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ABSTRACT

Presented in nine separate chapters are nine studies involving the direct observation of science classrooms. Eight of the nine chapters are based on qualitative data collection techniques which typically aim for depth of insight and understanding. Studies included are: "Critical Barriers to the Understanding of Elementary Science: Learning about Light and Color" (Maja Apelman); "Alternate Theories in the Classroom" (Keith Hanson); "Teaching for the Development of Understanding of Ideas: Forces on Moving Objects" (James Minstrell); "Using Classroom Observations to Improve Science Teaching and Curriculum Materials" (Kathleen Roth); "Can Science Teachers Promote Gender Equity in Their Classrooms? How Two Teachers Do It" (Susan Melnick, Christopher Wheeler, and Barbara Gunnings); "Philosophy as a Guide to Reflection on Classroom Events" (Thomas Russell); "A Study of Policy and Program Formulation and Implementation in a Secondary School Science Department "(James Gallagher); "Science Classroom Management and Organization" (Julie Sanford); and "Relationships between Classroom Processes and Science Learning" (Kenneth Tobin and William Capie). Each chapter (which is preceded by a short introduction highlighting the major issues examined) presents a particular theory or perspective and demonstrates how that perspective can enrich the understanding of science classrooms. (JN)


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1984 AETS YEARBOOK

OBSERVING SCIENCE CLASSROOMS: OBSERVING SCIENCE PERSPECTIVES FROM RESEARCH AND PRACTICE

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Preface

The ERIC Clearinghouse for Science, Mathematics, and Environmental Education is pleased to cooperate with the Association for the Education of Teachers in Science in producing this Yearbook, funded in part through the Center for Science and Mathematics Education, The Ohio State University.

We invite your comments and suggestions on this series.

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INTRODUCTION TO 1984 AETS YEARBOOK

Andy Anderson
December 1984

This is the second of the volumes of the AFT' arbook Series that emphasizes research conducted through obs.... on in science classrooms. The first AETS Yearbook, published in 1974, reviewed research on teacher behavior, both in science classrooms and in other settings. That volume was 515 pages long and contained 1,374 references. Even then, attempting an exhaustive review of research on teacher behavior was a mammoth undertaking.

Today, the field has grown to the point where such an undertaking would be impossible. This volume, in contrast with the first AETS Yearbook, makes no attempt to provide complete coverage. Rather, it provides a sampling of scholarly activities involving direct observation of science classrooms. The authors of the chapters in this yearbook all have spent a lot time in science classrooms, as observers, as teachers, or as students. The diversity of viewpoints represented among these authors is obvious. In addition to professors of science education who observe classrooms from a variety of perspectives, the authors include one person who was a science student, two who are practicing science teachers, and a graduate student.

This yearbook and the 1974 yearbook differ both in style and substance; there is one further substantive difference which will be immediately obvious to anyone who compares the two yearbooks. Eight of the nine chapters in this yearbook are based on qualitative data collection techniques. In contrast, not a single one of the 1,374 references in the first yearbook concerns a study in which data collection was qualitative. In this respect, at least, the field of research and science teaching has changed over the past decade.

A look at the chapters in this yearbook, however, indicates that differences among forms of research and scholarship are far more complex and multifaceted than a simple dichotomy between qualitative and quantitative research would suggest. The chapters are arranged roughly in a continuum, beginning with the most personal and ending with those adopting the most traditional research perspective. A look at the chapters reveals a number of interesting trends.

The role of the writer, for example, changes from one chapter to the next. The writers in the early chapters are actors in the classrooms that they describe. They write in the first person and describe their own thoughts and actions. In the later chapters, the writers become observers and the tone becomes more detached. The first person is used less and less frequently. Similar trends are apparent in the nature of the theories presented and the manner in which they are tested, in the number of classrooms observed, and in the attention to such issues as generalizability and reliability of measures.

The growth in the use of qualitative research methods has been accompanied by a loss of consensus about goals for research and scholarly writing and standards for judging quality. Recent writing about qualitative research methodologies has tended to emphasize the contrast between the goals and methods of qualitative and quantitative research. (See, for example, recent articles in the Journal of Research on Science Teaching by Douglas Roberts, Jack Easley, and Mary Lee Smith.) In what remains of this introduction I wish instead to emphasize some common goals and purposes which are shared by all research, including all of the chapters in this yearbook.

1. Providing Vicarious Experience

   Every chapter has the purpose of enlarging the reader's experience beyond what is possible for an individual to see. Every reader of this yearbook will learn something of what the chapter authors have seen in the thousands of hours that they have spent in science classrooms.

   One of the ways that we judge the quality of all research should be the quality of the vicarious experience provided by that research. At a minimum, all research should be accurate and precise in description and data reporting. Beyond that, qualitative and quantitative research have somewhat different objectives. In quantitative research there is typically a concern for breadth of coverage, thus we judge the quality of quantitative research by standards such as the size and the representativeness of the sample of classrooms observed. In contrast, qualitative research typically aims for depth of insight and understanding. Thus we judge the quality of this research by the vividness with which an author can portray an individual classroom, or by the ability to select critical details and present them appropriately.

2. Theory Building

   For some types of research, such as survey research, enlarging the reader's experience may be the primary or the only goal. That is not true of the studies reported in this yearbook. More important than providing vicarious experience is the process of developing and testing theories or ways of looking at science classrooms.

   Every chapter in this yearbook presents a particular theory or perspective and demonstrates how that perspective can enrich our understanding of classrooms. The development of these different perspectives is the main point of this yearbook and the source of its title. Ultimately, the success of each chapter and of the book as a whole will be determined in classrooms seen by you, the readers. If these chapters help you see aspects of teaching and learning in science classrooms of which you were previously unaware, or if they help you reinterpret your experiences in new and productive ways, then the yearbook can be judged a success.

INTRODUCTION TO CHAPTER ONE

This chapter is the most personal and furthest in style and content from the quantitative research reviewed in the 1974 AETS yearbook. This chapter is also unique in that it is written from the perspective of a learner of science. Maja Apelman describes how she and a group of elementary school teachers learned about light and color, progressing from acceptance of commonsense notions about light to questioning and confusion, then ultimately to understanding and philosophical insight. In the process, she offers a portrait of an extraordinary science teacher and philosopher, David Hawkins.

For people who, like most science educators, have always been "good at science," this chapter may offer greater vicarious enrichment of experience than any other in the book, for it is written from the perspective of someone on the other side of the gulf between C.P. Snow's Two Cultures.

This chapter also introduces what I believe to be one of the great research problems of science education. Even when the science is easy, the students' problems are deep and multifaceted, and understanding the "critical barriers" that they must overcome is a never-ending intellectual challenge.

Dr. Apelman is a former early childhood teacher who is now a teacher educator. She was a staff member of the Mountain View Center at the University of Colorado for more than ten years and more recently taught courses at the Bank Street College of Education in New York City. She is currently a free lance educational consultant living in Boulder, Colorado.

CRITICAL BARRIERS TO THE UNDERSTANDING OF ELEMENTARY SCIENCE:
LEARNING ABOUT LIGHT AND COLOR

Maja Apelman

THE RESEARCH PROJECT

Evolution

"Critical Barriers to the Learning and Understanding of Elementary Science" was the title of a research project directed by David Hawkins at the Mountain View Center,[1] University of Colorado, from 1980 to 1982. Professor Hawkins--philosopher, scientist and educator--had been involved with elementary science teaching for many years. He was the first director of the Elementary Science Study. In his work with pre-college, college, and adult students, he became increasingly aware of problems many of his students had in understanding what were generally considered simple, basic, scientific ideas.

In a talk at the Massachusetts Institute of Technology in 1976, Hawkins mentioned the need for "a radical reconstruction of the organization of scientific knowledge, a reconstruction designed to make science maximally penetrable from outside, to make it more readily accessible either by minds whose powers are first developing or by minds which have developed patterns other than those now deemed apt for science." He added that he wanted to search for and define "those almost irretrievably elementary stumbling blocks which pedagogy normally sweeps under the rug because it does not understand them . . ." (Hawkins, 1976, p. 16).

In 1978, Professor Hawkins was asked by the National Science Foundation to write a policy statement for improving elementary science education. He described in some detail a group of problems he had encountered in his science teaching experience and he named these problems "critical barrier phenomena." He noted that some so-called "elementary" ideas are "exceedingly unobvious to those who have not yet assimilated them." (1978, p. 4). He further said that

> Our failure to achieve a wide dissemination of scientific ideas and attitudes . . . suggests that we are up against something rather deep in the relation between science and common sense; we are up against a barrier to teaching in the didactic mode which has hardly been recognized, or if recognized has been seen mainly as a challenge to ingenuity in teaching rather than as a

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[1]A resource center for pre-school and elementary teachers originally funded by the Ford Foundation.

challenge to a deeper understandng of human learning . . . much greater and more systematic attention should be given to description and analysis of critical barrier phenomena. . . . To succeed well in helping more students overcome these barriers is to open doors for them into further learning, to help them find paths in which the growth of their scientific understanding is nearly multiplicative and irreversible rather than additive and reversible. (1978, pp. 7, 17-18)

Hawkins concluded that barrier phenomena needed wide and cooperative study and research and that such a focus should represent a major policy direction (1978, p. 21).

