or the cooperative learning group is required to demonstrate the ability to use the thinking skills within a context other than that of the unit on sound.

These steps support the nurturing of student metacognition and student self-direction in the formation and modification of concepts. It is proposed that each cooperative learning group follow its own conceptual path, guided toward accuracy by a challenging teacher and peers.

Chapter V is a discussion of my personal reflections. These reflections are largely based upon the actual implementation of the lesson series with my third grade students. I discuss practical issues of implementation, student attitudes, interpretations of student learning, and insight gained into student misconceptions. Ideas for the expansion of the lesson series on sound and the extension of instruction on targeted thinking skills beyond the lessons on sound are explained.

The appendices provide additional examples and information to support teachers who are implementing the lessons in this thesis. Appendix A gives the form of the senses chart used and an example of a chart which has been completed by students. Appendix B gives an example of the responses that one of my groups of students made on the fact/opinion/question charts. Appendix C gives examples of student responses to some of the questions posed within the lessons. Appendix D supplies trouble-shooting tips for the implementation of these lessons and techniques. Appendix E is a partial bibliography of other sources to which a teacher or a student may turn for further information.

I hope that this thesis provides teachers with not only a solid theoretical support for the embedding of critical thinking skills into a curriculum area such as science but also with examples of how this embedding may practically occur in the classroom. The goal as educators should be to prepare students to be effective participants in society. As our society develops technologically, effective participation is marked not only by the retrieval of a vast pool of knowledge but also by the ability of people to think critically about the effective use of that knowledge. Therefore, instruction in critical thinking skills has become a necessary part of public school curricula.

C H A P T E R I I

THINKING AND SCIENCE

Schools have often been thought of as places in which knowledge is presented by teachers, stored by students, and accessed for tests in order to pass on to the next level. However, as technology takes over the role of information storage, the focus of schools needs to shift to helping students to develop ways to think about and effectively use an ever-expanding pool of information. Though calculators, computers, and the like may be able to aid in the retrieval of facts, these facts must be judged for validity, applicability, and relevance. Facts must also be combined in meaningful ways rather than viewed in an isolated context. In current and future problem solving, knowledge will be only as effective as the thinking skills of the person using that knowledge. Critical thinking, therefore, is an essential part of a curriculum to prepare students to be effective problem solvers in the future.

Science, though historically part of the public school curriculum, has often been presented in a misleading way to students. Students participate in predetermined experiments by following predetermined procedures to achieve a predetermined result. Students, therefore, often imagine the role of a real scientist as much like that of a cook, one who follows recipes in a book to achieve a particular final product. Professional science, however, involves problem finding, hypothesizing, appropriate design of experiments, and the synthesis of results to formulate plausible, previously undetermined conclusions. Professional science processes require critical thinking skills. These thinking skills should be an integral part of science curriculum in order to train students in the skills used by scientists in the real world.

Critical Thinking

What is critical thinking? Though it is generally agreed by educators that critical thinking is necessary for the effective use of knowledge, those most prominent in the field define it in various ways. Robert Ennis (1987) defines critical thinking as "reasonable reflective thinking that is focused on deciding what to believe or do" (10). Critical thinking, according to Ennis, involves dispositions as well as skills. These dispositions, such as trying to be well informed and taking into account the total situation, provide the mental and emotional environment which facilitates the development and use of thinking skills. I have chosen to narrow my focus to thinking skills because they are more easily measured by observation of behaviors than are dispositions.

Richard Paul, a leading authority on thinking skills, acknowledges that there are many definitions of critical thinking and that most are not mutually exclusive. In his book Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World, Paul (1992) gives a multi-tiered definition of critical thinking:

> 1) Disciplined, self-directed thinking which exemplifies the perfections of thinking appropriate to a particular mode or domain of thinking. 2) Thinking that displays mastery of intellectual skills and abilities. 3) The art of thinking about your thinking while you are thinking in order to make your thinking better: more clear, more accurate, or more defensible. (643)

Part one of Paul's definition establishes critical thinking as a process requiring more discipline than might occur without training. Part two recognizes specific skills which are necessary in order to engage in the process. Part three includes metacognition as an integral part of the critical thinking process.

Metacognition, or thinking about one's own thinking, is a necessary part of being a well-rounded critical thinker. The ability to analyze and evaluate one's own ideas affects behavior. Although a person may attempt to think critically about problems and information presented, critical thinking skills cannot be honed without metacognitive evaluation. Metacognition allows a person to monitor and improve thinking skills. It involves not only critical thinking skills but the evaluation of their use.

The working definition of critical thinking which I use for this thesis is a synthesis of the aspects of other definitions which I find useful. My working definition is the following: Critical thinking is thinking which is objective, self-directed, and self-evaluative. It considers multiple aspects of an issue and sets criteria for evaluation of ideas based upon basic thinking skills. It includes a check of one's own thinking processes and plans specifically for improvement of one's own thinking.

Critical thinking skills. Effective critical thinking is a process which comes about through much practice and training in specific thinking skills. These skills have been delineated in various ways. Figure 1 on page 13 is adapted from the unpublished doctoral study of S. L. Winocur entitled "The Impact of a Program of Critical Thinking on the Reading Achievement of Middle and High School Students" (1981). Winocur categorizes critical thinking skills into three groups: enabling skills, processes, and operations. These groups are presented from top to bottom in the order of complexity of the skills in the group. The "Enabling Skills" group consists of skills which can be utilized in isolation. The arrow from the "Enabling Skills" group to the "Processes" group indicates the "Processes" group consists of skills which require facility in certain sub-skills, "enabling skills," in order to utilize them. For example, the "Process" skill of analyzing fact/opinion would require "Enabling Skills" such as observing, comparing/contrasting, and classifying/categorizing. The arrow from the "Processes" group to the "Operations" group indicates the "Operations" group consists of skills which require the orchestration of a number of "processes" and "enabling skills" in order to utilize them. Decision-making, for example, requires skills, such as analyzing reliable/unreliable information, inferring the meaning of statements, observing, and prioritizing. The arrows to "Application" in the diagram show that the utilization of skills from any of these groups constitutes critical thinking. This diagram is especially helpful to educators because it not only delineates critical thinking skills but also places them in a hierarchy based on degree of complexity.

Embedding thinking skills instruction into curriculum areas. Two schools of thought are now involved in the controversy over how to make thinking skills instruction part of formal education. The first advocates teaching thinking skills separately from the content in the curriculum. The second advocates infusing or embedding thinking skills instruction into the curriculum areas themselves. I have found no research which has derived conclusive evidence about the superiority of either of

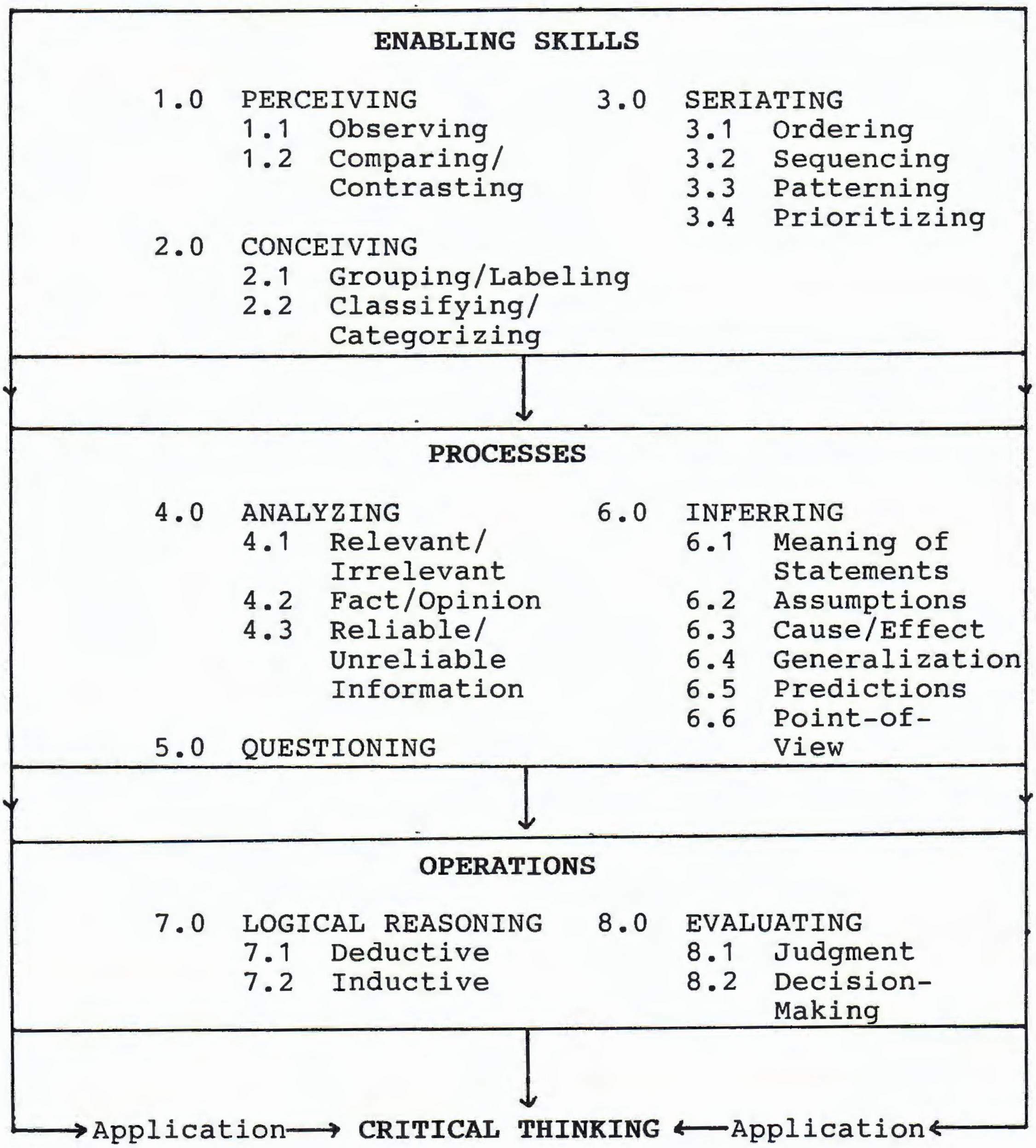

Fig. 1. Universe of critical thinking skills. (Adapted from the unpublished doctoral study "The Impact of a Program of Critical Thinking on the Reading Achievement of Middle and High School Students" by S. L. Winocur, 1981.)

these schools of thought. Based on my experience as a public school teacher, I have chosen the embedding technique because of an ever-expanding curriculum, a decreasing budget, and the inflexible school hours in which to teach. Embedding the teaching of thinking skills into other content areas allows process and content to be taught at the same time, requires minimal special instructional materials, and is perceived less as an "addition" to the already crowded curriculum.

Some professionals in the field of critical thinking base their advocacy of the embedding approach on less practical aspects and more on their understanding of the function of critical thinking. Robert J. Swartz (1991) views the embedding approach as an outcome of what he states is "the natural fusion of what we normally teach students with the forms of thinking that we use every day as we live our lives" (177). He believes that this type of infusion creates activities which mutually reinforce critical thinking skills and content area information. He stresses that process and content are goals of an infused lesson. Richard S. Prawat (1991) states that "advocates of the embedding approach argue that before one can adequately question a particular activity or belief, one quite naturally needs to understand what is involved. Disciplinary knowledge plays a key role here" (185). Therefore, without content with which to work, critical thinking skills instruction may be an empty exercise and, conversely, without critical thinking skills employed in the learning of content, content instruction may become a passive absorption of material.

Paul's 35 instructional strategies. Knowledge of the specific critical thinking skills one wishes to teach is but the first step in critical thinking skills instruction. It is more difficult to devise a method which presents these thinking skills in usable groups. Paul (1992) has devised 35 instructional strategies which aid in doing just that. These instructional strategies are designed for use with the embedding approach. Each strategy focuses upon orchestrating the critical thinking skills which are most often used together in real life. Paul's strategies do not treat critical thinking skills as isolated, disjointed skills but as integrated components of efficient critical thinking.

Though each strategy may be used to focus upon more than one skill and indeed does give the opportunity for growth in a variety of skills, I have chosen to focus upon single skills due to the age of the students I teach. This is not to say that multiple skills are not practiced as each strategy is implemented. As will be discussed in Chapter IV, opportunities for practice with thinking skills which may be considered auxiliary to the lesson are a bonus of using Paul's instructional strategies.