Two years later, Hawkins submitted a proposal to the National Science Foundation to further investigate some of the critical barriers. In the propoaal, critical barriers were defined as follows:

1. They are conceptual obstacles which confine and inhibit scientific understanding.

2. They are "critical" and so differ from other conceptual difficulties in that:

   a. They involve preconceptions which the learner retrieves from past experiences that are incompatible with scientific understanding.

   b. They are widespread among adults as well as children, among the academically able but scientifically naive as well as those less well educated.

   c. They involve not simply difficulty in acquiring scientific facts but in assimilating conceptual frames for ordering and retrieving important facts.

   d. They are not narrow in their application but when once surmounted provide keys to the comprehension of a wide range of phenomena. To surmount a critical barrier is not merely to overcome one obstacle but to open up stimulating new pathways to scientific understanding.

Teachers' Seminars

Most of the data for the Critical Barriers Research came from two semesters' work with small groups of elementary school teachers who came to the Mountain View Center once a week for two-hour work-and-discussion sessions.

Selection of teachers. The Mountain View Center had been in existence as a teachers' resource center for ten years prior to the beginning of the research project. Many local teachers had taken courses over the years and some had developed close working relationships with members of the staff. Thus, we already knew a number of teachers who were interested in science but had little or no formal science background. But our criteria were not primarily negative--i.e., teachers who had trouble understanding science. We also looked for strengths in teachers--those who were interested in learning science both for their own sake and for the sake of the children they were teaching, and those who were interested in becoming more aware of their own learning styles and would be willing to talk and write about them. We worked with ten teachers each semester, three of them attending both semesters' seminars. A few teachers we did not know but most of the group had previously worked with the Mountain View Center.

We considered the teachers to be participants in the research, though I don't know that the teachers really thought of themselves as co-researchers. They did know, however, that we respected their thinking and valued their efforts and struggles toward a better understanding of science. They trusted us even before we began to teach--a big advantage since establishing trust in this sort of situation is not always easy.

Selection of content. For the first semester's course, David had chosen the topics of Size and Scale, and Heat, primarily because of his experience with students' previous difficulties in these areas. At the end of the first semester I interviewed the participating teachers and asked them, among other things, if they would be interested in continuing for another semester and, if so, what topics they would like to explore. Many topics were mentioned, but the following recurred most frequently: "Light, color, optics . . . light spectrum, prisms . . . light--different spectrums of different rays . . . lenses, optics, how a camera works . . . light, continue with radiation (from the heat course -- 'I just don't understand it.')"

In the staff discussions which took place at the end of the first semester's course in June, 1981, we considered many different subjects and talked about possible changes in the format of the courses. We finally settled on Light and Color and the same weekly two-hour sessions we had before. Plans for the classes were developed by Hawkins an .onald Colton, project co-directors, in conjuction with Abraham Flexne d myself.

The classes. Courses at the Mountain View Center when it a teachers' resource center re always informal: Small classes, gen ly no more than 10 teachers, mostly hands-on activities, and plenty of time for questions and discussions. The research courses were similar in format. We generally started with a discussion of the previous class, then worked in small groups with materials and, towards the end of the session, came together again as a group to share impressions, raise questions, and plan for the following week. We asked teachers to write brief notes at the end of each class--"immediate reactions"--hoping to get further clues for planning the next session. We also asked for longer, more reflective notes to be handed in at the following class, and for a final evaluation at the end of the course. These notes, together with the transcripts of the class (and, during the first semester, transcripts of the staff planning sessions) constitute the major part of the raw data of the research.

My Role in the Research Project

My background. My real science education did not begin until I joined the staff of the Mountain View Center in 1971. The little science I had learned in high school I had quickly forgotten. In college, I managed to avoid science completely, fulfilling my requirement with a one-semester course in experimental psychology. After that, science played a very minor role in my life.

I always loved the outdoors, so as a kindergarten teacher I often went on field trips with the children to collect rocks, leaves, twigs, insects and worms from a nearby park. Later I started to read children's science books and I introduced magnets, batteries, balances, and other simple science materials into my classroom. I took a science class for teachers taught by a high school science teacher but found it dry and difficult to understand. My knowledge and understanding of science was at a very elementary level when I joined the staff of the Mountain View Center.

My own expertise was in early childhood education and social studies, but at the Center there were many math and science materials and much fascinating informal talk on a wide range of science topics. I started to ask questions, timidly at first, but I soon sensed that asking questions at Mountain View entailed no risk. In fact, I gradually came to realize that David and other staff members were not only patient with and tolerant of my questions, they were actually interested in them and in the thinking behind them. I still remember the surprised look of a physicist staff member when I asked whether an inclined board was steeper at the top than at the bottom. He wanted to understand my reasoning.

There were many discussions over the years about such confusions and I always tried to articulate my thought processes. Because of my growing interest in science and my ability to verbalize clearly what and how I was thinking, David thought that I could make a useful contribution to the research effort.

Student and student advocate. My position on the critical barriers research project was two-fold: I was to be a participant observer in the classes, learning with the teacher/students but at the same time I was to be alert to any non-voiced difficulties they might be having and to encourage them, partly through my own question-asking, to speak up in class. I also attended all the research staff planning meetings and was able to give my colleagues further feedback from my informal talks with the teachers as well as from interviews which I conducted. Because I was trusted and respected by both teachers and researchers and because I felt equally comfortable with both groups, I often could play a useful liaison role. I also had the opportunity to get help with my own learning problems between the classes, and I found that if I had just gained a new understanding I could assist teachers still struggling with similar problems. I was closer to the teachers' stumbling blocks than the other researchers, having only just surmounted them.

Although I loved my work, there were times when I found it difficult to be of value primarily for my ignorance. I believe, however, that such an intermediary role of student advocate is an important one in this kind of research or in any class in which adult students are struggling with difficult "elementary" concepts.

In the following pages I shall discuss the Light and Color Course[2] from the teachers' and my own point of view: Class transcripts, teachers' notes and evaluations and my own often extensive notes provide the data on which these discussions are based.

[2]I shall deal with the content of 6 out of a total 11 sessions in some detail, touch on 2 additional classes and omit work with mirrors, and the final summing-up session.

A COURSE ON LIGHT AND COLOR

Thoughts and Questions on Light and Color Before the First Class

At our first orientation meeting (some teachers had not yet decided whether to attend) David discussed the goals of the research. He talked about the need to reorganize "the furniture of the mind" when a new idea has to be accommodated to an old way of thinking that no longer works.

> This is not just a matter of getting rid of an old notion, it involves restructuring . . . Instead of saying that common sense is wrong and science is right, say common sense is right too, but it's a different representation using a different language useful for somewhat different purposes. We don't want you to discard common sense but we hope you will try to acquire other ways of thinking which you can relate to common sense . . . We want to explore the relations between our common sense understanding of the world and what the scientific world considers to be elementary, scientific ideas that are important and powerful.

At the end of this meeting, David asked the teachers to write some notes for the next session describing their present thinking about light and color. "We are interested," he said, "not in whether people's ideas are right or wrong, but in what their ideas are. We are trying to find out how people think."

Some teachers did discuss how they thought about light and color; others mainly asked questions. In my first notes for the Light course I wondered about the relation between light and color: Would I ever have made that connection, I wrote, if I hadn't attended the planning sessions? I certainly never asked myself why things were of a certain color. I decided to make a list of things I knew about light:

- Light travels in straight lines (whatever that means)

- Light gets bent when it passes through certain things - water? "Bent" I think is a bad word. It implies to me something straight that becomes rounded. But that's not true. It just means it turns a corner with a sharp angle - but it still goes in a straight line afterwards.

- Light - white - is a mixture of all the colors of the spectrum. That has always been somewhat of a mystery to me. But one learns to repeat the words. Perhaps it is not totally useless to have some of these barely-understood science tidbits. Then when you do begin to understand something, you can connect it with these statements and say - "Oh, that's what this means! I see."

- Light is related to heat. It can be changed to heat, inside a car, that's the famous greenhouse effect.

After making the list, I started to raise some questions:

What is light anyway? How can you talk about something so abstract? How can you describe something that you can't see (well, not really), touch, smell, etc. I guess you do see light, or rather you need light to see. So light becomes related to vision. Light plus eyes make vision possible. If you need light and eyes to see, what do you see? The object which reflects light or the image on the retina?

David had said, "Light is emitted by excited atoms." How do excited atoms behave? And how do you know they are excited? Because they emit light? How did people ever figure that out and how is that motion different from the motion of a molecule which emits heat?

If color depends on wavelength, does light come through the atmosphere in separate colors? Then how is it put together to become white light? Do we ever see white light since most things have color? I am so confused, I think I'll quit for today.

The teachers' notes and my own notes from that first day of class convey the kind of thinking--tentative, speculative, circuitous--which occurs when a new topic or idea is introduced. The rush of questions, present in so many notes, seems to be triggered by the intensive effort to assimilate new ideas and also by the sudden realization that things which have never been understood before may actually become accessible.

I tried hard in the Light course to keep track of my thinking and learning. I find that in writing things down, my thinking becomes more focused, as unexpected questions and answers pop into my mind. I have found, however, that it is extremely difficult to keep track of all the thoughts that relate to the learning of a new concept. I would virtually have to walk around with a tape recorder so I could talk into it whenever I have an insight, a question, or a confusion. Thoughts come into my mind at quite unpredictable times and it is impossible to remember the whole learning progression. Keeping detailed notes along the way helps to record the stages in understanding which otherwise are quickly forgotten.

Throughout this chapter I shall quote freely from my own notes as well as from the notes of teachers. I hope these excerpts will give the reader some clues about adult students' naive scientific thinking about light. Many science teachers have probably forgotten their own beginning confusions about this difficult subject.

Experiments with Light and Color

Mixing light: colored shadows. "We'll get into trouble if we start with color," David had said in one of our planning meetings. I can't remember how he wanted to begin, but for a number of reasons we ended up starting with color--and there was plenty of trouble.

We had set up three working stations, each one with three projectors and with a number of red, blue, yellow, and green colored gels. The projectors were arranged so that the beams of light overlapped on the wall. The lesson was to be on additive color mixing.

We worked in three groups, each one with a staff member as leader. We mixed light and most of us were startled by the unexpected results--unexpected because our point of reference was that of mixing pigments. Even more startling, however, were the shadows we produced with hands, sticks, and other objects. I found these multicolored shadows very confusing and wondered if I had ever seen colored shadows before--"How could a shadow be anything but black?" I asked, and then I wondered:

> If a shadow means there is no light hitting this area and the sun or a lamp make a black shadow, why do colored gels make colored shadows? What colors make what shadows? When you have several lights and gels, why and where do you get black and why do you get different intensities of colors?

Some of the teachers asked similar questions:

> What causes the shadows to be the colors they are? When you shine three lights it never made sense to me what color the shadows were going to be. I never knew what colors would appear as a result of the color combination of light. (Cindy)

> If a normal grey or black shadow is the absence of light, then what is a red shadow the "absence of"? Something is being let through and something isn't. Why does a gel create a colored shadow? It's still light being obstructed--why doesn't it leave a grey shadow? Why does the color come through? (Hedy)

I wanted to get the shadow problem solved and decided to work it through slowly and systematically. I set up two projectors, got some colored gels, and asked a friend to work with me. First we turned on one projector and made a shadow with a yardstick. It looked black. Then we turned on the other projector and got two grey shadows. We figured out which projector made which shadow but we didn't yet understand why the two shadows were not as dark as the first shadow made by only one projector. Now we turned off one projector, put a red gel in front of the light and turned it back on, still holding the yardstick in front of the area on the wall where the two projected beams of light overlapped. The previously black shadow became bright red. I was puzzled: How could red <u>cover</u> this deep black? I wondered. Then I remembered: Black is the <u>absence</u> of light. The red can "move in" because there is <u>no</u> light there. The black shadow is caused by the yardstick held in the path of the light of the first projector; the second projector lights up the shaded area with its red light. When all your experience with color is relat to pigment, this is a difficult switch to make.

It took a good deal of time and much hard thinking to figure all this out. Ron had wondered earlier why none of the teachers had caught on to the geometry of the projection and the shadows. I don't think he realized how long it takes just to become comfortable with something as new and strange as colored double and triple shadows, some with complementary colors which aren't even on the wall? You are so confused at first that it takes a while to realize that geometry is involved at all.

Several classes later, there were renewed questions about the colored shadows. "If you covered one projector with a green gel and one with a red gel, why is the shadow cast by the green light red and the shadow cast by the red light green?" someone wanted to know. David replied:

> I think a lot of people have real trouble seeing which of the shadows is going to be red and which is going to be green because they are not thinking of light traveling. They are thinking of the pattern on the wall but they're not thinking of the projector. When you think of a pattern on the wall, you're not thinking about the fact that it's being created by beams of light. When you're thinking about beams of light, you're not thinking about patterns on the wall. Only when you get the two together do you say: "Oh yes, the shadow of the green light is red because the red light is shining right on that part of the wall and the green light isn't.

It might surprise David to learn that even after I figured out the geometry of the colored shadows, I did not think of light traveling. I knew that the light went from the projector to the wall--I associated what I saw on the wall with the source of the light. But I did not think in terms of light traveling from the projector to the wall. The light on the wall, somehow, was part of the light of the projector. I did not question how it got there.

White light. After solving the colored shadows mystery, we turned to the questions raised by the mixing of colored light. There was less confusion but there were many questions. First, we had to learn to forget about pigments in order to understand the mixing of colored light, and that was difficult. Is this problem partly caused, I am now wondering, by our use of the word "color" in both instances? If we just talked about the difference in mixing pigment and in mixing light would that help? But then we use pigment on the gels to make colored light. It is confusing!

Some of the teachers had mixed light by putting different colored gels over the different projector lenses; others wanted to see what would happen if they mixed, that is, superimposed, different colored gels over one projector lens. Cindy made an analogy between the dark, murky colors you get when mixing the primary colors of pigments and the somewhat similar effect you get by superimposing colored gels. She then tried to define what "adding" and "taking away" light means:

When we put the three gels on top of each other on one source of light, it got murkier on the wall. We were cutting out the light. But when we have the three lights separate, from three separate light sources, it was like "adding" light. When we added them separately, we ended up with white light. We're not just getting red, yellow, and blue, we were actually getting more light.

I also struggled with the concept of adding colors to make white light and after our third class I wrote in my journal:

> I think in order to understand how colored light, when mixed, makes white light, you have to think of more and more <u>light</u>, rather than colors being mixed. I just realized that that statement already presumes an acceptance of the fact that light--when broken up, consists of separate colors, and when they are all mixed up again, you get "white light." You are mixing the separate components, getting back the whole. We've only had a few classes, but the "breaking up of light" into colors is being accepted by my brain.

Just now, as I was reading these notes, I realized that physicists must think very differently about light and color than I do. Even though I know that light can be broken up into different colors, I don't really think of color as being the property of light. I think that color is the property of the colored objects which I see. In the course this never became a problem for me because I wasn't far enough in my thinking to become confused. Jean, on the other hand, really struggled with this idea:

> I don't understand how colors fit in with the whole spectrum that we call light energy. I don't even know how to ask about it. Colors are part of the visible light, and the color that light breaks into, that's energy? I don't understand that at all.

There were other interesting comments on white light:

> Cindy: I would never have thought that white light includes all other colors. Even as we saw the white light in the center of the shadow, I called it "absence of color."

> Sue: I thought that we got white because all the colors cancelled each other out, . . .

> Polly: I have great difficulty understanding why I get white light when I add colored light. Is it because each color is saturated with light and where they all meet, that is the most saturated, therefore it becomes white? Or is it that one color blocks out the other color and so on until you get white light?

Because there were so many questions about the mixing of light, Ron borrowed from the Physics Department a light mixing machine which had much purer color in its filters than we had in our gels. We worked slowly, all together, mixing first two colors at a time, and then all three colors. There really was white on the wall. This convinced almost everyone that the colored light, when mixed, produces white. Cindy was still skeptical: she wondered if the white was not just the color of the wall. If we were to project the colors onto a black wall, would we still get white?

After mixing light, we separated out the colors with the help of a prism. The brilliant spectral colors were greatly admired by everyone. We held up a second prism, which brought the colors together again. Ron then gave us a spectacular light show by hitting two chalk erasers together in front of a projector light and also spraying water into the beam of light. If you looked along the beam of light, little specks of color were swirling all around. If you looked across it, the light looked "white". Ron explained that the different colors of light were hitting the little specks of chalk and the water droplets were bouncing off in all different directions--"every little speck of chalk or drop of water is reflecting a different color." It was an amazing sight and further helped to convince the teachers that there really was color in light.

After further experimentation and much discussion about prisms, spectral colors, and wavelengths, another problem came to the surface. The term "white light" bothered some of us. I was one of the people who had trouble with this, and I wrote in my journal:

> I find white light very confusing. On the one hand there is the fact that light consists of a mixture of all the colors of the spectrum, and so white surfaces, white objects, contain all the colors. But to me that is color, not light. You can't ever <u>see</u> white light. In fact, I have a hard time even thinking about light, except at night. Light bulbs make light, so do candles, fires, and all the things that light up the dark. During the day the sun gives us light. But although I sort of know that the sun is the source of light, when I look around in a room, or outdoors when you cannot see the sun, where is the light? I just realize that as I keep looking around to see the light, I am confusing light with air. Light is all around us like air. But by comparison with light, air is very real. I have an image of light seeping in, maybe between the air molecules, just sort of being all around and making things light. I would never think of "white" in that connection. I would like light to be "just light," "natural" light. I know that it contains all the colors, but that doesn't make it white.

David came to my rescue with regard to white light. He informed us that he was not going to call light "white" anymore--"it's an incorrect word to use," he said. He settled for "ordinary light" and then continued:

Take a piece of white paper, like typing paper. If you shine colored light on it, it always takes on the hue of the colored light. If you shine "ordinary" light on it, it looks white. So white light is that thing which makes white things look white.

So much for white light! Terms can be changed easily enough. But there was still in my mind a difference between the ordinary light that's all around us, the ordinary light that makes white paper look white, the light that "just is," and the light that you actually perceive as light, that you can look at--the source of light, whether it is the sun, the moon, street lights or candles.