Figure 2 on the next page shows the strategies from Paul's list of thirty-five I have chosen to teach the critical thinking skills within the sample lessons. The complete list of 35 instructional strategies developed by Paul may be found in his book Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World (1992, 394).

Critical Thinking Skills Related to Scientific Processes

The idea that science is a dynamic endeavor and not merely the memorization of facts and processes has long been agreed upon. However, this idea has not been historically reflected in most science classrooms. Recently the critical thinking movement has re-emphasized the issue of the disparity between that which happens in the typical science class and professional science.

Bruce Wellman (1991) states "In real-world science, content exists within a context and within several interactive processes. Content is defined by its relation to these processes, and each is embedded in the other" (159). In order for science instruction to be more realistic, the processes in which real scientists engage must be an integral part of the curriculum. When embedding thinking skills instruction into the content

Strategy	Skill
S-11 comparing analogous situations S-29 noting significant similarities and differences S-34 recognizing contradictions	comparing and contrasting
S-13 clarifying issues, conclusions, or beliefs	analyzing fact/ opinion
S-25 reasoning dialogically: comparing perspectives, interpretations, or theories	logical reasoning
S-32 making plausible inferences, predictions, or interpretations	inferring cause/ effect

Fig. 2. Instructional strategies and thinking skills.

area of science, the thinking skills chosen should directly connect to these scientific processes.

Before thinking skills can be chosen for infusion into a science curriculum, the science processes must be identified. Note that Wellman (1991) and Winocur (1981) use the word "process" differently. Winocur labels a skill requiring some basic subskills a "process." Wellman uses the word "process" to denote a skill; some of Wellman's processes require subskills and some are basic enough that they are utilized alone.

Wellman (1991) identifies four key scientific processes. The first is observing, which includes the use of all of the senses. Winocur labels this an "enabling skill." The second is communicating, which includes describing observations, recording them on paper, and researching. Though not mentioned by Winocur, I believe this would fall under her category of "processes" as it requires facility in a few academic skills such as reading and writing, and thinking skills such as observing. The third is comparing, which includes estimating, measuring, and comparing from different perspectives. This might fall under the category labeled "operations" by Winocur since it requires the orchestration of more complex skills such as analyzing point of view. The fourth is organizing, which includes seriating, sorting, and classifying. This skill is included by Winocur under "enabling skills." I would add to the list problem solving, which Wellman categorizes as a cognitive skill. Problem solving is more complex than a basic skill. It is the orchestration of many skills which may be considered a process. The process of problem solving would include hypothesizing, experimental design, qualitative and quantitative observation, recording observations in various ways, analyzing, interpreting, inferring, generalizing, communicating, and predicting.

Allowing students to engage in the above processes would allow them to experience that which professional scientists experience. Recipe-like experiments which leave no room for student-initiated changes and science activities which do not allow for any true thinking to occur give the student no knowledge of what science is like in real life. Teaching students to think and act like scientists, by allowing them to learn the basic skills needed to engage in professional scientific processes and then allowing them to participate appropriately in those processes, will give them a realistic view of science. Students will no longer believe that scientists follow directions in a book in order to execute an experiment. Students will no longer have only vague impressions of who it was that designed those experiments and for what purpose. Teaching students to think and act like real scientists will allow them to realize that they may someday be scientists. Motivation to explore more and learn more will no longer be such a problem in science class.

The critical thinking skills which will be infused into the sample lessons are directly related to professional scientific processes. Comparing and contrasting has been defined as a basic science process by Wellman (1991) as well as a critical thinking skill by Winocur (1981). This skill must be used not only to categorize but also to identify patterns in the universe by recognizing analogous situations. Analyzing fact/opinion is necessary in the process of problem solving to determine the validity of information and the weight given to each piece of information in formulating conclusions. Logical reasoning is an intrinsic aspect of effectively comparing various perspectives, weighing hypotheses, and problem solving. Inferring cause/effect is often part of problem solving and determining relationships among pieces of data. It is also important for developing plausible predictions based on past scientific inquiry.

All of these skills are related to the public communication of ideas and results. Science is a work in progress which depends on public rather than private inquiry. The effective use of these critical thinking skills in order to engage in basic scientific processes within a public forum--for students, the classroom--will make students budding scientists rather than passive performers of directions which have no connection to the real world.

Transfer of Thinking Skills

The goal of education is to teach students skills which they can utilize throughout life. This requires that the students transfer knowledge from classroom situations to situations in their daily lives. However, various studies on transfer of knowledge indicate that transfer often does not occur (Perkins and Salomon 1991). These results indicate that current teaching techniques are often failing to teach for transfer. A major goal, therefore, of any instruction in critical thinking skills should be the ability of the students to transfer these skills to their everyday life experience.

Perkins and Salomon (1991) delineate two types of transfer which may occur: 1) "low road transfer" (218) which is manifested by the triggering of well-learned routines in situations which are extremely similar to those in which the routine was learned; 2) "high road transfer" (218) which is manifested by the abstraction of a learned skill or concept from the original learning context to another which is highly dissimilar. High road transfer is a deliberate act; whereas low road transfer is more automatic. Metacognition is necessary for high road transfer. By definition, it is apparently most desirable to bring about high road transfer in students. The range of situations in which they can then use their skills and knowledge becomes much more vast.

Perkins and Salomon (1991) also discuss two techniques for teaching which promote transfer: "hugging" (220) and "bridging" (220). Hugging would be used when low road transfer is acceptable and in the initial stages of teaching when high road transfer is the goal. Hugging requires that the teacher present knowledge in such a way so that the conditions are similar to the situation to which they want the knowledge transferred. In a lesson on sound, the teacher may demonstrate how sound travels by dipping a vibrating tuning fork into water to show the splash. Once the student understands the idea of moving molecules causing adjacent molecules to move, the teacher might ask the student to explain why pepper on plastic stretched over the mouth of a cup jumps when the plastic is touched by a vibrating tuning fork. The student would be required to use newly learned knowledge and skills in a context which is similar enough to the original learning context that the transfer is an automatic response.

Bridging would be used when high road transfer is desirable. Bridging requires that the teacher promote transfer by challenging the students to use knowledge and skills in situations which require abstraction in order for connections to be made. An example for an elementary classroom might be for the teacher, after presenting hugging activities on how sound travels, to ask students to describe how space sounds. The students would have to apply their knowledge of moving adjacent molecules to a situation in which there are no molecules to move and then infer that space is silent. The teacher using this technique is required to manipulate the learning situations of the students much more purposefully with the goal of high road transfer in mind. The students are explicitly asked to relate newly learned skills and knowledge to seemingly dissimilar situations.

Most teachers sequentially use hugging and then bridging techniques at some point in instruction. However, in order for these techniques to promote transfer effectively, they must be implemented on a continuous and consistent basis. "Taken together, the notions of bridging and hugging write a relatively simple recipe for teaching for transfer" (Perkins and Salomon 1991, 220).

In order to teach students how to think and act like professional scientists, teachers must create an environment in which students actively participate in real scientific processes. The thinking skills related to these processes must be an integral part of science instruction. Teachers need to create a classroom environment in which critical thinking skills are fostered within the process of scientific endeavor by the students. Metacognitive activity will enable students to improve their thinking skills and become better scientists. Teachers must use tools and strategies which nurture the utilization of science processes and which also encourage transfer of learned skills.

CHAPTER III

COOPERATIVE LEARNING AND PORTFOLIOS

When attempting to pinpoint specific strategies and tools which would aid me in embedding critical thinking skills instruction into the science curriculum, I first explored the tools and strategies encouraged in various school systems. Among the many to be found, cooperative learning and the use of portfolios came to the forefront not only as facilitators of thinking skills instruction but also as methods which may be reasonably used simultaneously in today's busy classroom.

Classrooms are complex environments in which a variety of types of student relationships are encouraged, each with a specific effect on student motivation to interact with peers. In Cooperation in the Classroom, David W. Johnson, Roger T. Johnson, and Edythe Johnson Holubec (1991) delineate three classes of student-student interaction:

1. Competitive interactions encourage an undesirable student perception of interdependence. Students perceive that they can attain their goals only if other students fail.
2. Individualistic interactions discourage all interdependence. Students view the successes, ideas, and efforts of other students as irrelevant to their own work.

3. Cooperative interactions encourage positive interdependence. Students work together to achieve shared goals. Each student seeks outcomes which are beneficial not only to the individual but also to the entire group.

Cooperative learning affects the classroom environment in a way that encourages communication, sharing of ideas, and consideration of other points of view. This atmosphere is essential to promote critical thinking.

Portfolios are tools which provide concrete records of student thinking to which students may turn when trying to evaluate their own thinking. They make possible the metacognition in young students which facilitates improvement in critical thinking skills. Since portfolios also empower the student to determine, at least partially, their contents, they provide a good basis upon which teacher-student conferences can be held. Teachers can learn a great deal about how a student is thinking by having the student discuss the portfolio. That which is learned can then be used to guide the teacher in the next step of critical thinking skills instruction.

Cooperative Learning

What is cooperative learning? As defined by Johnson and Johnson (1991), cooperative learning is "the instructional use of small groups so that students work together to maximize their own and each other's learning" (298). I would add that cooperative learning fosters free discussion, sharing of opinions, and constructive challenging of ideas within emotionally supportive groups. Cooperative learning is differentiated from standard group work often found occurring in classrooms and is characterized by five basic elements: positive interdependence, face-to-face interaction, individual accountability, cooperative skills, and group processing. Without these five elements, the effective cooperation is taken out of cooperative learning and it can become riddled with pitfalls.

Positive interdependence maximizes the learning of all of the group members by allowing them to share resources. This type of relationship among students also provides mutual support allowing for greater persistence on challenging tasks. Students are able then to celebrate their joint successes.

Face-to-face interaction gives students the opportunity to promote the success of others by assisting, supporting, encouraging, and praising one another's efforts. This element also requires students to explain to each other how answers have been derived, the nature of concepts, and connections between prior and new knowledge. Students are then able to influence and challenge the reasoning and conclusions of others in the group. Face-to-face interaction helps to avoid the lack of participation by some students by giving other students the opportunity to encourage unmotivated group members to achieve within a supportive context.

Individual accountability is another component of cooperative learning that allows the group to avoid the lack of participation by some members because all students know that their personal contributions to the group are being noted by the teacher. This also avoids the suppression of individual efforts and power struggles within the group as the teacher makes clear that each student is expected to contribute in order for the whole group to succeed.

Cooperative skills allow the students to get to know and trust each other and resolve conflicts constructively. This element requires the students to communicate with an effort to be clear and accurate and to accept and support each other as people.

Group processing involves a group discussion about what has been done. Member actions which were helpful or unhelpful are delineated, and group actions to continue or to change are decided upon after each session of group work (Johnson, Johnson, and Holubec 1991).

Johnson, Johnson, and Holubec (1991) explain the unique role the teacher must play within an effective cooperative learning environment. "Within cooperative learning situations, the teacher, besides being a technical and subject-matter expert, is a classroom manager and consultant to promote effective group functioning" (2:3). The role of the teacher shifts from instructor to facilitator, guiding students to, rather than telling, accurate information.

Cooperative learning promotes thinking skills development. Several researchers have found that cooperative learning is directly related to the development of thinking skills and metacognition. Arthur L. Costa (1991) describes one characteristic of a classroom which is organized for developing thinking skills: it is one in which students work cooperatively in groups. They, not the teacher, plan strategies to carry out group projects, each member contributes to the information and ideas used during the group project, and each member participates in identifying information which is missing and strategies to obtain that information. These are all processes which are characteristic of cooperative learning. He also notes that "students working cooperatively in groups used more higher-level reasoning strategies and greater critical thinking competencies than students working in competitive and individualistic learning situations" (Costa 1991, 199).

Jay McTighe and Rochelle Clemson (1991) state that "cooperative learning promotes the interactive processing of ideas and thus naturally complements other instructional approaches for developing student thinking skills" (306). Particularly relevant to the topic of this thesis is their opinion that group investigations and experiments in science are especially well-suited to encouraging thinking skills. These are typical cooperative learning activities.

Johnson and Johnson (1991) found that tasks which required great amounts of problem solving and creativity in order to obtain solutions, tasks for which long-term retention of learning is most desired, were best addressed through cooperative rather than competitive or individualistic learning. They drew this conclusion after researching the findings of over six hundred studies which have been conducted in the past ninety years.