I did not think of these two kinds of light in the same way and I also had difficulty understanding that you only see reflected light. "Must light go from the light source to an object to our eyes?" I asked in my notes. "Is there no light just bouncing around in my room, like air? But you can see light if you look at the moon, or at a bulb in a lamp? So what is light?"

Marilyn, apparently, had a similar problem when she wrote in her notes: "I want to be able to relate white light to light bulbs, street lights, stadium lights, etc. How is light from these sources seen as white?

Discoveries with colored gels. I was still puzzling about these two different kinds of light when I came up against another problem. In one class we were looking at different colors of construction paper and at multicolored book jackets through different colored gels. It was fascinating to see how the colors changed--for example, green looked at through a red gel, became black--but I wasn't quite sure what was happening. What colors did the colored gels let through and what colors did they block?

When I thought about the projector lights shining through the red gel and coloring everything red on the other side, I was able to figure out that the red gel lets through only red light. But when I tried to transfer this knowledge to the situation where I held the gel in front of my eyes, I became confused. With an effort I could make myself think of light going from the projector bulb to an object, then to my eyes. Therefore, a red gel, placed anywhere on this path, whether in front of the projector or in front of my eyes, would allow only red light to go through.

Then I made a discovery: As I was trying to clarify what was happening with the gels, I suddenly realized that much of the time I was thinking of light going from my eyes to an object on the other side of the colored gel. I wrote:

> I never realized that I had been thinking about this in just the wrong way. How could that be? Did I think my eyes were little flashlights? Or is the idea of seeing being done by eyes so strong that I just assumed that the source of light was in the eyes and that somehow my eyes were sending out secret little rays of light?

Some teachers apparently had similar problems. Sue commented:

> I find myself looking at things and trying to realize that the image was being imprinted on my eyeball. When you are "child like," you think that your eye initiates the seeing--but actually it's the object, right?

A friend told me that when he was little, he wondered if objects got tired being looked at, whereas Jean, when realizing that light comes <u>to</u> her eyes, expressed concern "about all the light my poor eyes have had to stop, absorb, over the years. I wonder whether that is related to poor vision as you grow older?"

Polly asked how <u>looking</u> through a gel related to light <u>shining through</u> a gel and then said:

> I realize that I do have difficulty thinking of light coming to my eye when looking at an object. Somehow I feel my eye is doing all the work. Light is such a given, I forget that it plays an active role. I don't think of empty space as being filled with light; in a way I take light for granted.

It is interesting to note how often the teachers and I talked about having taken light or color for granted. This is how Marilyn reflects on the experiments with the colored gels:

> I feel I have a better understanding of color and of what the colored gels do after the last class . . . I had never really thought about colors of the spectrum entering the gel and being either absorbed or let through. It always seemed to me that things appeared red when looking through a red gel because of <u>only</u> the red gel itself, and that there were no other factors involved. In other words, I never considered the light coming through a gel and going out--what was being absorbed and what was not. Thinking in those terms was something new for me.

From talking about light going through the colored gels--transmission of light--we came to ask questions about absorption and reflection. Light is reflected off shiny surfaces, David said, and absorbed by dark surfaces. He mentioned that he preferred to use the "scattered" to describe light that is bounced back by non-shiny surfaces. To me scattered light sounded too random--how could we see it if it goes off in all directions? "It <u>is</u> random," David said, "only a small fraction of the light that is hitting this table goes to my eyes, the rest bounces around in the room and eventually gets absorbed."

What happens to the light that gets absorbed? some teachers wanted to know. "When light is absorbed in a surface," David told us, "the light <u>as</u> light disappears and the surface gets warm. The temperature of the material rises because it has more heat energy . . . When sunlight feels warm, you say there's heat coming from the sun as well as light. Actually, there's just more light. "If you're burned by the sun," Sue wanted to know, "are you burned by the light or by the heat?" David said:

> Your body absorbs the light, your body stops the light. The energy of the light is transformed into the acceleration of the motion of the atoms of the material, which causes the temperature to rise. Heat is energy in another form. Absorption of light is the transformation of energy from one form to another.

David then told us of Benjamin Franklin's experiment in which he put different cloths out in the snow and observed that the white cloth melted the least amount of snow and black cloth the most. "He concluded from this that the black cloth was absorbing all the light and putting it into heat and that the white cloth was absorbing the least. But it's the fact that heat is produced that convinces you that light is being absorbed."

The heat is the evidence for the absorbed light! I had been troubled about the relationship between heat and light ever since taking an energy course the previous year, and now I understood! This new understanding represented an important stage in my learning and gave me great satisfaction: I had come to accept an invisible process through observable evidence.

After discussing how different colored materials absorb and reflect different wavelengths of light, some of us began to wonder about color itself. Why are things the color they are? We understood that a green object "absorbs" all the colors except green which it "reflects." But why is it reflecting green, rather than red, blue, or yellow? We got considerable resistance from the research staff to these questions, but when we became insistent, David did tell us that color had to do with "the interrelationship between electromagnetic radiation and the electromagnetic properties of ordinary matter . . . The fine structure of ordinary matter is such that it will be emitting radiation and absorbing radiation."

Now we "knew" that color depended on the interaction between light and matter and if we could not understand this on a deeper level, at least we had a phrase to hold onto, and that helped.

After four classes on color, David was ready to leave this topic and to "retreat," as he put it, "to the much simpler subject of light and shadow."

Light travels in straight lines: Shadows. We left color, though we came back to it later for one final summarizing session. Because of the confusions around the colored shadows, David wanted us to work with ordinary light and shadow.

"I never thought about a shadow as absence of light," I said in class, even though I had already worked with this idea when I was solving the colored shadow puzzle (see p. 10). "How did you think about shadows," David wanted to know. I replied:

I don't think I ever really thought about them. It's just a dark area. I knew it was related to the object that cast the shadow and I knew that there had to be a source of light somewhere, but beyond that I never gave it much thought.

Hedy's experience was similar to mine:

I never thought much about shadows and I would never have thought of them as the absence of light, not in a million years.

Marilyn agreed:

I had always thought of a shadow as being something in and of itself, rather than the absence of something . . . I would never have thought of a shadow as absence of light. That phrase seems to imply that there is complete darkness.

Polly was even more explicit:

I know that a shadow is caused because the light shines on something and somehow that causes a shadow but I always thought about shadows in a sort of positive way, as an imprint, or a photograph, or like the way you step in sand and leave a footprint . . . I really thought of shadows as being "cast" not as something which was caused because light was stopped.

I added:

A shadow is a black image. It's not the absence of something. It is something, and it's dark and real.

In my everyday common sense world, an absence is a lack of something, a nothingness. An absence of light means no light. In a different context, for example, at night, I would have no trouble saying that it was dark because there was no light. But that is what Marilyn called "complete darkness." Shadows can be seen only when there is light around them, and often that light is very bright. Is that, perhaps, why it is so hard to think of shadows in terms of "absence of light?" Or is this related to the problem mentioned by David earlier (see p.11) when he told us that while we were looking at the patterns on the wall created by the colored gels we were not thinking about the beams of light which produced these patterns? In Polly's analogy, a shadow was compared to an imprint, to something positive. An imprint is hard to reconcile with an absence. If this is how most of us had been looking at shadows, a radical change in our thinking was called for.

Why was our thinking so different from that of scientists, I wondered. In all my life I had never thought that shadows were caused by an absence of light, yet David had probably never thought of them in any other way. In our relaxed and informal class atmosphere this gap was responsible for a

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Why was our thinking so different from that of scientists, I wondered. In all my life I had never thought that shadows were caused by an absence of light, yet David had probably never thought of them in any other way. In our relaxed and informal class atmosphere this gap was responsible for a wonderful and often amusing sharing of scientific and naive ways of thinking about light and shade. In a regular science class, such a gap, if not dealt with, could cause serious problems for both teachers and learners.

After much discussion and experimentation, first with light sources and objects, then with paint sprayed across a pair of scissors held in front of a piece of paper--the paint represented the light rays now and the outline of the scissors on the paper was the "shadow"--we came to accept the idea that shadows exist because light travels in straight lines. Ken thought this was obvious and was amazed that the whole demonstration was set up just to make this point. I, on the other hand, had always found the phrase "light travels in straight lines" rather mysterious. I thought that "straight lines" had some special meaning which was beyond my comprehension. When I found out that it just refers to the fact that light can't travel around a corner or can't curve around an object, I was also amazed. "Is that all it means?" I thought to myself. Once you accept that light travels, there is no problem in understanding that it travels in straight lines.

But there was another problem: accepting that the light from the bulb traveled did not help us to understand that ordinary, natural light also travels. I mentioned earlier that I did not think about these two kinds of light in the same way. Some of the teachers were similarly troubled. Ordinary light, it seemed, wasn't doing anything. "You just think it's there, it's just there," said Marilyn. Polly wrote: "I took light for granted. It just was. I thought of it as coming from the sun, but also as just being part of our earth." "I've been sitting here," said Hedy, "trying to think that the light from up there (ceiling lamps) is coming in straight lines down to me. I can't transfer that idea at all. Ten zillion little straight lines that are coming at you? My sense of the light is that it's here, all around me." "You've got to come to terms with the notion that light is something that's in transit," David explained. "It isn't just sitting around stationary. Now that's going to come in conflict with your ideas about the light in this room because you don't see any light traveling around."

David knew that our confusion represented a major barrier and he devoted a considerable amount of time trying to help us to cross it. In the following section I shall quote extensively from his discussion of this subject.

Light and vision. David introduced the next class with a brief talk on sense perception, comparing light and sound. Hearing and seeing, he said, are both examples of perception but you cannot think about them in the same way. He illustrated his point by talking about a bell.

> You can say "I hear a bell," and you can amplify this by saying "I hear the sound made by a bell." Saying you hear the bell is a sort of shorthand for saying you hear the sound made by a bell.

If you say you see a bell, you do not find it correct to say you see a sight made by the bell. That sounds queer. So hearing and seeing are not the same kind of thing.

David than asked for suggestions on how one could amplify the statement "I see a bell." We proposed "I see the shape of the bell," or "I see the color of the bell." Polly finally concluded: "There's not a word that does for 'see' what 'sound' does for 'hear.'" David agreed but then brought up an example in which seeing does seem to parallel hearing:

> There is one case in seeing which is like hearing the sound made by the bell and that is seeing a light. If I shine a light in your face, you don't say you see the flashlight. You say you see the light. In that case it seems all right to say the light is coming to your eyes. It's common sense language. In the same way, isn't it all right to say you hear the sound coming to your ears? Sound traveling is okay, isn't it? In the common sense world you say I hear a sound over there, but what you mean is: the source of the sound that comes to my ears is over there.

"Well that's interesting," said Hedy, "I hear the sound of the bell, it's right here, but I see the bell and the bell is over there." David agreed. Vision is more complicated than hearing, he said, because in vision we sometimes think of light coming to our eyes as when a bright light is shining in our faces, but at other times, we think the object of vision is "out there."

> When we see each other sitting around the table, we're not seeing light, we're not thinking about light coming to our eyes. We're seeing objects out there and that's what we're directly aware of psychologically . . . When we're talking about our own perception of physical objects in the world around us, we don't think of light traveling at all. I think we think of light then as what fills space. Let there be light. It's the opposite of darkness, and that's another conception. My hunch at this point, after listening to a lot of your comments, is that these are really two different ways of thinking and they very seldom meet. The light fills space and our eyes reach out to the objects in the world around us and give us knowledge about the world. That's a totally different thing from seeing lights and shadows or thinking about light traveling. The scientific theory is going to insist that there's only one kind of light. We're going to have to construct a picture in the scientific domain that will somehow correspond to these two very different ways of thinking in common sense. We have to reconcile these two ways of thinking about light by insisting that there's really only one way of thinking about it.

It was nice to have our common sense approach validated, but how were we going to change? Our view of ordinary light had served us well for all our lives, but now it was in conflict with scientific thinking. At least David was sympathetic:

> Think of light in this room for a moment. The room is full of light. What happens when you try to describe this in terms of light rays? There are some coming in the window from the sun, indirectly scattered from the sky. There's some coming from these lamps. It's going out in all directions in the room. It's hitting all sorts of objects--us and tables and chairs--and bouncing off of them and being scattered in all directions. A tremendously complicated and random mix. And that's the physicist's version of the room being full of light. It seems terribly complicated compared to the common sense version where the room is just full of light.

David is always ir*erested in the historical development of scientific ideas, and he shar ' with us an old theory about light.

> 1ne favorite theory I have from antiquity is that light is something that chases away the darkness. Darkness is an obscuring medium, it keeps your eye from going out to things. And when you turn on the light or the sun comes up, all that dark mist is pushed out of the way. Isn't that a nice idea? There's a blackness that fills space and the light pushes it out of the way. The emptiness is transparent now and your eye can get through. It's a theory that was propounded in antiquity. It's totally at right angles to anything present-day science would talk about but it's sort of a nice theory, it feels right somehow.

"Oh, that's so much better!" exclaimed Sue. We all felt comfortable with this ancient way of thinking. David than gave us a handout, an excerpt from Gerald Holton's Thematic Origins of Scientific Thought (1973). Holton discusses the old dual view of light with which we were struggling--the ordinary, all-around light which allows our eyes to see, and the other kind of light which is coming to our eyes from a source. He calls the former lux and the latter lumen. Both come from the same Latin root, David said, lumenare: lumen from the present tense lumenare" meaning "to light," and luxfrom the past tense "luxit" meaning "it lighted."

In the old emission theories of light, Holton writes, there is an intimate interaction through contact between the observer and the observed.

> Plato held that as long as the eye is open, it emits an inner light. For the eye to perceive, however, there must be outside the eye a "related other light," that of the sun or some other source that allows rays to come from the objects . . . a coupling between the outer and inner world is clearly attempted. (p.123)

The Greeks, the Arabs, and the Medievals, David told us, thought it was improper to separate questions about what's happening out there in the physical world from questions about what's happening inside the human mind. They wanted to have a unified picture of light and vision, all in one piece. Modern optics, he said, stops at the point where light forms an image on the retina. That's the end as far as physicists are concerned. They don't talk about what happens behind the retina.

> Physicists will say that's a problem for psychologists and psychologists will discuss vision but not in terms that will match what the physicist is doing. There is no unity, no coherence between the two pictures of light and vision.

We didn't know that our thinking about light was so similar to that of the ancient Greeks. I liked their attempts to unify light and vision. If I were starting college now, I thought to myself, I might try to take a double major: physics and psychology!

From pinholes to light rays. The topic of shadows introduced us to the concept of light traveling in straight lines: The two classes on pinholes consolidated our still-tenuous understanding.

To illustrate how pinholes work, David drilled a small hole into a door leading from our classroom to a large closet. A large board was put up in the classroom about six feet from the pinhole, and facing it. Several large alphabet letters cut out of colored construction paper were pinned to the board. In the closet, tacked on the wall opposite the door, was a sheet of white paper. We went into the closet, a few people at a time, and after our eyes got accustomed to the darkness, strong floodlights in the classroom were turned on, lighting up the letters and the area in front of the door. Inside the closet, we saw reversed and upside down images of the letters on the board. Then a teacher in the room happened to walk past the door and we saw her image, upside down, passing across our "screen." That was truly an amazing sight and somehow more convincing than the reversed alphabet letters. Everybody was really excited and the teachers took turns now going into the closet to see their colleagues walking, skipping, or jumping in front of the pinhole door.

Almost every teacher wrote enthusiastically about this experience. Here are some sample responses:

> We got to be in a pinhole camera set-up. That was as wonderful as liquid nitrogen. I'm still amazed thinking of it. I can hardly believe such a miraculous thing as a pinhole image was on that paper but I have my experience that it really was! (Hedy)

> I loved the pinholes . . . At first I thought, how is that done, and was really blank, but the minute I thought of light traveling from the top right hand corner and in a straight line, it became clear in a flash. Understanding is always fun! (Polly)

> I didn't know what we were going to do when we started talking about the pinhole camera . . . I had no idea what we were going to see when we went into that room. I thought we were going to look out the hole . . . When I realized what we were seeing, and how things were reversed, it blew my mind. (Sue)

Betsy, who had done pinhole photography with her sixth graders, remarked that she was surprised to see color when looking at the screen in the closet. "I guess I just always pictured this 'film' from a pinhole to be black and white," she wrote.

Some teachers understood what happened. Others needed to clarify for themselves why the image was reversed. To help us with the geometry, David and Ron devised a piece of apparatus which proved most successful (see Figure 1). A large construction paper "F" was pinned to a board which was mounted parallel to and about four feet from a blackboard. Between the letter "F" and the blackboard was mounted a small plate with a hole drilled in it. A dowel with a piece of chalk attached to one end was pushed through the hole: by following the outline of the letter "F" with the other end of the dowel and touching the blackboard with the chalk, an upside down and reversed "F" appeared on the blackboard. Even though all the teachers had seen the upside down image in the closet and knew that it was formed by light coming through the pinhole, several teachers reported that they needed the experience with the dowel to fully understand what was happening.