Johnson and Johnson described several specific ways cooperative learning promotes cognitive and metacognitive development. In an earlier book on the subject, Cooperation and Competition: Theory and Research (1989), they discuss the beneficial relationship of child-to-child which cooperative learning promotes and other strategies often ignore. The child-to-child relationship, rather than the adult-to-child relationship that is most often focused upon in the classroom, contributes to cognitive development in four specific ways:

1. It provides models for viewing situations and problems from alternative perspectives.

2. It promotes the development of autonomy. Children learn to balance their own perspectives with others and take a more objective stance, one that is neither extremely self-centered nor selfless.
3. It provides a frame of reference for the child to judge his/her own effort, progress, and ideas.
4. It supports productivity of students who are unmotivated and comparatively unproductive when working alone.

The social support provided within the cooperative learning group has been seen by Johnson and Johnson (1989) as related to achievement, successful problem solving, persistence on complex and challenging tasks, and more time spent on task.

Cooperative learning promotes cognition and metacognition in several other ways. When students know they will have to teach or explain material to others in their group, they organize it differently than when learning it just for themselves. They tend to use higher-level thinking strategies. The discussion inherent in cooperative groups provides oral rehearsal in the form of summarizing, explaining, and elaborating which is necessary for storage of information in long-term memory. This discussion also provides the opportunity to assess one's understanding of relevant concepts. Cooperative groups are heterogeneous, a condition which allows the experience of each member to be enriched due to the necessity for each student to constantly accommodate to new perspectives and views.

Each member of the group is also likely to have incomplete information. Cooperative learning provides the opportunity for the synthesis of each member's information into a new whole, thereby enriching the knowledge of each student. There is opportunity for peers to monitor and evaluate each other's reasoning and enhance it. Feedback from peers is personalized and suggestions for improving performance or reasoning can be given. It is recognized that conflict among ideas in a cooperative learning group is inevitable. However, this can also be beneficial. It gives each student the opportunity to choose a position, gather relevant information, and support the chosen position (Johnson and Johnson 1991).

Strategies used in the lessons. For the purpose of implementing lessons on the subject of sound in my third grade classroom, I have chosen four cooperative learning techniques. I chose these techniques for the benefits derived in the area of thinking skills as well as the efficacy with which they may be used within a science education context. The four techniques are Jigsaw, Think-Pair-Share, Three-Step Interview, and Co-op Co-op.

For the Jigsaw technique, students work within small cooperative learning groups. Each member of the group is given an area in which to become an "expert." The experts on the same topic from each group in the class research their topic together. Each expert then goes back to his/her own cooperative learning group and shares the new knowledge. Each expert within the group is responsible for educating the rest of the group in his/her area of expertise and each member of the group is responsible for learning about all aspects of the topic.

A study done by Huber and Eppler "proved positive achievement effects of the jigsaw technique" (1990, 158). The jigsaw is best suited to non-hierarchically organized skills. It is very effectively used for complex problem solving where great amounts of information must be gathered and combined in order to formulate the solution.

Think-Pair-Share is a technique wherein a question or problem is posed; the students are given a certain amount of time to think about it; they then pair up with a peer and discuss responses; and then each pair shares ideas formulated with the class. Each student is responsible for generating and listening to ideas.

The Think-Pair-Share technique is beneficial to the development of thinking skills because it allows time specifically set aside for thinking before any response is expected or allowed. McTighe and Lyman (1991) found that this benefit results in longer, more complex answers, better logic, support of the inferences which are given, increased student participation, and increased sharing of ideas with peers. This technique is also quite manageable for teachers.

The Three-Step Interview involves students getting into pairs and taking turns interviewing each other about a specific topic. All of the students then get back together in a group and share that which they learned during the interviews. All students are responsible for generating and listening to ideas for the purpose of sharing the information with the larger group in the end.

According to Kagan (1989-1990), the overwhelming benefit of the Three-Step Interview is the requirement of the student to listen to and express ideas. The production and reception of language allow more effective formation and modification of hypotheses and conclusions. The fact that the students know they must reiterate ideas for the group causes them to listen more intently and think more about the ideas expressed.

The Co-op Co-op technique requires students to work in groups together to produce a group product for the purpose of sharing it with the rest of the class. Each student is responsible for making a contribution to the product, and the contributions of each student are identified in some way by the teacher. For example, each student might have a different color pen with which to write. Individual accountability is an integral part of this technique.

The Co-op Co-op technique is fairly simple to implement and is very flexible. Kagan states that it "affirms the intelligence, the creativity, and the prosocial tendencies of students" (1985b, 452). This technique is especially beneficial because it gives the control of what is learned and the responsibility of learning back to the student. The effect is greater student involvement, ownership of knowledge, and motivation to share.

The environment which the use of cooperative learning techniques foster is one which nurtures the student attitudes, or dispositions as Ennis (1987) would call them, of open communication, trying to be well informed, being open-minded, and considering all aspects of a situation which aid in critical thinking. Cooperative learning techniques especially facilitate the development of critical thinking skills by allowing the students to think not only in isolation but also aloud with their peers. Feedback from peers serves as one way students can evaluate their own thinking. The use of portfolios is another.

Portfolio Assessment

What is a portfolio? Though the concept of a portfolio carries with it a variety of specific implications regarding its structure, the definition of a portfolio stated by Paulson, Paulson, and Meyer best suits my purposes:

> A portfolio is a purposeful collection of student work that exhibits the student's efforts, progress, and achievements in one or more areas. The collection must include ... evidence of student self-reflection. (1991, 60)

Two structural levels of a portfolio have been delineated by Linda Vavrus (1990). The physical structure of a portfolio refers to its organization and physical housing. A portfolio may be organized chronologically, by type of work or curriculum content, by skill being assessed, or in a variety of other ways depending on the preferences of teachers and students and the purpose for the portfolio. Portfolios may be housed in a number of ways, again depending on student and teacher preference. Some examples of housing are hanging files, individual loose-leaf notebooks, large manila envelopes, and shirt boxes. The housing must be accessible to both teacher and student in order for it to encourage effective use.

The conceptual structure of a portfolio refers to the learning goals it will aid the student in attaining. These learning goals then help determine the actual contents of the portfolio. For example, if the learning goal is to demonstrate the ability to create an accurate final product in photography, the portfolio may only contain the final products for the specified period of time. If the learning goal is to demonstrate specific critical thinking skills during the process of creating that final product, the portfolio would then contain not only the final product but also evidence of decision-making, reasoning, and self-evaluation. Howard Gardner (1991) narrows the possibilities for the form of the conceptual structure of a portfolio by contending that an effective portfolio must include the evaluation and self-evaluation of the process undergone by the student. He proposes calling effective portfolios "process-folios" (240) in order to reflect this basic element.

"Portfolio Culture". Duschl and Gitomer (1991) propose the widespread use of portfolios within the science classroom creating an environment they call a "portfolio culture" (848). These authors state that a portfolio culture "creates opportunities for teachers and students to confront and develop their scientific understanding and to equip students with the tools necessary to take increased responsibility for their own restructuring, to assess for themselves what might be the next step" (840). The portfolio culture would promote interactions around a collection of work, promote assessment-based interactions of teachers with students to monitor meaningful learning, and include a project orientation of instructional activities and tasks.

Within Duschl and Gitomer's model, assessment is viewed as formative, instructional, and collaborative between the student and the teacher. Criteria for assessment are made clear at the beginning of the process. Assessment of the understanding a student has of fundamental scientific principles, rather than numerous facts, is stressed. The process involved in the work of a student is as important as the outcome of that work. Assessment is based on the quality of knowledge rather than its proximity to pre-determined ideal answers.

Instruction is portfolio-based and interactive rather than passive on the part of the student. Curricular objectives and lesson plans focus on the understanding a student has of scientific explanations which inevitably involves the assessment of evidence, knowledge claims, and data. Instructional activities which encourage the student to restructure previous, inaccurate explanations are developed. Instruction is based on projects and activities as well as student self-evaluation of the process and a high level of reflection.

Portfolios support metacognition. I propose a modified version of the portfolio culture described by

Duschl and Gitomer (1991) for the science classroom. Though the interactive and collaborative aspects of the model remain the same, modifications to the focus of assessment are made. For the purpose of thinking skills instruction within the content area of science, the emphasis of portfolio use shifts from a tool used to assess knowledge of fundamental science principles to a tool which facilitates metacognition within the process of scientific inquiry. This shift is especially important when dealing with young students whose science curriculum is exposure-based and who will benefit greatly from learning to learn more independently at such an early age.

Portfolios are especially suited to aiding metacognition in younger students. Young students tend not to be trained to think about their own reasoning and feelings when producing work. They often demonstrate impulsivity and answers based on nebulous hunches. They often cannot articulate the process through which they went to obtain an answer even in an area as concretely process oriented as arithmetic.

Portfolios provide a tangible record of procedures used and conclusions drawn. They often contain student journal comments about feelings and thoughts at each step. The tangibility of a record, such as a portfolio, allows students to go back and "replay" the experience which led them to their finished products. They are able to read about and see each step in the process, helping them to recall specifics about their thinking at each step more easily. They are also able to flip back to earlier experiences in their portfolios and see physically recorded ideas which they had previously and with which they may no longer agree in the present.

Paulson, Paulson, and Meyer (1991) recognize the role portfolios play in student metacognition. When delineating guidelines for effectively utilizing portfolios, they state that it must contain evidence that the student has engaged in self-reflection, that the student is in the process of learning to learn. Howard Gardner also feels that teachers must emphasize "the importance of care, revision, reflection, discipline, regular self-examination, and sharing reactions with others" (1991, 242). This type of self-examination and sharing would support the metacognition of the individual as well as that of the group.

Advantages of portfolio assessment. Portfolio assessment has three advantages over other types of assessment. First, as discussed in the previous section, portfolios are a tangible record of the process the student has undergone. The teacher and student can, therefore, sit down and review the portfolio together and make specific comments about steps in the process, ideas generated at each stage, the progression of thought, and evidence used to substantiate conclusions. This tangible record gives the younger student an opportunity to demonstrate his/her reasoning through concrete examples within the portfolio. Most traditional assessment tools rely on a final product to determine the understanding a student has of specific curriculum content. Most do not allow space for a student to justify his/her work with examples from the process involved. Those tools which do allow a student to justify conclusions are usually geared to older students who may have more of an ability to think back on the process in their minds.

The second advantage portfolio assessment has over conventional tools is that it combines assessment with instruction. Most tools are used for assessment only. The most that is done with the results is the determination by the teacher of that which should be taught again. Portfolios allow student involvement in assessment and instruction. "If carefully assembled, portfolios become an intersection of instruction and assessment . . . . Together instruction and assessment give more than either gives separately" (Paulson, Paulson, and Meyer 1991, 61). Portfolio assessment, since it is a collaborative endeavor between teacher and student, gives students the power to influence their own instruction. The collaborative assessment of the portfolio leads to collaborative planning for instruction, the results of which are collaboratively assessed and future instructional steps are collaboratively determined. The extent of this cycle is determined by the grade level, the learning objectives, and practical matters such as time.

The third advantage of portfolio assessment over other assessment tools is that it teaches students that they have a responsibility for their own learning. Most traditional assessment tools discourage self-evaluation. Dennie Palmer Wolf (1991) delineated the negative lessons traditional assessment often teaches:

> (1) assessment comes from without, it is not a personal responsibility; (2) what matters is not the full range of your intuitions and knowledge but your performance on the slice of skills that appear on tests; (3) first-draft work is good enough; and (4) achievement matters to the exclusion of development. (351-352)

By allowing students to participate in a collaborative process with the teacher and have some decision-making power, students gain ownership of their learning and the teacher shifts from supplier of knowledge to mentor and partner in the learning experience.

Suggested contents. In order to create portfolios which will fulfill the expectations and ideals previously discussed, their contents must include a variety of materials. Brainstorming products, early drafts, final drafts, data sheets, conclusions, evidence used to support conclusions, and the like should be included to effectively record the process the student has undergone.

Journal entries, records of thoughts and feelings about the process, and individual and group self-evaluation records should be included to track metacognitive activity. Final products should be included in order to determine the efficacy of the process. However, they are not the core of the portfolio. It is suggested that the teacher and the student select contents for the portfolio together. The portfolio may be used as a place to hold all work until the completion of a task. It can then be weeded out by the student(s) and the teacher as a team.

Applications for Lessons on Sound

It should be noted that my class was able to participate in the lessons on sound using the cooperative learning techniques I previously discussed without any preliminary training. My students have been exposed to cooperative learning methods for at least a year, some since kindergarten. They are quite familiar with cooperative learning; they do not resist sharing their ideas; and they do not participate in power struggles or significant arguments during group work. Teachers who are exposing their students to cooperative learning techniques for the first time should take a few months to work on cooperative learning with their classes before attempting to integrate it into the curriculum. Teachers wishing to find activities expressly for practicing specific strategies with their students may find the work of Johnson, Johnson, and Holubec (1991) extremely helpful. Once the students participate in cooperative groups freely and confidently, they will be ready for integration of cooperative learning into the curriculum such as occurs in the lessons on sound.

I use portfolios in the lessons on sound as tangible records of student thinking. These portfolios are group portfolios rather than individual since they are based on group activity and discussion. The portfolios are used by the students to help them remember specific details of previous thinking and discussions. Based on these records, the individuals and groups of students can metacognitively evaluate their thinking. The portfolios may also be used, between lessons, to initiate discussion between teacher and students in order to aid the teacher in evaluating student thinking. Again, my class has been exposed to portfolios for at least a year. Teachers who are exposing their students to portfolios for the first time may need to spend more time reiterating the purpose of portfolios during the lessons on sound. I have found that even students who are experienced with portfolios experience some difficulty viewing them as works in progress.

CHAPTER IV

DISCUSSION OF SAMPLE LESSONS

The sample lessons in this chapter are two of the four actually taught in my classroom. I chose to include the first and the last lessons taught so that I could discuss student growth from the beginning to the end of the lesson series. Lessons are delineated by the concept taught rather than the time required to teach the lesson. Therefore, I found that each lesson required approximately five hours of instructional time. Within lesson plans, I stopped where it was practical or necessary, depending on the schedule of the day. My class engaged in a creative activity at the end wherein each group developed a way to present something they had learned during the lesson series. A description of this activity is not included in this thesis due to its creative nature and the focus of this thesis on critical thinking skills.

Student Groups

During the implementation of the sample lessons, the third grade students were placed in small, heterogeneous groups. These groups remained the same throughout the series of lessons. As the class as a whole represented a wide range of abilities, backgrounds, personality types, and interests, grouping of the students was done very deliberately by the teacher with the goal of exposing each student to as wide a range of thinking as possible.

First, consideration was given to personality type. As these lessons require a great amount of inter-student communication, it was very important not to place all students of the same personality type together, for example the loquacious students in one group and the quiet students in another. Nor was it desirable to put extremes of personality strength together. For instance, putting a shy child in the same group as an overbearing child may result in the suppression of the ideas of the shy student. Students were categorized by the teacher into three groups: strong personality, average personality, and reserved personality. These categories were then used to place students into groups of five with as much mixture of personality as possible. However, since extremes were not placed in the same group, each group had either strong and average personality types in it or average and reserved personality types in it.

The next consideration was observed ability in science. Throughout the year prior to this series of lessons, this class had engaged in science study using cooperative learning methods. Based on observation of participation and accuracy of ideas, these students were placed into three categories: wide knowledge of science, average knowledge of science, and limited knowledge of science. Students in each previously established small group were checked to ascertain the makeup of the group based on science knowledge. Whenever extremes were in the same group, an effort was made to interchange them with students from other groups. However, extremes were allowed to remain in the same group if the student with wide knowledge of science had a more reserved personality than the student with limited knowledge of science. This is due to my judgment that the stronger personality of the student with limited knowledge would lessen the possibility of suppression of the ideas of that student. The stronger personality would compensate for lack of background knowledge and both the student with wide knowledge and the student with limited knowledge would have equal chance to participate in the activities. A concerted effort was made to make sure all students with wide science knowledge were not all in one group and those with limited knowledge in another group.

Student interest in science was the next consideration. This was not a particular problem in this class as most students exhibited great enthusiasm for science. Categories were not employed due to the general interest which seems to me to be a function of the age group. A couple of students seem to lack the motivation to fully participate in any activity in the classroom. These students were interspersed among the groups so that no two were in the same group.

A few of the students have parents who are employed in a field of science and, therefore, receive great support for science activity at home. These students also tend to know, or think they know, a bit more about science. Since these students were few, it was possible to intersperse them among the groups as well.

Lastly, the gender of the participants in the groups was determined more by the make-up of the class than anything else. This class has only six boys in it, most of them of a fairly reserved personality type. Boys in third grade strongly prefer not to be the only boy in a group. Therefore, of the five groups which were established, three had two boys in them and two were all female.

Overview of a Unit on Sound

Comprehensive unit. The scope of a comprehensive unit on sound is much more extensive than that which is appropriate for a third grade classroom. The possible topics to be addressed would include sound as vibration, sound waves, and interference caused by the interaction of multiple sound waves. A discussion of pitch would include the frequency of sound waves, that which affects the frequency of sound waves, and the Doppler effect (the perception that the pitch of a fast-moving object is high as it rushes toward you due to sound waves piling up before it; the pitch then apparently drops significantly as the object rushes away from you due to the sound waves being stretched apart). The unit would also include volume (loudness) as a function of the strength of a sound wave at the point it strikes the eardrum and how that strength, in turn, is affected by the surface area vibrating, the medium, and the distance between the source and the eardrum. The conduction of sound and that which affects it, patterns of sound, and the reflection and refraction of sound waves would also be part of a comprehensive unit. Related topics, such as hearing, musical instruments, the sound industry with a history of sound recording, deafness, noise pollution, and animals which use sonar should also be touched upon and available for expansion by motivated students.

Concepts addressed in grade three. When thinking about the topics which would be included in a comprehensive unit on sound, I realized that most of these topics would not be appropriate for the average third grade student. The teacher, however, should be ready to provide materials and guidance relating to all of the topics should an especially motivated or talented student express an interest in any of them. Individual research on any of the topics can be done by the student and teacher working as partners. Background information for the teacher is provided at the beginning of each lesson plan so that the teacher can be more knowledgeable about the given aspect of sound than the students.

In the school system in which this series of lessons was tried, the curriculum on sound is based more on the goal of exposure than that of mastery of concepts. Sound is not a topic which is part of the science curriculum prior to third grade and, therefore, the students enter the lessons typically not having considered sound on a formal level. However, students do enter the lessons with some of their own ideas about sound based on personal experience. The goal of a series of lessons on sound is to provide the students with sequential experiences which are broader than those they have had informally and the opportunity to analyze and discuss these experiences. Mastery of the concepts introduced is not expected. However, shaping of ideas which approximate scientifically accepted ideas is desirable.

The third grade science curriculum on sound includes the following topics: sound as vibration, observation of variations in pitch and observable reasons for the variations, the loudness of sound and that which observably affects it, and the conduction of sound. The topics obviously needed to be scaled down compared to a comprehensive unit. However, working from the experiences of students is important when working with young children and it takes time. Also, sound, since it is not easily "seen," is a fairly abstract concept for young students.

Lessons 1, on vibration, and 4, on conduction, are delineated in this chapter. Lesson 2, on pitch, focuses on pitch as a function of the frequency of vibration and the amount of substance vibrating. Lesson 3, on volume, stresses that volume means loudness in this case. Focus here is placed upon loudness being determined by energy put into the vibration and the amount of surface area vibrating. Both lessons 2 and 3 are activity-based, requiring student groups to move through a series of stations, just as in lessons 1 and 4.

Thinking skills addressed in each lesson. As this thesis includes the plans for two sample lessons, lesson 1 and lesson 4, the reader may find it difficult to follow the sequence of thinking skills taught within the series. Therefore, Figure 3 on the following page delineates within which lessons each thinking skill is taught.

I planned to focus upon each targeted thinking skill in two of the four lessons. Lesson 1 on vibration targets logical reasoning and inferring cause/effect, as I felt these skills are used in tandem in real life, and inferring cause/effect is essential for students to determine the cause of sound. Lesson 2 on pitch targets analyzing fact/opinion, because I wanted my students to begin to make this delineation early in the lesson series. It is an integral part of professional science. Logical reasoning is also targeted because it is necessary in determining factors contributing to change in pitch. Lesson 3 on volume targets comparing/contrasting and inferring cause/effect. Students are required to use comparing/contrasting, rather than just logical reasoning as in lesson 1, to infer cause/effect relationships regarding volume. Lesson 4 on conduction targets analyzing fact/opinion and comparing/contrasting. Comparing/contrasting is used not only to determine materials through which sound travels versus those through which it does not, but also to identify any discrepancies in thought evident in the portfolios at the end of the lesson series. Analyzing fact/opinion is used to make observations and conclusions as objective as possible.

	Lesson 1 Vibration	Lesson 2 Pitch	Lesson 3 Volume	Lesson 4 Conduction
Fact/ Opinion		X		X
Compare/ Contrast			X	X
Logical Reasoning	X	X		
Cause/ Effect	X		X	

Fig. 3. Thinking skills in the lesson series.

Sample Lesson 1: Sound as Vibration

Background information for teachers. Sound is produced by objects and substances vibrating. This vibration causes sound waves. These sound waves travel out from the object in all directions and, if they could be seen, would look like the ripples emanating from the spot in the water where a stone had been dropped. These sound waves get weaker as they travel further from the source of the vibration. When an object begins to vibrate, due to being struck for instance, the vibrations cause the adjacent air molecules to move. These moving air molecules cause the air adjacent to them to move and so on. The motion of the air molecules adjacent to the eardrum of a person is the first condition needed for hearing.

Science objectives. The following three objectives pertaining to science content and scientific behavior are addressed in this lesson:

1. The student will infer the cause of sound and give evidence for the inferred cause.
2. The student will participate in a small group discussion to share various thoughts and points of view about the cause of sound.

3. The student will participate in the design of an experiment to test the cooperative group's hypothesis about the cause of sound.

Targeted thinking skills. Two thinking skills are addressed in this lesson. They are:

1. Inference of cause/effect.
2. Logical reasoning.

Objectives for use of thinking skills. The targeted thinking skills for this lesson are used in the following ways:

1. The student will support with evidence another cause/effect relationship of his/her choice.
2. The student will use logical reasoning to interpret observations.

Instructional strategies. The following two instructional strategies are utilized in this lesson. They come from Paul's 35 instructional strategies (1992).

S-32 Making plausible inferences, predictions, or interpretations.

S-25 Reasoning dialogically: comparing perspectives, interpretations, or theories.

Cooperative learning techniques. Two cooperative learning techniques are used in implementing this lesson.

They are as follows:

Think-Pair-Share.

Co-op Co-op.

Contents of portfolio. The students will save some of their written records for future use. The following are placed in the portfolio during this lesson:

1. Final copy of Facts/Opinion/Questions chart (see Appendix B).
2. Observation sheets and responses to metacognitive questions.
3. Inference about the cause of sound.
4. List of questions generated at the end of the activity.

Motivation. This part of the lesson is implemented with the class as a whole. The procedure is as follows:

Show students a bowl of water. Hold a tuning fork out of sight of the students. Say "I am going to splash all of you with water and never get my hands wet." Then go to each student, strike the tuning fork, dip it into the water tipping the end toward the student, and splash each student using the vibration of the tuning fork. Students write observations on senses charts (see Appendix A).

Prior knowledge. The students should be placed in cooperative learning groups of five. Through the implementation of the following activity, the prior knowledge of each student is activated in preparation for the rest of the lesson.

1. Set up five stations with the following materials:

   Station 1: ruler, desk, rubber bands of various widths/lengths, shoe box with $2\frac{1}{2}$ inch holes in the top, string, two chairs.

   Station 2: tuning forks of various sizes, plastic wrap, pepper, string, ping-pong ball, water table.

   Station 3: plastic/foam/wood sheets, bell, tuning forks, large jar, water.

   Station 4: grass, straws, triangle, mallet, scissors, four bottles of the same size, water.

   Station 5: slinky, string, tuning forks, bells, paper cups.

2. Focusing on "What is sound?", the students move through the stations in their groups. As they go, they may "play" and discuss. They may take notes on that which each individual believes to be true but judgment should be deferred. Questions may also be listed.

3. The group then sits in a circle with chart paper. Using "Fact: We Know," "Opinion: We Think We

Know," and "Questions" as headings, the group will list student ideas generated at the stations.

4. For each "Fact," the following questions will be discussed:
   1. Can this be directly seen, heard, felt, tasted, or smelled? Or would you have to think about what you observe to arrive at this statement?
   2. Might someone else say something different or would everyone agree? What might be another explanation?
   3. What evidence is there for and/or against the fact?
   4. Is there a more accurate way to say this?

   For each statement under "Opinion," discuss:
   1. What would the world be like for this to always be true?
   2. What would the world be like for this to always be false?
   3. What evidence is there for and/or against this?
   4. Is there a more accurate way to say this?