> It was very exciting to see the pinhole camera effect. And to figure it out! But it did not come to me until I traced the letter "F" on the board. Only then was I able to understand it. (Marilyn)

> The work with the pinhole was the first time I'd ever thought through what does happen. I am excited about understanding this better. I was impressed with the apparatus for tracing the letters and the obvious connection with what happens with the light through a pinhole. I felt such a sense of satisfaction tracing those lines. (Jean)

When I figured out how light traveling through a pinhole produced a reversed image, I felt very satisfied. The idea of light going from a place, in a straight line, to another place was becoming quite clear. I even figured out how to make the image larger or smaller by moving the plate with the hole closer or further away from the letter "F." But then I again began to wonder about light: What is it really, I thought, that bounces off my head and carries an image to a piece of paper and from there to another person's retina? How do light rays carry images? I didn't undrstand that at all. I was thinking of a light ray as consisting of little particles of light that travel down from the sun in straight lines and I was trying to figure out how these rays carry images. When I asked David, he said that this was not the way to think about light rays. A

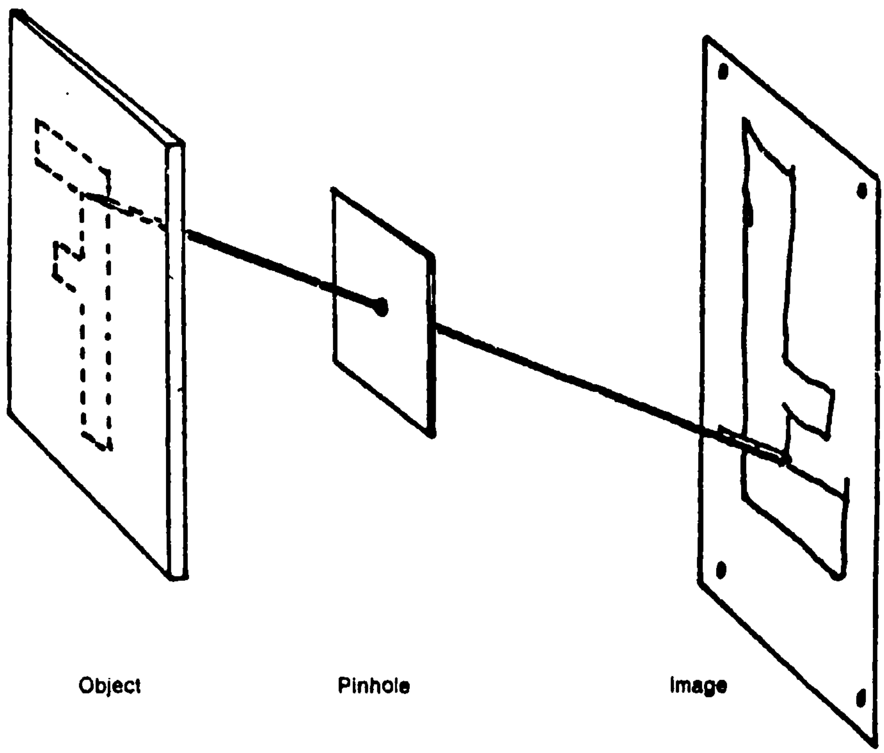

Figure 1: Apparatus used to demonstrate pinhole image with dowel rod.

light ray, he told me was a geometrical construction with which you can predict; it was a useful model. "When we talk about light rays traveling in straight lines, we go beyond experience, we make a representation to explain the behavior of light. A ray is an invention of the mind." I was even more confused now. Light rays weren't real? I always thought when I saw a beam of light, extending from a flashlight, a projector, or coming down from the sun through clouds, it was made up of rays. Because my problems in understanding new ideas often were indicators of teachers' problems, David spent a good deal of time at the next class meeting discussing light rays.

> I want to talk just briefly about one very central, very important, and in a sense very simple idea, but also in a sense a very hard one to accept, and that is this notion of a light source which emits light. You can think about the light emitted in terms of rays of light. The light ray is the basic abstraction used in all the thinking about light and vision. It is indeed a straight line because that just expresses the statement that when light is traveling through a uniform medium like air or empty space, it is traveling in straight lines. So you represent a tiny little bit of light traveling in a straight line by a straight line. In other words, it's just a symbol to represent the pathway.
>
> How can you think of defining a light ray? Take a small source of light and then at some distance have a screen with a small hole in it. Then the light that goes from the source through that hole is like a pencil of light. Don't pay any attention to the light that hits elsewhere, it can't go through the hole. Just the light that comes through the hole is that pencil of light which you can imagine as a very very small straight line, a ray. It's kind of an abstraction, an idealization. Any old geometrical straight line is an idealization. A piece of string has thickness but you pretend it's just a line.
>
> All of the everyday phenomena about shadows and pinhole images and lenses can be translated into the language of geometrical straight lines and you can make pictures of it and it gives you a kind of unified account. All of these phenomena you can work out for yourself once you get the idea that you're going to describe what's happening with this kind of geometrical representation. It's called geometrical optics and it does not answer the question, "But what is light, really?" It only talks about how light is transmitted. It only talks about the pathway and not about <u>what</u> it is that follows this pathway. You see, that's enough. Why does light behave this way? Well, that's going to be a much deeper and much more difficult question.

David had called light rays symbols, abstractions, idealizations; the straight line in a diagram is a geometrical representation, a model for a way of thinking about the behavior of light. This seemed strange to me. I can accept a line on a map as being a representation of a road or a dot on a chart as being a symbol for a star, but I can see roads and stars in the real world. How do I think about a line that represents something that is not only invisible but that does not even exist? Polly had written in her notes: "A big part of all my difficulty is that I can't see physically so much of what it is I am trying to understand."

David had said that the model of a straight line representing a light ray would help us to figure out a whole range of optical phenomena. That was not clear to me. Moreover, I would still only know how light behaves when I wanted to know what light really is. How will an understanding of geometrical optics lead me to an understanding of the nature of light? David had mentioned the book The Philosophy of Science by Stephen Toulmin (1960) and in it I found a description of the role of models in physics that I found very helpful.

Toulmin discusses the nature of discoveries in the physical sciences, using geometrical optics as his example. He writes:

> The discovery that light travels in straight lines . . . was a double one: it comprised the development of a technique for representing optical phenomena which was found to fit a wide range of facts, and the adoption, along with this technique, of a new model, a new way of regarding these phenomena, and of understanding why they are as they are . . . The very notions in terms of which we state the discovery, and therafter talk about the phenomena, draw their life largely from the techniques we employ. The notion of a light ray, for instance, has its roots as deeply in the diagrams which we use to represent optical phenomena as in the phenomena themselves: one might describe it as our device for reading the straight lines of our optical diagrams into the phenomena. We do not find light atomized into individual rays: we represent it as consisting of such rays. (p. 29)

This gives me a beginning understanding of the relation of models to invisible phenomena in the world though it requires a kind of thinking that I am almost completely unfamiliar with.

Toulmin also helped me with my question about how I would get closer to an understanding of the nature of light by starting with geometrical optics:

> One might speak of models in physics as more or less "deployed." So long as we restrict ourselves to geometrical optics, the model of light as a substance travelling is deployed only to a small extent; but as we move into physical optics, exploring first the connexions between optical and electro-magnetic phenomena, and later

> those between radiation and atomic structure, the model is continually further deployed. (1960, p. 37)

A good model, Toulmin says, is one that suggests further questions, that takes us beyond the phenomena from which we began, and tempts us to formulate hypotheses which turn out to be experimentally fertile.

David put it this way in class:

> You invent a hypothesis and then it becomes a powerful descriptive tool. Scientific theories are inventions that we credit and believe in and support because they unify our experience but not because they are somehow the absolute truth. They are models; they are representations. They must have something right in them or they wouldn't have the power that they have. The fact that they predict and unify all kinds of otherwise unrelated experiences is terribly impressive. And yet fifty years later they say, "well that was a very good theory but now we can reconstruct it . . ."

We were not only learning about light and color in this course. We were learning about scientific models and scientific theories, about new ways of thinking which were necessary both for specific understanding and for the much broader understanding of the development and the history of science.

I was so pleased about my better understanding of models and theories after listening to David and reading Toulmin that I decided to venture further. I took home an old copy of the Scientific American and tried to read Victor Weisskopf's (1968) article entitled "How Light Interacts with Matter." I understood just enough of it to know that there is a reason for the color of objects. That was exciting. In the evening I wrote in my notes: "A lot of things are falling into place and as usual when that happens, I get overstimulated. I'll probably have trouble falling asleep tonight."

Postscript: images. In my earliest thinking about light, in the energy class the year before, I wondered whether light flowed, like heat. Later, in the Seminar on Light and Color, I found myself confusing white light with air. Both are "all around us" and are taken for granted in everyday life. When I realized that this neutral kind of light was quite different from air, I had trouble relating it to the light that comes from a lamp or from some other source. I found out that the Ancients thought about light in two different ways, but that in modern physics there is only one kind of light. Then I learned that light travels, and that all light is constantly in motion, "in transit" as David put it. While this idea was becoming acceptable to me, I tried to understand that a light ray is a model for the behavior of light and I figured out the geometry of the reversed pinhole image. I grappled with the understanding of absorption, reflection, and scattering of light and I even obtained a rudimentary understanding of what accounts for the color of different objects. But I still didn't understand how light actually produces images.

all through the Seminar and all through the writing of this essay, I was thinking about images as if they were pictures. In some vague way, I thought of all the little particles of light scattered off an object as somehow "carrying" in a straight line a tiny part of the picture of the object to where the image was formed. In my mind, the pieces of this picture were traveling through the air on light rays! This formulation strikes me as so ludicrous now that I am almost too embarrassed to report it. I knew this wasn't really how things worked but I didn't know how to think about it. Did the language--words like "traveling" or "carrying"--throw me off? Or were all my points of reference to pictures?

I became so frustrated by my confusion and so impatient to understand this that I phoned a physicist friend of mine, long distance. He explained to me that images are formed by light--more or less light and light of different colors--and that the images we <u>see</u> are representations of the <u>pattern</u> of light and color produced by the objects from which light is scattered. Obviously this must have been discussed many times in our classes but it wasn't till I had almost finished writing about the course that I became aware of my confusion about images. My old question--how does the image get from the object to the paper (or the eye) was finally answered. How long it sometimes takes for the pieces of a puzzle to be put together and how tremendously exciting it is when the last piece is finally fitted in. Well--the last piece of <u>this</u> particular puzzle. I know there will always be more.