Activity. The central activity of this lesson is done in cooperative learning groups of five. The procedure is as follows:

1. The student groups move through the following five stations, each recording observations:

Station 1: Hang a ping-pong ball from a string. Touch the hanging ball to a struck tuning fork (AIMS 1990), the plucked strings of a guitar, and the back of a piano while it is played. Put your hand on a struck tuning fork, a guitar being played, and the back of a piano being played.

Station 2: Stretch plastic wrap over a plastic cup and sprinkle pepper on it. Strike a tuning fork and touch it lightly to the stretched plastic wrap. Place the cup on a guitar being played and a piano being played.

Station 3: Wrap tissue paper around a comb once. Put lips to it and hum. Hold grass tightly between thumbs allowing thumbs to touch only at the tips and the bases. Blow into the space and over the stretched grass.

Station 4: Fasten a rubber band between two nails, put two small crumpled balls of paper on the band, and pluck the band (Friedl 1986).

Station 5: The teacher darkens some glass with the carbon of a flame. Affix a fine wire to the end of one of the tines of a tuning fork, strike the tuning fork and hold it so that the wire lightly touches the glass. A student can pull the glass in one direction so that the track can be seen (Friedl 1986).

Portfolio and metacognition. For this activity, the students are in cooperative learning groups of five and use the Think-Pair-Share technique. The targeted thinking skills of inferring cause/effect and logical reasoning are addressed in this section. The procedure is as follows:

1. Gather the class together temporarily for this step. Each student completes the statement "I infer the cause of sound to be _____." or "Based on my observations, I think the cause of sound is ____." Each student will then find a partner and discuss the statement. If necessary, each partner will clarify his/her ending to the statement. The cooperative learning groups will reform.
2. The group will review each station using the following questions for portfolio response:
   a) What happened? (observations)
   b) How did I interpret what happened?
   c) Are there other ways to interpret (think about) what happened? What are they?
   d) What factors did I think were important to consider when coming to my conclusion?
   e) Did I consider all sides of the problem or might there be other points of view?
3. Each group member will share what s/he infers as the cause of sound and give specific evidence

from the activities, and outside world if possible, to back up the inference.

4. The group will discuss inferences and agree on one for the group based on the evidence given. The group will concentrate on the following questions: How does your view relate to another's? Would a musician agree? A singer? Why or why not?
5. The group will design another experiment to test its hypothesis in another way using the Co-op Co-op technique. They will vote on the idea to use. They will conduct the experiment. The group will answer:
   a) What have you learned from your experiment?
   b) What questions about sound might you ask now?

Transfer. The cooperative learning groups will use the Co-op Co-op technique in the following activity to bring about transfer of thinking skills:

Each member of the group will think of another cause/effect relationship s/he believes is true and present evidence to support the belief, including examples of other interpretations and why they would be less believed. The group will create a list of cause/effect relationships.

Sample Lesson 4: Conduction

Background information for teachers. Sound energy travels in waves. How quickly and easily sound travels through a substance is determined by the density and elasticity of the substance. The more elastic the substance, the faster sound will travel through it. The more dense the substance, the slower sound will travel through it. For instance, steel is 6000 times denser than air but 2 million times more elastic. Therefore, sound travels faster and more easily through steel. Clarity of sound depends on the percentage of sound waves of different frequencies which successfully travel through a substance. The smaller the range as compared to the original sound, the less clearly the sound will be heard. Volume of sound depends on the strength of the sound waves. The thickness of a substance and how much it dissipates energy will also affect the volume and clarity of the sound traveling through it.

Science objectives. The following two objectives pertaining to science content are addressed in this lesson:

1. The student will compare and contrast the way sound travels through various substances.

2. The student will give reasons for the differences in the conduction of sound.

Targeted thinking skills. Two thinking skills are addressed in this lesson. They are:

1. Comparing and contrasting.
2. Analyzing fact/opinion.

Objectives for use of thinking skills. The targeted thinking skills for this lesson are used in the following ways:

1. The student will analyze ideas to determine whether they are fact or opinion.
2. The student will compare and contrast observations in a clear manner.
3. The student will identify contradictions between prior and present thinking by comparing lists of conclusions generated during the lesson series.

Instructional strategies. The following four instructional strategies are utilized in this lesson. They come from Paul's 35 instructional strategies (1992).

S-11 Comparing analogous situations: transferring insights to new contexts.

S-13 Clarifying issues, conclusions, or beliefs.

S-29 Noting significant similarities and differences.

S-34 Recognizing contradictions.

Cooperative learning techniques. Three cooperative learning techniques are used to implement this lesson. They are:

Co-op Co-op.

Three-Step Interview.

Jigsaw.

Contents of portfolio. The students save some of their written records from the lesson. The following are placed in the portfolio:

1. Prior Knowledge "facts" and "opinions."
2. List of materials and similarities/differences in how they conduct sound.
3. Answer and reasons for the answer to the question about the quality of the teacher demonstration.

Motivation. This activity is done with the class as a whole. The procedure is as follows:

The teacher will affix a large plastic cup over his/her mouth, fasten a large scarf over that, and pin cotton batting between two scarves to tie over the cup and first scarf. S/he will walk into the classroom and begin to give directions. As students begin to comment on their inability to understand that which is being said, the teacher will remove one layer at a time and give directions after each layer is removed. The students will be asked to write about that which they have observed and the thoughts they had as they observed it.

Prior knowledge. In this activity, the students work in cooperative learning groups of five and use the Three-Step Interview technique. The targeted thinking skill is analyzing fact/opinion using instructional strategy number S-13 (Paul 1992). The procedure is as follows:

1. The group of students will sit in a circle and take turns interviewing the students to their right focusing upon the question "Does sound go through things? If so, explain what you know about it." The students should have 5-7 minutes to interview. They may take notes. The teacher should emphasize that special attention should be paid to differentiating fact from opinion and clarifying what students specifically mean by their statements. As five students are in each group, two interviews will usually be taking place at once and each student will have a period of time in which s/he is not interviewing. This time can be spent formulating questions and/or clarifying his/her own ideas.
2. The students will then each share with the group what they learned about the ideas of the other student. They will indicate ideas as facts

or opinions and state reasons for these designations. The group recorder will record all ideas on chart paper with two columns, "Facts" and "Opinions."

3. Students from the group as a whole will ask questions in order to clarify stated ideas or establish possible error in designation of fact or opinion.

Activity. Students begin this activity in expert groups as explained below. The Jigsaw technique is used. The targeted thinking skill of comparing/contrasting is addressed utilizing Paul's instructional strategies S-29 and S-34 (1992). The procedure is as follows:

1. Students will be given the focus topic of "How Sound Travels through Different Materials."
2. Each student in the group will be assigned a station to which to go and become an "expert." The five stations are as follows:

   Station 1: Ring a bell in the air, on the other side of a window, on the other side of a wooden door, and on the other side of a concrete wall.

   Station 2: Wind up an alarm clock and let it ring in the air, in a coffee can, in a shoe box with newspaper around it (AIMS 1990), and in the water table with an ear in the water.

Station 3: Drop a dictionary from waist high onto a carpet, onto the tile floor, and onto a gym mat.

Station 4: Use a mallet to hit a steel strip, a sponge, and a felt eraser.

Station 5: Make and use a telephone with two paper cups and string, and a rubber band, and a slinky (AIMS 1990).

The group experts should read the directions for the station, predict what will happen, and then record observations on individual senses charts (see Appendix A). Each group of experts should consider and take individual notes on the following questions:

a) How are the sounds we heard the same? Different?

b) Why do the similarities and differences exist?

c) What do the similarities and differences teach us about how sound travels?

d) Under what conditions might sound NOT travel?

3. The group experts will go back to their cooperative learning groups and share their observations and ideas. A chart will be used delineating each station for group note gathering.

4. The group will list three different materials and note similarities and differences in the way sound traveled through them. They will give

at least one reason for each similarity and difference. This list will be hung up in the classroom to share with all.

5. After the group has perused the lists of the other groups, it will sit to watch a teacher demonstration.
6. The teacher will fill a tank with water and ask each student to put his/her ear to the side of it while the teacher bangs rocks together under the water (Friedl 1986). After all of the students have had a turn, the teacher will ask if this is a good way to demonstrate how sound travels through water.

<u>Portfolio and metacognition</u>. During this activity, the students work in cooperative learning groups of five and use the Co-op Co-op technique. The two targeted thinking skills are comparing/contrasting and analyzing fact/opinion. Instructional strategies S-11 and S-13 (Paul 1992) are utilized. The procedure is as follows:

1. The students will each state whether or not s/he felt the demonstration was a good way to show how sound travels through water and give reasons for his/her statement.
2. The group will discuss the validity of the reasons given by the members as they are given. Questions such as "Would everyone agree with this?", "Might

someone else see it differently?", or "Could there be another explanation?" should be discussed.

3. The group will agree upon an answer to the question "Was the demonstration a good one?" and list reasons for the answer on a piece of paper for the portfolio.
4. The group will peruse its entire portfolio, concentrating on conclusions drawn and "facts" and "opinions" stated. The group will try to identify any contradictions in its notes taken throughout the lesson series.
5. Contradictions will be circled and the following questions will be discussed:
   a) Why did we think two different things?
   b) Could both ideas be true?
   c) If not, which idea has changed and why?

Transfer. In this activity, the students work in cooperative learning groups of five using the Co-op Co-op technique. The targeted thinking skills are comparing/contrasting and analyzing fact/opinion. The procedure is as follows:

The student group will compare and contrast two analogous situations, the recent fight on the playground and the attack on U. S. figure skater Nancy Kerrigan. They will be encouraged to use a Venn Diagram to help them record their thoughts. They will then be asked to discuss the similarities and differences between the two situations which they have recorded and determine which differences and similarities are a matter of fact and which are opinion. The students will then describe the roles fact and opinion had in the unraveling of each of these situations.

Notes on Student Critical Thinking Behaviors

Lesson 1. During this first lesson, it should be expected that students will demonstrate very little critical thinking unless guided. The teacher should look for and encourage student use of critical thinking vocabulary and phrases such as "Sound is caused by ....", "I infer that ....", "I observed ....", and "My reasons for this are ...." The use of such vocabulary should be modeled by the teacher by reiterating student statements. For example, if a student says "I think that sound is made by something moving because something moved at all of the stations," the teacher could restate this by saying "So you infer the cause of sound to be something moving, or vibrating, based on what you observed at the stations." At first, this type of thinking vocabulary will be used very infrequently by the students.

Teachers should also look for and encourage the support of student conclusions by observable evidence from the activity or from life experience. Students should be asked not only to say what they think but to back it up with observable evidence. Students should begin not only to consider other viewpoints but also hypothesize reasons for other views agreeing or disagreeing with their own.

Finally, teachers should begin to listen for and reinforce better questioning by the students themselves. It is desirable at this point for students to begin to independently ask peers to back up statements by asking questions such as "Why do you think that?"

Lesson 4. By the last formal lesson, it is desirable for students to be in the habit of using critical thinking vocabulary. The use of words such as "fact," "opinion," "similar," "different," "compare," and "contradiction" should be encouraged as a sign of a good thinker. The teacher should continue to model this type of vocabulary but will know the students have made it a part of their own working vocabularies when they use it independently.

The students will demonstrate improvement in critical thinking skills in this lesson by giving real-world or observable reasons for determining facts and opinions and specifically defining how compared objects and situations are similar or different. Students in third grade cannot be expected to be completely independent in this regard, but the teacher should be looking for increased independence.

Students who are becoming better critical thinkers will more often back up their observations and conclusions with concrete, observable evidence than they did at the beginning of the lesson series. They will more often recognize contradictions in their portfolio notes and be able to discuss them. A student who consistently supports statements with "I don't know.", "It's just what I think.", and statements such as these should be recognized by the teacher as one who has not internalized critical thinking skills.

The greatest evidence that a student is progressing well in critical thinking is that not only is s/he able to back up statements but also s/he is able to question other students independently in a way that closely resembles that delineated in the lessons. A student showing good improvement in questioning skills is showing evidence of becoming a good critical thinker. Such evidence is shared in the next chapter which discusses student discussions and portfolio entries.

CHAPTER V

REFLECTIONS

Though my students were used to cooperative learning and portfolios, the implementation of the types of lessons in this series on sound was quite new to them. The implementation of the lessons brought about surprises for both the students and myself. Though individual student results varied somewhat, there were some interesting consistencies in how the students received this new type of learning and the conclusions they drew.