IMPLICATIONS

Questions

"When have you planted enough clues so people can ask questions?" David once asked at one of our meetings. There is a stage in learning when you don't have any questions. The words or concepts have no meaning yet, the confusions haven't been uncovered, you don't know in what direction the learning is going to take you, and therefore you have nothing to ask. What is the teacher's role at this stage? For me as a student, this is a "taking in" period--hearing about the topic, listening to discussions, doing some experiments, reading, and gradually letting the new ideas sink into my consciousness. Then one dav I may surprise myself with a statement that shows that I understand more than I realized. At this stage I appreciate having a teacher pose questions which "plant clues," which arouse my curiosity, focus my learning, make me aware of things I hadn't noticed before, and sustain my interest in additional investigations. There is a subtle dividing line between leaving students alone to make their own discoveries and telling them just enough so that they can proceed on their own. If a teacher tells too much, students are deprived of the pleasure of making their own discoveries. Answering <u>your own</u> questions leads to the most meaningful and lasting learning. Marilyn wrote in her evaluation:

> At certain times during the course I felt angry about not being given more information. However, now I am grateful that I wasn't deluged with facts. If I'd been given too many explanations, I'd never have had the positive experience of discovering concepts on my own.

Hedy described what learning situation she liked best:

> None of the experiments which were set up for us to observe had the impact for me of that initial "just playing" with the colored gels, when Ron came by and raised questions, gave us "clues" but did not answer our questions. That seems like the best model. When experiments were set up to teach us something, it was very different from playing around and stumbling and questioning and coming out with a "burning desire" to know.

I know what Hedy means when she talks about having "a burning desire" to know something. The closer I come to understanding a new idea, the more urgently I seem to want an immediate answer to a question. I often wondered about this sense of urgency. Is it that I am afraid I will forget what I know? Or is it that I am at the end of a long struggle to understand and when the goal is finally in sight, I want to get there fast to resolve the tension? Polly once described her experience in the course as being both frustrating and exciting. Doors were opened, she said, and suddenly you realized how little you know and how much you would like to know. "The process of learning is fun but I want it to be leading somewhere."

Once you find out that there is a way to understand something that you have always ignored or considered inaccessible, you become impatient to know. We were at times quite insistent in class about wanting answers which we thought would be of help to us. When we got an explanation, we often did not understand it. Our knowledge and experience were too limited to process the new information. One day David tried to explain the reason for his reluctance in giving us quick answers:

> We honestly don't know how to answer some of your questions. They are very insistent and very hard to deal with because the typical way of answering them makes use of ideas that haven't been developed yet . . . An awful lot of what is called science is the outcome of people wrestling with problems over a long period of time and gradually developing pictures that are not the ordinary ones. The attempt to translate all the things that happened in that development into a few well-chosen sentences just doesn't make sense.

David often talked about the history of a scientific idea, stressing how long it takes for a theory to develop. During the Heat course, he once said that he would like us to stay in the 19th century for a while longer, to work with the ideas of heat and temperature of that time. (We wanted to rush into an understanding of electromagnetic radiation!) I asked him then whether he thought that working through the stages of historical development of a scientific idea would give us a better foundation for the understanding of modern theories. "Yes," he answered, "at least that is my hunch." In some ways, David's gradual historical approach was reassuring. If it has taken physicists hundreds of years to understand the nature of light, we should not expect to understand it in one brief semester!

There were certain kinds of questions which we tended to ask which troubled David: "What is electromagnetic radiation?, how do light waves work?, what exactly are photons?" and so on. "If you are thinking about a subject which you understand very well," he said, "do you ask for explanations of the kind 'but what is light really'? If you're thinking about children's minds, for example, do you ask 'what are children's minds, really?'" He continued:

> I think you recognize that you're constructing and choosing models, images, useful metaphors, and devices for how you think about these things. And you're very conscious of the fact that day after tomorrow you may revise your picture . . . With anything you really understand and come to terms with, you recognize that you always have more to learn and that therefore you don't have a final explanation. The more you know, the more you're like that. Whereas when you have a passing interest in

something that you feel you don't understand, you want to get an answer that eliminates further questions. We've all been frustrated by so-called scientific explanations and we'd like to be relieved of that frustration. I don't think you can quite be relieved of it, you've got to get used to having it. Then you slowly build up a picture that is more and more satisfying but never with the feeling that you've said the last word or that anybody can tell you what the last word is.

Because several students had expressed frustration about having answers "withheld," David posed the following question in his request for a final evaluation paper: "We have left some topics hanging, inadequately described or explained, such as light waves, resonance, lenses. How do you now react to our diffidence about plunging forward with explanations?" Interestingly enough, by the time the course was finished and the teachers had had some time to reflect upon their experiences and their learnings, no one seemed to mind having been "left hanging." Here are excerpts from the teachers' answers to this question:

> These dangling questions don't seem like difficulties now, just more to know about. That's very positive for me because I don't have to understand them right away. I'm under no pressure to unravel them. (Hedy)

> I expect to have lots of loose ends. This is what this is all about and also the state of my understanding of concepts. I'm prepared for that to be the way of things, not only with this seminar but with how I operate in the world. (Jean)

> Not truly understanding light waves is another thing to which I have resigned myself. I feel overall that I have learned so much, therefore it is acceptable to leave a few things hanging. (Polly)

I had a hard time learning to accept the open-endedness of science. "Does everything have to lead to other, more complicated questions?" I once asked. It took me a long time to become comfortable with this lack of closure. The more I know about a subject, the better I can accept open-endedness, probably because my existing knowledge gives me the security to be left hanging. When I delve into new subject matter, my tolerance for open-endedness decreases noticeably. I feel insecure with my lack of knowledge and, as David said, I seek answers that eliminate further questions.

How can students be helped to accept open-endedness, ambiguity and temporary confusion as a normal part of the learning process and how could they be better prepared to tolerate the discomfort that often accompanies not understanding?

Feelings

Learning is never just a cognitive activity. The teachers' feelings during the seminar played an important role in the learning that took place. There were many highs and lows, joys and frustrations. I shall mention only briefly some of the more important points that were raised by the teachers in their journals.

Difficult material often produced a feeling of "overload." When the saturation point is reached, no more learning can take place. "I am tired and it takes too much of an effort to understand this"; "I didn't even try to understand that--maybe another time"; "I don't want to deal with this right now." These were typical comments. I sometimes felt in myself strong resistance about getting back into thinking about light after being away from it for a week. "Do I have to struggle with this again?" I wondered. Yet as soon as I was in class, this resistance quickly vanished. One week Jean wrote:

> At one time I needed not to come to class. This happened when I was feeling particularly confused with putting together what I was observing and hearing. It was such a dilemma for me. I felt I needed time to absorb and not to work with equipment that week, yet I knew I would be missing so much.

The pace of our class often seemed slow to the research staff, yet teachers were asking for more time: they wanted more time to work with materials, to explore things by themselves and at their own pace, to let ideas sink in. "I like to think about the class for a day or two and then I find I wake up with questions and ideas coming together," said Sue. And Jean wrote:

> I need to hear things more than once, or to hear them in another context, or to have some exploration time and to hear them again, or to have some discussion time and then hear again with different ears.

The need for repetition was expressed frequently:

> I wanted to play more with the pinholes, to come back on other days and do it some more and some more, for the part of me that needs repeated experiences of the same phenomena to really believe it. (Hedy)

Hedy mentioned another reason for slowing down: "I didn't have any interest in the other questions," she said, "I was too content with my new glimpses." I remember often feeling the same way when I reached some new understanding. I wanted time to savor my success, to enjoy having reached a plateau. All too often, teachers get carried away by their own enthusiasm when students are learning and do not allow them sufficient time for this kind of celebration.

Finally, comments by Sue bring up two more important points:

> I never questioned. It says in my fourth grade science book that light travels in a straight line. I accepted that as a child accepts the faith of someone they admire and respect. I am changing. My mind is opening up more since we started the class. Now I think: what other ways could light travel? How do things go from one place to another?
>
> I wonder if you realize the level of trust that is needed as we write these stream of consciousness papers. It's one thing, and rather easy, to say: I don't know, or I don't understand. It's quite another thing to expose yourself so completely, to explore all the ways you don't understand, not monitoring any of your questions.

The seminar participants were encouraged to express and share their feelings about the content, the teaching style, and the philosophy of the class. I hope that the students' comments quoted in this section will help to sensitize science teachers, for whom concepts already mastered may seem easy or obvious, to the feelings <u>their</u> students may have as they struggle with new ideas.

<u>Teaching and Learning</u>

The Seminar on Light and Color was a very special course. There were three instructors for ten students. There was no time pressure to cover prescribed topics. There were no concerns about grades. Classes were informal, discussions free and open, the climate supportive. The participating teachers had limited experience with science and were grappling with a difficult subject, but David had convinced them early in the course that their troubles and confusions were of great interest to him and his associates. The teachers were respected, their thinking was valued, and they soon developed trust in the staff.