Trial Implementation of the Lessons

Practical issues of implementation. The series of four lessons on sound plus a creative culminating activity were tried in my third grade classroom. The first impression which became clear was that this series of lessons taught in this way consumed much more class time than had been predicted. From first lesson to final activity, this series took approximately one hour per day for about six weeks. The method of teaching seemed to be the main factor contributing to this unpredicted length of time. The method of instruction required great amounts of time for student exploration and discussion. This is not to say that the time was not well-spent. On the contrary, the extra time was used by the students to actively engage in learning rather than passively absorb meaningless facts presented by the teacher in some more traditional models of instruction. However, when engaging in this type of instruction, a teacher should be forewarned that periods of time more extensive than might be the norm for a unit should be expected.

This method of instruction which embeds the instruction of thinking skills into content area instruction also requires much more teacher effort, preparation, and involvement than most traditional methods. This seems a like paradox when considering that the role of the teacher is to be a facilitator and that more of the responsibility for learning is placed on the students than in a more traditional model. However, in order for the teacher to set up activities and ask questions which will guide students in their own learning, the teacher must constantly be truly listening to student responses, and interpreting the meaning of those responses in relation to student learning. The students really become more in control of exactly which path they will take in learning. The teacher can still determine the goal or final outcome of learning. In order for the path the students take to reach the goal desired by the teacher, the teacher must strive to design activities and ask questions which will constantly reshape the thinking of the students. The teacher also must serve as a model of good questioning techniques and critical thinking. All of this requires much more involvement by the teacher than the traditional textbook approach.

The physical limits of the classroom were also a concern while implementing this series of lessons. Many of the materials were cumbersome and needed to be kept in place in the classroom all day. Materials such as a water table or a piano are much more easily kept in place for the entire seven weeks than moved in and out of the room every day. However, these types of materials also consume valuable space in a classroom when they are not being used. The ideal would have been to maintain a science center in the school for classes to use during their science lessons. Unfortunately, this is not possible in most schools.

The physical limits of the school also constrained the types of activities which could be designed to help students reshape their thinking. Space was small and available materials were limited. The school does not have rooms unused for part of the day because it is fairly crowded. Therefore, our class could not even expand the activities into another room. This is a limitation which teachers must deal with on a daily basis.

Student attitudes. Third grade students tend to prefer lots of activity within a classroom and most have great enthusiasm for science. The majority of students enjoyed the series of lessons and the group work which was involved. Many of them seemed to experience a sense of wonder at their own learning, especially apparent when faced with written records of ideas they had at the beginning of the lesson series versus those they had formed closer to the end. Many comments such as "I can't believe I said that!" and "I've sure gotten smarter!" were made during the metacognitive review of the portfolios.

Two students seemed to feel uncomfortable with the method of instruction used during this lesson series. When I recognized their discomfort, I engaged in the following dialogue with the two students. This dialogue was taped during Lesson 3 of the series. It should be noted that both are boys. Student A was categorized as a quiet student and Student B was categorized as loquacious for the purpose of grouping.

Teacher: You seem uncomfortable. Am I right?

Students A and B: Well, yeah, yeah.

Teacher: Can you explain why? What are you feeling?

Student A: I just don't like this stuff.

Student B: I'm tired of all this talking!

Teacher to Student A: Can you tell me what part of these lessons you don't like?

Student A: I don't know. (pause) When are you going to teach us something?

Teacher to Student A: Do you feel you have learned anything about sound which you didn't know before we began to study it?

Student A: Well, yeah, I guess.

Teacher to Student A: Can you tell me something you've learned?

Student A: Well, that things make sound when they vibrate and that the vibrations make the air move and the air moves other air 'til the air near your eardrum moves and makes you hear a sound.

Teacher to Student A: Wow! How did you learn all of that?

Student A: We figured it out at the stations.

Teacher to Student A: Who do you think set up the stations?

Student A: You.

Teacher to Student A: Yeah. See, a teacher can only plan activities that will help you learn. I can't learn for you. I can tell you a bunch of stuff but you probably won't remember it as well as if you figure it out for yourself. So I plan things for you to do that will help you figure things out for yourself. Do you understand?

Student A: Yeah.

Teacher to Student B: You said you were tired of all this talking. Can you tell me what you mean?

Student B: We talk, talk, talk. I don't like it.

Teacher to Student B: What would you rather be doing?

Student B: I like to write and draw, like those books, ya' know? (referring to creative writing)

Teacher to Student B: Well, there are other things that will be helpful for you to learn, too. Why do you think I'm asking you to do all of this talking, discussing?

Student B: I don't know.

Teacher to Student B: Well, what would be your best guess?

Student B: I don't know, so we can tell each other ideas, I guess.

Teacher to Student B: Good thought. Sometimes other people think of ideas that we don't. Have you ever heard of the saying "Two heads are better than one?"

Student B: Yeah.

Teacher to Student B: Well, that's the idea of discussing things. Since you like to write so much, how would you like to write a science newspaper? You could think of questions you would like to ask the people in your group like an interviewer - but they have to be questions about what the group is doing and each student's ideas. Afterward, you can draw pictures for it and we'll make copies. Are you interested?

Student B: Yeah. Can [Student A] help?

Teacher to both students: Yes. But you have to make sure you participate in the group work, too.

Students A and B: Okay.

Upon subsequent observation of the group to which these students belonged, it was noted that Student B and the group as a whole were no more talkative than other groups. These two students went on to become active participants in their group. They did most of their interviewing during snack time and, at the time of this writing, are still working on The Science Sounder as it has expanded beyond the topic of sound.

Without exception, each student was involved in the activities and discussions. Some of the students who felt more reluctant about their knowledge of science seemed to become much more talkative when "science babble" was banned from all discussions (see Appendix D - Trouble Shooting Tips for Teachers). When students were required to use language which all members of the group understood, the more reserved students began to take part in the discussions and explain their own ideas. This may have been due to greater comprehension of the discussions by these students or greater confidence in their ability to explain their ideas in acceptable ways. Whichever was the key factor, greater participation resulted.

Interpretation of student learning. I have interpreted student learning based upon my observations. Emphasis in this lesson series has been placed upon the learning of science-like behaviors and critical thinking skills rather than upon the memorization of facts. No test was given at the end of this series. The culminating activity was more of a creative endeavor than a test of skill. Transfer of thinking skills was assessed at the end of each lesson.

One of the goals of this series was to impress upon the students that science is a work in progress and that with each new finding come new questions. A full realization of this would be indicated by the ability of the students to accept the existence of unanswered questions. During the lessons, the students were periodically asked to record questions which they had about sound.

At the beginning of the series of lessons, the students desperately attempted to answer all of the questions they had recorded by the end of the lesson. I had to continue to reiterate that unanswered questions are a natural part of science and I discussed with them examples of such questions as "Is there an end to the universe?" or "What causes some people to be talented in some things and other people to be talented in others?" By the end of the series of lessons, though the students seemed to be able to articulate the idea that unanswered questions were acceptable, they continued to have trouble accepting the idea as demonstrated in this short dialogue:

Student C: We still have to find out how a soundproof room works.

Student D: No, we don't. That's one of the questions that we thought of at the end.

Student C: But we didn't answer it yet.

Student D: That's okay. Sometimes you can't answer all the questions in science.

Student C: We could look it up.

Student D: We're not supposed to be doing that. We're supposed to be going through our portfolio.

Student C: Okay, but if we get it wrong it's not my fault.

Clearly Student C did not truly accept the idea that unanswered questions are acceptable. This was surprising because she was categorized as a person with a strong, seemingly flexible, personality. This student was later asked if she would like to do some research on the subject of sound proofing. When told the research would be to satisfy her own curiosity and she would not be given a special grade, an idea that usually takes pressure off students, she chose not to do it. She was more interested in giving the teacher that which she perceived the teacher wanted. Many of the other students clearly demonstrated ambivalence about leaving their earlier recorded questions unanswered. Six weeks of instruction clearly cannot always undo previous years of programming.

Many of the students did begin to ask more effective questions as the lessons proceeded. At the beginning of the series, I had to do much prompting and modeling of questioning. Students left on their own began the series asking questions such as "What do you think?" or "What happened?" By the end of the series many of the students were observed to be asking questions such as "Did you see that happen?", "Did you have to think about it before you understood it?", "Is that the only way to explain it?", and "Would someone else have a different point of view?" These questions parroted the type prompted by the teacher.

The portfolios allowed a feature of student learning to be recognized which would otherwise have been overlooked. The students, as their understanding of concepts changed, tended to forget their prior thoughts completely. Only upon seeing them recorded in the portfolio did they remember. An example of this occurred during the lesson on the conduction of sound. One of the groups went back to the tuning fork in the water and began to discuss how sound travels through air to get to the ear. They were following the transmission of vibration from air "spot" to air "spot" and on to the eardrum. (They studied the ear in grade two.) I then asked them if sound travels in space. They unanimously answered an unequivocal "no." They were then asked to check in their portfolio and read their first list of "facts" about sound. They had, in fact, written that sound was everywhere in the universe. I had also recorded them saying that space must be very noisy with all the hissing and banging planets, meteors, and stars must make, not to mention the spacecraft which might be there. When they read their first comments about sound and listened to their conversation about sound in space, they were shocked. The following dialogue occurred:

Student B to teacher: Can we erase what we put before?

Student D to Student B: No, we just didn't know before and now what we think has changed. Like you used to not know how to read and now you do.

Student E: Yeah, there's nothing wrong with that. That's what scientists do.

Students in other groups demonstrated surprise at some of their preliminary ideas about sound, also. They may someday be surprised at some of what they think about sound now. The portfolios are being kept, because some students decided to participate in some extension activities.

The portfolios also aided the students in recognizing discrepancies in their recorded thinking even before recognition of discrepancies was a targeted behavior in a lesson. Within the very first lesson one student said to another "We can't say you can see sound vibrate because here we said vibration can't be seen!" This prompted a lively discussion among the group members and eventually led them to change their first recorded response due to new evidence.

Observed transfer. A few of the more loquacious, talented students began to ask their own questions linking that which they had learned to their own lives. One of the students is a gifted musician. During his group's discussion about how sound travels and through what it travels easily, he asked a fellow group member "If I'm playing my trumpet and I want to mute it, you know, make the sound that comes out muffled like [he demonstrates the sound], what material would I use for the cone?" This is an example of "low road transfer" (Perkins and Salomon 1991, 218).

Another said to a fellow group member "When I went to the doctor when I was sick he used a tuning fork on my head. He banged it and put it on my head, here between my eyes. I could hear it real loud in this ear and that's how he knew I had a[n] ear infection. How do you think he knew?" To clarify this event, the parent explained to me that the doctor had determined that there was fluid in the sinuses on one side of the head. He did so by using the tuning fork as the student explained. The excessive loudness of the sound the student heard in one ear was because the fluid vibrated, causing the eardrum to vibrate. The student was not only hearing through the bones in her skull on this side but also through the back of her eardrum where the fluid came in contact with it. The first student knew the answer to her question and the second one thought he had figured it out. However, rather than partly attributing the travel of sound to the fluid in her sinus and ear, he attributed it to the bones of her skull, disregarding any effect the fluid might have had. However, both students attempted to ask questions which dealt with real-life situations and extended learned concepts beyond the classroom in this second example of "low road transfer" (Perkins and Salomon 1991, 218).

One serendipitous incident started unplanned discussions in all of the groups. Within the first period of group activity in the first lesson, the plastic which was stretched across the opening of a cup ripped slightly. The original intent of the station was to have students use a vibrating tuning fork to make pepper bounce on the plastic by holding the tuning fork lightly on the surface of the plastic. Once the plastic ripped, the sound created was much more audible, it reverberated inside the cup. One student, during the discussion his group had about how the new sound was created, said "That must be why guitars have holes in them. So the sound sounds louder and kind of echoey." This is a display of "high road transfer" (Perkins and Salomon 1991, 218). All of the groups were given the chance to participate in the activity with intact plastic and then allowed to experiment with ripping the plastic, an idea about which I had never thought until the accident. Some of the groups tried enlarging the rip to see how the sound changed. Upon finding that the sound actually sounded better with a small rip, they discussed why this might be. They concluded that the sound needed "tight" things to bounce off and a large hole caused the remaining plastic to be too loose.

Enrichment of the Topic of Sound

Enrichment activities will be prompted by student reaction, interests, and findings during the lesson series. Later in the school year, this third grade class will definitely study sound as it relates to the functioning of musical instruments. Much student interest lies in this area, and many of the questions derived from the lessons were related to musical instruments.

Some of the more motivated students will be doing some activities to study the Doppler effect. This will require some preliminary investigation into sound waves, and complete mastery of the concepts will not be expected. However, many of the students are very aware of the manifestation of the Doppler effect and are curious to know why it happens. These activities may need to take place after school with parental permission to visit the highway nearby the school.

Finally, a field trip to the local Army Labs to investigate soundproof rooms and materials would be very instructive. If this cannot be done, a trip to the local fitness club will provide opportunity for the students to ask questions about the materials used to build racket ball court walls. These materials provide a certain amount of soundproofing and one side is a window through which very little sound travels.

Extension Beyond the Topic of Sound

Extension beyond the topic of sound would focus upon the critical thinking skills taught within the lesson series. It may also include concepts which do not exclusively apply to the topic of sound.

This class will be investigating the concept of vibration. The recent earthquake in California provides a good way to connect this concept with a topic other than sound. Vibrations of different magnitudes and their effects on a home, specifically the bedroom of a student, will be discussed. Tables and small models of the bedroom will be utilized. The students can first construct a models of their bedrooms using map skills learned in Social Studies and the concept of scale learned in Math. These models will then be put to the test by shaking a table to various degrees to see the type of damage which might occur. Vibration can also be investigated using the car commercial in which a stack of wine glasses is placed on the hood of a car as it is running. Some more motivated students may then want to research shock absorbers independently. The possibilities for finding examples of vibration in the world of the students are great.

The thinking skills focused upon in this series of lessons can be extended into many other content areas. Analyzing fact/opinion is ideal to utilize during Social Studies, especially current events. The widely publicized controversy about whether Tonya Harding was involved in the attack on Nancy Kerrigan allowed this third grade class to do just that. Playground scuffles can also be a medium for practicing this skill. Comparing/contrasting can be used in geometry when identifying various shapes and solids. It can be used when analyzing characters in a story. Events in history can be discussed using this thinking skill. Especially helpful is the use of a Venn Diagram. Most interesting is to present the students with two seemingly very different events, such as Rosa Parks refusing to sit at the back of the bus and Henson and Peary's race to the North Pole, and ask them to compare and contrast them. One difference cited by this class was that Rosa Parks acted for her civil rights and Henson and Peary were trying to discover and explore something new. Two similarities stated were that in both cases the people became famous in history and in both cases someone did something which no one else had ever done.

Inferring cause/effect can be used when teaching students about social behavior. It can also be used when talking about pet care. Art is a fun place to practice this thinking skill. Mixing colors, using various materials, watching what happens to balloons with papier-mâché over them are all opportunities for this type of skill to be utilized. A unit on ecology will offer many chances for students to utilize the thinking skill of inferring cause/effect.

Logical reasoning can be used throughout the curriculum and is often the most encouraged in a typical classroom. Using a discovery approach and allowing the students to take more responsibility for actively learning while in school will open up many opportunities for them to use logical reasoning skills.

Unexpected Discoveries

As the lesson series was implemented and I intently observed student behaviors and comments, I was surprised to discover several significant misconceptions the students held about sound. I define a student misconception as a concept apparently held by a student or students which is incompatible with accepted scientific thought and which shows resistance to change in light of opposing evidence. Posner et al. describe misconceptions as "alternative frameworks" (1982, 211). Both definitions suggest that misconceptions are not isolated but become the basis for future concept development. Some researchers have noted that misconceptions are formed through the interaction of previously formed concepts of a student with experience. Some of these previously formed concepts began in early childhood and may, indeed, be misconceptions themselves (Stepans 1988; Strike 1983). Misconceptions are particularly worrisome, therefore, because they may be cumulative. A misconception formed in early childhood may form the basis for more misconceptions in later childhood and these, in turn, may form the basis for misconceptions held into and throughout adulthood.

The tenacity with which students hold onto these misconceptions, an aspect which is a defining feature of a misconception, also makes them difficult to address.

The reason for this tenacity is attributed to how very well misconceptions work in the everyday lives of students in and out of the classroom (Anderson and Smith 1983; Stepans 1988; Viennot 1979). I found it difficult to create situations in which some of the misconceptions of my students did NOT work. This difficulty was because of the physical limitations of the school.

The first misconception which readily became apparent was that sound is an independent entity which is ever-present everywhere in the universe. Students described it as "a thing that goes through space and when it vibrates it can be heard." When I asked if there was ever a time that sound did NOT vibrate, the students replied "Yes, but then you can't hear it." I then asked if sound is still called sound if it cannot be heard, the students replied "Yes, but it's silent then. But it's still there." Attempting to get students to describe sound exactly was difficult. One student said "You can't see, feel, taste, or touch it but you can hear it when it vibrates." Even after the students could trace the transmission of vibration from the source through a medium to the ear, they still often spoke of sound in other situations as though it were a separate entity rather than the vibration itself. The concept of "What is sound?" may be too abstract for this age group to completely understand.

Based upon the aforementioned misconception was the misconception that sound cannot be seen or felt. Since the students considered it an independent entity in the air, of course it could not be seen or felt because we do not see or feel it in the air. Though a hearing-impaired student disagreed and explained that she feels sounds all of the time, most students continued to discuss sound as though it could not be seen or felt. Students did begin to correct each other, reminding each other about observations made during activities where they could see vibrations or feel sound that was being produced. However, most of the students showed that their first impulse was to fall back on the idea that sound cannot be seen or felt.

A misconception which surprised me was the idea that the louder a sound becomes, the higher the pitch and, conversely, the more quiet a sound becomes, the lower the pitch. One student commented "When something gets loud it goes higher and higher. I've seen it on 'Star Trek: The Next Generation.' The sound goes higher and higher and louder and louder and you can go crazy!"

Another student in the same group said "That's why we say 'Keep your voices low.' when we mean talk quietly." I observed this lowering of pitch when the students were asked to talk quietly and realized it is a common reaction which I never noticed before. To try to counteract this misconception, the students were allowed to beat on drums and compare whether the pitch gets higher as the drum beat becomes louder. They were also allowed to play the high notes on the piano at various volumes and decide whether the pitch changed. They did eventually agree that pitch does not necessarily go up as the sound gets louder and vice versa. They began to connect the energy put into the vibration with volume, such as when one beats a drum harder to make a louder noise, and the amount of substance vibrating with pitch, as seen when plucking rubber bands of various widths and thicknesses. However, one student cited the Blue Angels' demonstration, a show featuring Naval pilots flying state-of-the-art aircraft in various formations, and race car sounds as examples when the misconception held. This student has not yet had the chance to research the Doppler effect.

The most difficult misconception with which to deal, due to the physical limitations of the classroom, was that the transparency of a substance determined how easily sound travels through it. The students stated that if a substance is transparent, sound travels through it easily and, if a substance is opaque, sound does not travel through it. One group of students insisted that sound would not travel through the wooden door because one cannot see through it. Though I brought up instances when the class could hear other students walking down the hall and the students experienced hearing a bell ringing on the other side of the door, they held on to their misconception. The students explained sound being heard on the other side of the door by saying it went under the door. When the opening under the door was sealed with paper and cloth, the students still insisted that the sound could come through the cracks around the door. This type of thinking was difficult to counteract.

An ideal situation would have been to have access to a large wooden box in which each student could be sealed for a moment to determine whether or not s/he could be heard making sounds or hear sounds on the other side of it. Glass is a substance which seems to substantiate this misconception because one can see through it and hear through it. An ideal situation would be to have access to a soundproof booth with a window so that students could see that, though they can see into the booth, they cannot hear sound from inside it. Again, this misconception was difficult to counteract.

Concluding Remarks

Though most of the misconceptions identified in this thesis, and undoubtedly others not yet evidenced, are very difficult to change in one series of lessons, it was apparent that a definite change in the way students think took place. The use of cooperative learning techniques and portfolios to aid in embedding critical thinking skills into lessons on sound brought about definite positive results in which students became much more aware of other possible points of view; they asked more investigative questions rather than factual ones; and they did not passively accept that which they observed but more often asked why. Students could be heard using phrases such as "It's my opinion that ..." or "What evidence did we observe that helps us know that?" These changes may seem slight but they change the whole way in which students view and participate in science activities. They help students dig more deeply into issues, clarify problems and conclusions, and take charge of finding answers to their questions.

The process of becoming a good critical thinker is a slow one. Some of the students continue to have great difficulty backing up their thoughts with more than "gut feelings." The students seem less willing to participate in livelier group discussions and activities at the end of the week. Embedding critical thinking instruction into curriculum takes a great deal of time and energy for both teachers and students. However, the observable results are that the students are beginning to take more of an active role in their learning; they are much less likely to accept everything I or other students say without asking questions; and they are voicing the opinion that they are learning themselves. The students are thinking for themselves, feeling empowered, and learning from each other.

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The information about misconceptions that I was able to glean from implementing the lesson series has formed the first stepping stone in my investigation of instruction based on modifying student misconceptions. Since misconceptions can have such significant and long-lasting consequences, the development of a tool which facilitates the identification of misconceptions is of particular interest to me. Once misconceptions are identified, instruction can then begin from the conceptual point at which students actually are rather than at the same point for all students.

SELECTED BIBLIOGRAPHY

AIMS. Primarily Physics: Investigations in Sound, Light, and Heat Energy. Fresno, CA: AIMS Education Foundation, 1990.

Anderson, C. W., and E. L. Smith. "Children's Preconceptions and Content Area Textbooks." In Comprehension Instruction: Perspectives and Suggestions, ed. G. Duffy, L. Poehler, and J. Mason, 187-201. New York: Longman, Inc., 1983.

Anderson, Ronald D., Alfred DeVito, Odvard Egil Dyrli, Maurice Kellogg, Leonard Kochendorfer, and James Weigand. Developing Children's Thinking Through Science. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1970.

Baron, Joan Boykoff, and Robert J. Sternberg, ed. Teaching Thinking Skills: Theory and Practice. New York: W. H. Freeman and Company, 1987.

Costa, Arthur L. "Teacher Behaviors That Enable Student Thinking." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 194-206. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Duschl, Richard A., and Drew H. Gitomer. "Epistemological Perspectives on Conceptual Change: Implications for Educational Practice." Journal of Research in Science Teaching 28 (1991): 839-858.

Ennis, Robert H. "A Taxonomy of Critical Thinking Dispositions and Abilities." In Teaching Thinking Skills: Theory and Practice, ed. Joan Boykoff Baron and Robert J. Sternberg, 9-26. New York: W. H. Freeman and Company, 1987.

Friedl, Alfred E. Teaching Science to Children: An Integrated Approach. New York: Random House, 1986.

Gardner, Howard. The Unschooled Mind: How Children Think and How Schools Should Teach. New York: Basic Books, 1991.

Huber, Gunter L., and Renate Eppler. "Team Learning in German Classrooms: Processes and Outcomes." In Cooperative Learning: Theory and Research, ed. Shlomo Sharan, 152-171. New York: Praeger Publishers, 1990.

Johnson, David W., and Roger T. Johnson. "Collaboration and Cognition." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 298-301. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

________. Cooperation and Competition: Theory and Research. Edina, MN: Interaction Book Company, 1989.

Johnson, David W., Roger T. Johnson, and Edythe Johnson Holubec. Cooperation in the Classroom. Edina, MN: Interaction Book Company, 1991.

Kagan, Spencer. "Co-op Co-op: A Flexible Cooperative Learning Technique." In Learning to Cooperate, Cooperating to Learn, ed. Slavin et al., 437-452. New York: Plenum Press, 1985a.

________. "Dimensions of Cooperative Classroom Structures." In Learning to Cooperate, Cooperating to Learn, ed. Slavin et al., 67-96. New York: Plenum Press, 1985b.

________. "The Structural Approach to Cooperative Learning." Educational Leadership (December 1989/ January 1990): 72-75.

Lindsey, Crawford W., Jr. Teaching Students to Teach Themselves. New York: Kogan Page, 1988.

McTighe, Jay, and Rochelle Clemson. "Making Connections Toward a Unifying Instructional Framework." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 304-311. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

McTighe, Jay, and Frank T. Lyman, Jr. "Cueing Thinking in the Classroom: The Promise of Theory-Embedded Tools." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 243-250. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Minstrell, James A. "Teaching Science for Understanding." In Toward the Thinking Curriculum: Current Cognitive Research, ed. L. B. Resnick and L. E. Klopfer, 129-149. Washington, DC: Association for Supervision and Curriculum Development, 1989.

Narode, Ronald, Marcia Heiman, Jack Lochhead, and Joshua Slomianko. Teaching Thinking Skills: Science. Washington, DC: National Education Association, 1987.

Paul, Richard. Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World. Rev. 2d Ed. Santa Rosa, CA: Foundation for Critical Thinking, 1992.

Paulson, F. Leon, Pearl R. Paulson, and Carol A. Meyer. "What Makes a Portfolio a Portfolio?" Educational Leadership 48 (February 1991): 60-63.

Perkins, D. N., and Gavriel Salomon. "Teaching for Transfer." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 215-223. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Posner, George J., Kenneth A. Strike, Peter W. Hewson, and William A. Gertzog. "Accomodation of a Scientific Conception: Toward a Theory of Conceptual Change." Science Education 66 (April 1982): 211-227.

Prawat, Richard S. "Why Embed Thinking Skills Instruction in Subject Matter Instruction?" In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 185-187. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Stepans, Joseph. "What Are We Learning From Children About Teaching and Learning?" Teaching and Learning 2 (Winter 1988): 9-18.

Stevens, S. S., Fred Warshofsky, and the Editors of Life. Sound and Hearing. New York: Time Incorporated, 1965.

Strike, Kenneth A. "Misconceptions and Conceptual Change: Philosophical Reflections on the Research Program." In Proceedings of the international Seminar on Misconceptions in Science and Mathematics, ed. H. Helm and J. D. Novak, 85-97. Ithaca, NY: Department of Education, Cornell University, 1983.

Swartz, Robert J. "Infusing the Teaching of Critical Thinking into Content Instruction." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 177-184. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Vavrus, Linda. "Put Portfolios to the Test." Instructor 100 (August 1990): 48-53.

Viennot, L. "Spontaneous Reasoning in Elementary Dynamics." European Journal of Science Education 2 (January 1979): 205-221.

Wellman, Bruce. "Making Science Learning More Science-Like." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 159-163. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

Winocur, S. L. "The Impact of a Program of Critical Thinking on the Reading Achievement of Middle and High School Students." unpublished doctoral dissertation, U. S. International University, 1981.

Wolf, Dennie Palmer. "Portfolio Assessment: Sampling Student Work." In Developing Minds: A Resource Book for Teaching Thinking, Rev. Ed., ed. Arthur L. Costa, 351-355. Alexandria, VA: Association for Supervision and Curriculum Development, 1991.

APPENDIX A

SENSES CHART

	See	Hear	Feel	Smell	Taste

"How Sound Travels Through Different Materia[ls] Is"

③	See	Hear	Feel	Smell	Taste
Bell 1	Pred: see bell moving in air, see bell moving threw window, nothing threw door or wall.	Pred: loud and clear in air loud and clear threw window, Soft and mufled threw door, cannot hear threw wall	Pred: Nothing unless if your ringing bell then you feel bell shake		
	Act: Same	Act: loud and clear in air, not as loud but clear threw window, very soft and fuzzy threw door, most soft and most fuzzy threw wall.	Act: Same, I can't even feel window, door, or wall move		
Clock 2	Pred: Clock shake in air, can shake paper in box shakes water waves	Pred: loud and clear in air, not loud or clear in can, not loud or clear in box, bubbly in water	Pred: Nothing unless you touch the thing the clock is in then you feel it shake		
	Act: bells on clock shake, can doesn't shake but bells on clock shake, box doesn't shake but paper shakes, water wiggles a little.	loud and clear in air, very loud and clear in can and louder than air and goes high in pich, not loud and a little clear in box, not loud or clear in water and pich is low	Act: I was righte about air, I was righte about can, feel paper and box shake, feel waves and inside my ear it feels tickly.		
Dictionery 3	Pred: See dictionery drop	Pred: on rug its not loud, on floor it's loud on mat it's not loud like rug.	Pred: Nothing eccept if it drops on your foot.		
	Act: I was righte!	Act: on rug little loud like medium, on floor it is loud like a bang and clear, on mat it is softer but like a snap	Act: on rug nothing eccept if you stand close then you feel it in your foot, on floor same as rug but you can feel more stronger, on mat can't really feel alot but a tiny bit if you stand close.		
telephone 4	Pred: You will see nothing.	Pred: metal will be loud and clear, spong will be soft, eraser will be soft.	Pred: You will feel nothing.		
	I was righte! The spong jumped a little.	Act: Metal is loud and clear, spong is soft and mufled, eraser is soft and clear.	Act: I felt nothing eccept when I put my hand on the metal, spong, and eraser. Metal shakes, spong and eraser jumped a little.		

Miniature of group senses chart.

(Lesson 4 Activity)

APPENDIX B

FACT/OPINION/QUESTION SHEET

Facts

? - sound can't be seen
- sound can be heard
X - sound is evrywhere in the univrse
- breath blown through a straw makes a sound
X - sound vibrates
- sound sounds different under water
? - you hear sound through your ears
- it is hard to hear sound through thick things like wood or walls
- it is easier to hear sound through clear things like a window
- the more stuff is moving it is a lower sound and the thinner the stuff is it has a higher sound.
? - sound can travel to Mexico in 1 day.

Sample of facts written in a group fact column. Question marks indicate "facts" which, upon metacognitive review, are no longer viewed as facts confidently by students. X marks indicate "facts" which, upon metacognitive review, were later considered to be invalid.

Opinions

- sound sometimes can be good or bad

F - sound is a vibraton

- sound is made by doing things

? - when a sound gose louder it gose higher and higher

? - when sound gets quiet it gets lower and lower

F - you can make noise under water

F - you can feel sound

- heavy things make a low sound,

- light things make a high sound

? - sound is sometimes still

X - space is loud because evrything is crashing together

X - girls have high voices and boys have low voices except when they yell.

Sample opinions written on a group fact/opinion/question sheet. Question marks indicate "opinions" which, upon metacognitive review, are no longer viewed as opinions confidently. "F" indicates items which later were deemed to be facts. X marks indicate items, which upon metacognitive review, were later considered to be invalid.

Questions

- Why do sounds change with different things?
- Is sound dangerous?
- Does evrybody like sound?
- How does sound get lower and higher?
- How fast does sound travel?
- Why did the sound change when there was a hole in the plastic?
- Why does sound make noise?
- Why does sound vibrate?
- Why are some sounds loud and some quiet?
- What makes ekows?
- Why do some people not hear sounds?
- Why do rugs make the room quieter?

Sample of questions from a group fact/opinion/question sheet.

APPENDIX C

SAMPLE STUDENT RESPONSES

What is vibration?

1. Vibration isis somthing that moves through the air real, real fast and when somcone or somthing tries To make a sound (This all happens withen 1 second) the vibration comes and makes the sound.

This student presents an example of how "science babble" (the word "vibration") can hinder a student. This student does not understand the meaning of the word s/he is using.

What is vibration?

It is a movement (moving fast.)

Can sound not vibrate?

No, Vibration makes the sound. With no vibration there would be no sound.

This student is one of the few that was able to demonstrate an understanding of the word "vibration."

Can sound <u>not</u> vibrate?
My opinion right now is no.

This student demonstrates an acceptance of questions which cannot be confidently answered at present and the use of fact/opinion language.

Station 1

a. They were the same because I knew they were all bells. They all sounded jingly. They were different because some were soft and some were loud. Some I could hear clear and some sounded kind of fuzzy.

b. They sound similar because it was always a bell ringing. It sounded soft and quiet because the sound was a little bit stoped by the wall or the door or the window. It sounded fuzzy bec-ause you can't see through the door and the wall and the sound had a hard time going through.

c. They teach us that sound travels through air easy, throug-h glass a little bit easy, and doesn't go through cement or wood very easy. When sound travels through wood or ceme-nt, it changes a little.

d. Sound will not travel if something like a wall is very fat. It will not travel if there is nothing to shake like if there is no air or water or like that like in space.

Example of a Station 1 expert's answers to questions for consideration. (Lesson 4 Activity)

APPENDIX D

TROUBLE-SHOOTING TIPS FOR TEACHERS

1. Invite conversation and participation by directing students to sit in a circle during small group discussions.

2. Teach students the proper use of the equipment, such as the tuning fork, before beginning the activities.

3. Prior to the lessons, decide how important the learning of exact science content, rather than science-like behavior, is for your students. If you feel science content is extremely important, you will want to build more time into the lessons and have a lot of alternate activities ready. This is to avoid the "Oh, I'll just tell them, it's easier" syndrome. Remember that what students figure out on their own will be knowledge owned by the students. If you tell them the accurate information, they may choose to "borrow" it for class time and fall back on their own ideas when in the real world.

4. Give each student a different color pen to use to show his/her personal contribution to the group. If you have one recorder per group, you should consider purchasing a set of multi-ink pens.

5. It seems probable that one or two of your students will find these types of lessons too much work for their liking. However, if most of your students are feeling that way, you may not be planning enough activity to off-set discussion in groups.

6. Frequent conferences between the cooperative groups and the teacher will alleviate the students' uneasiness about "wrong" answers in the portfolios. Continually reassure them that portfolios show growth and are a work in progress. If you don't, you may find students doing a lot of editing which will make future metacognitive activity limited.

7. If students find it difficult to describe something, ask them to describe what it is not. This is often a "back door" way of defining something for a student.

8. If power struggles begin in cooperative learning groups, try making someone else the recorder because that is often the real person in power. Or try eliminating a recorder and allowing all students to record their own contributions.

9. If students are interrupting each other, give them an object such as a small box of crayons. Tell them that the only person who can be speaking is the person holding the crayons. Others must raise their hands if they would like the box passed to them. Remind the students that everyone should hold the crayons at least once. You might want to ring a bell at intervals. Instruct the students that anyone who has not held the box since the last bell should be passed the box now.

10. Don't be afraid to say "I don't know" and investigate with the students. Since these types of lessons are not completely directed by the teacher, they are very challenging to teach because you don't know exactly what direction they'll take. It is a good idea to keep your own portfolio to track your own thinking during the series of lessons. Students love to see it and it is very helpful.

11. If students are unmotivated or unsure about specific activities, ask them why. Get them involved in the evaluation of the lesson series. Good information can come from asking students about what made sense to them and what did not.

12. Discourage "science babble." The best way to do this is not to use it yourself. Let the students know from the beginning that vocabulary is not impressive, ideas are. If students begin to use vocabulary which you suspect they do not fully understand, investigate by questioning. If your suspicion is correct, you might want to ban the word from use. A "rest home for over-worked words" is a fun way to help students keep track of words which are to be avoided. Praise clear description and coherent explanations.

APPENDIX E

ADDITIONAL RESOURCES FOR TEACHERS AND STUDENTS

AIMS. Hardhatting in a Geo-World. Fresno, CA: AIMS Education Foundation, 1986.

________. Sense-able Science. Fresno, CA: AIMS Education Foundation, 1994.

Batzle, Janine. Portfolio Assessment and Evaluation: Developing and Using Portfolios in the Classroom. Cypress, CA: Creative Teaching Press, 1992.

Graves, Ted, and Nan Graves, ed. Cooperative Learning. April 1991: entire issue.

Harlen, Wynne, ed. Primary Science: Taking the Plunge. Portsmouth, NH: Heinemann, 1985.

Hassard, Jack. Science Experiences: Cooperative Learning and the Teaching of Science. Reading, MA: Addison-Wesley Publishing Company, 1990.

Hazen, Robert M., and James Trefil. Science Matters: Achieving Scientific Literacy. New York: Anchor Books, 1991.

Hewitt, Paul G. Conceptual Physics. New York: Harper Collins College, 1992.

Jasmine, Julia. Portfolios and Other Assessments. Huntington Beach, CA: Teacher Created Materials, Inc., 1993.

Kirby, Dan. Mind Matters: Teaching for Thinking. Portsmouth, NH: Boynton Cook Publishers, Inc., 1991.

Kuntz, Margy. Adventures in Physical Science: Process-Oriented Activities for Grades 4-6. Carthage, IL: Fearon Teacher Aids, 1987.

McGinley, Avalyn. Light and Sound. St. Louis, MI: Milliken Publishing Company, 1990.

Rybak, Sharon. Cooperative Learning Throughout the Curriculum: Together We Learn Better. Carthage, IL: Good Apple, 1992.

Sonnenberg, James, and Allen Windsor. Cooperative Learning: Thinking and Problem Solving. Minneapolis, MN: T. S. Denison and Company, Inc, 1991.

Van Cleave, Janice. Physics for Every Kid. New York: John Wiley and Sons, Inc., 1991.

Wood, Robert W. Physics for Kids: 49 Easy Experiments With Acoustics. Blue Ridge Summit, PA: TAB Books, 1991.