In a typical science class, whether for adults or younger students, the instructors work with many more constraints. In a course in which a definite amount of material has to be covered, it is difficult to <u>uncover</u> students' problems. In the Energy course, which I audited as part of this research, the instructors were often concerned about falling behind in their schedule because many students were having difficulties with the course material. A month or so after the beginning of this class, a student commented to me how little material had been covered. He appreciated the slow pace and the instructors' patience with student problems: "They could have covered a lot more," he said, "but then we wouldn't have understood anything."

Science teachers may become frustrated when their students fail to learn, and students tend to become frustrated when they cannot understand what is being taught. In traditional science teaching, the burden is on the student to understand the lesson. In a class which focuses on barriers to the understanding of science, the burden is on the teacher to present material in such a way that students will be able to learn. If teachers could become more interested in their students' thinking--no matter how elementary--their frustration might change to fascination.

David was always interested in our confusions because they taught him something about a more naive way of thinking about science which he knew was widespread but poorly understood. As students, we valued his attitude enormously. "I truly do appreciate being treated as a person whose ideas and thoughts receive credibility and respect," Jean wrote in her final evaluation. "That, as much as anything, is what is important to me about this approach and what has the greatest impact upon my teaching and dealing with younger humans."

The course had a powerful impact on almost all the participants. Let me end this essay with some of the teachers' comments:

> The course made me feel more confident about my own capability in terms of understanding science. Even though I'm not clear about all the information we covered, I feel I could be if I had more time and experience to do some further explorations. The difficulty is in finding similar learning situations in which to pursue science. (Diane)

> This course has fundamentally changed the way I approach the physical sciences. I have always felt fairly comfortable with the biological sciences, but I saw the physical sciences as something that wasn't for me, as something which required a lot of effort for results that seemed not important to me. This class helped me to see that all this "science" is truly relevant on a day to day basis and is part of the real world in which I am very interested. I have in fact been toying with the idea of taking a college physics class. (Polly)

> This kind of science teaching is precisely how I wish I had learned science in junior and senior high school. I never had the chance to explore science this way . . . As a result of this class, I've had an experience quite unlike any other I've ever had. I value quite highly the method of my being able to come into an understanding of these ideas in my own way and in my own time. Learning about light has certainly sparked a new curiosity within me. I want to think and wonder about it further. It has become a more accessible subject and I'm not as intimidated to plunge in. (Marilyn)

And lastly, Hedy who attended both our Seminars and who had "never felt friendly toward science":

> What I got from this course is not earth-shaking new understanding, but many topics of a scientific nature now seem

> more accessible to me . . . I feel better about myself, more powerful. It shakes the old negative ideas of myself to enter into new understanding . . . I am immeasurably broadened by both semesters, doing something I haven't done before.

> I feel wistful. I've had a little taste and now I'd like more. I don't feel trusting of the science/math world at large and would be reluctant to take the risk with anyone else yet. You've made it very safe for me . . . I would love to go on indefinitely meeting weekly, and exploring new ground.

We "opened doors," gave "a little taste," made science "more accessible and more part of the real world." All these teachers wanted to continue their studies, but most of them did not want to take a regular college class. As Diane said, "Where do you find a similar learning situation?"

An important finding of our research was the confirmation that given the right set-up and approach, teachers who had previously avoided or feared science became excited learners with a strong desire to continue their scientific explorations. If our group of teachers was at all representative of elementary school teachers at large, there is a great need for science courses, both at the pre-service and in-service level, which have an informal, supportive, slow-paced approach with plentiful "hands on" activities and opportunities for teachers' personal involvement. Teachers must be studying science themselves if they are to become enthusiasts for science in their classrooms.

At a time when good science instruction is considered one of the nation's educational priorities, we should not ignore the capabilities and interests of large numbers of elementary school teachers. Nor must we ignore the fact that traditional science teaching has not educated them well and is not likely to educate well many of the students who are now in school. As David Hawkins said:

> An awful lot of our troubles in science education come from the fact that we are fed conclusions without being offered the opportunity to arrive at them ourselves from any kind of evidence. We therefore are not able to tie things together with our experience and so science remains something detached, bookish, propositional. You can state scientific facts but they don't affect your awareness of the world.

Our research has shown that with a different approach, it is possible in a relatively short time to bring about a significant change in students' attitudes towards the learning of science and towards the role that science can play in their lives.

REFERENCES

Apelman, M., R. Colton, A. Flexer, & D. Hawkins. A Report of Research on Critical Barriers to the Learning and Understanding of Elementary Science. National Science Foundation Contract #SED 80-08581. Boulder, Colorado: Mountain View Center, 1982.

Hawkins, D. Talk presented to a symposium in honor of Victor E. Weisskopf, published in Physics and Our World: A Symposium in Honor of Victor F. Weisskopf. New York: American Institute of Physics. Reprinted in Outlook, No. 22, Winter, 1976.

Hawkins, D. "Critical Barriers to cience Learning." Outlook, No. 28, 3-23, 1978.

Holton, G. Thematic Origins of Scientific Thought. Cambridge, MA: Harvard University Press, 1973.

Toulmin, S. The Philosophy of Science. New York: Harper and Row, 1960.

Weisskopf, V. "How Light Interacts with Matter." Scientific American, No. 9, September, 1968.

INTRODUCTION TO CHAPTER TWO

Like Maja Apelman, Keith Hanson is interested in students' confusions and the alternate theories that develop during science instruction. However, his perspective is that of a teacher, rather than a student.

Doctor Hanson is particularly interested in the alternate theories that he sees in his students and their implications for inquiry teaching. Is it possible for students to inquire freely and still reach correct conclusions? What should we do when their conclusions are wrong? These are among the issues that Dr. Hanson illustrates and considers in this chapter.

Dr. Hanson currently teaches middle school in Danville, Illinois. His current interests include reviving little known science demonstrations and developing the teaching approach that recognizes and encourages the development of science talents in students.

ALTERNATE THEORIES IN THE CLASSROOM

Keith Hanson

INTRODUCTION

This paper describes a series of studies that I began as a graduate student at the University of Illinois and continued on an informal basis after I returned to teaching. The study described in the first part of the paper was a formal study in which I observed small groups of students taught by other people. The study described in the latter part of the paper was informal; I was the teacher, and no effort was made to be scientific--other than being a careful observer. I made no attempt to control conditions in a manner satisfactory to researchers used to the controlled conditions of laboratory settings. I collected information that describes how I observed alternate theories, and, to some extent, induced their formation to better understand how inquiry in the classroom develops. I hope to share my experiences with investigators and researchers who might be more able to interpret what is happening and formulate explanations for the observed phenomena.

BACKGROUND INFORMATION

Learning Modeled on the Concept of Absorption-Assimilation

Learning in the classroom is more than the transfer of scientific knowledge and ideas. It is also a process that involves absorption and transformation of scientific knowledge and ideas in light of the knowledge and ideas the student already possesses. Teachers have to check student learning to confirm and correct the transfer of knowledge and ideas. Unfortunately, students make mistakes in the information transformation process and arrive at very different conclusions.

The mistakes often occur when students engage in inquiries, settings wherein the teacher presents data and asks the students to participate in creating a conceptual or theoretical framework for the data. When teachers open inquiry by asking students to create explanations for data that are explained by an existing scientific conceptual or theoretical framework, there is a very narrow pathway students have to follow to the correct formulation. Students know the rules for inquiry, but don't know where the path's edge is. They have the ability leave the permitted pathway and create one that leads to an alternative explanation.

Problems Associated with Inquiry Teaching

Initially, I was interested in correcting those errors teachers made in conducting inquiries. It was obvious to me that teaching students in the inquiry mode leads to a better understanding of science; it was also obvious that many teachers avoid inquiry for its frequent unexpected turns and unsatisfactory conclusions. I felt a collection of good and bad examples of inquiries, along with strategies for achieving proper conclusions, would make inquiry an acceptable tool for teaching.

I observed some well-taught sessions that I thought were models for teaching inquiry. I documented the data for the inquiry, and how the underlying concepts developed. I also documented instances of poor data presentations where the concepts weren't developed. I hoped a comparison of good inquiry development and poor inquiry development would lead to ideas for controlling the outcomes of inquiry. My first observations of teaching sessions supported the thesis: The addition of data, modification of methods, a review of ideas, or resorting to scientific tradition salvaged many inquiries and produced satisfactory conclusions.

Problems Generated in Inquiry by Students' Thinking

Yet, there were those instances when appeals to reason, data, and the like made no difference in the outcome of the inquiry. The teacher presented the data in an acceptable manner, used procedures designed to produce the correct conclusions, but the students formed alternative conclusions. It made no difference whether the teacher used paper data or laboratory exercises, the students saw and/or interpreted data to formulate concepts that were definitely different and unacceptable to the teacher. These were called alternate theories and were the very ideas that forced me to reconsider my effort to bolster inquiry teaching through the description of good and bad examples. Schwab (1963) had already documented examples of good inquiries, and my efforts to develop strategies to correct "bad" inquiries had demonstrated, to me, that "bad" inquiries deserved closer examination. Therefore, my first study became an investigation of situations where acceptable inquiry procedures had resulted in unacceptable conclusions from students.

FIRST STUDY

Method

My study (Hanson, 1970) was exploratory and examined specific episodes in which students advanced alternate theories. I observed 12 student teachers as they taught freshman biology students. The student teachers were enrolled in a methods course and worked in pairs with groups of freshman.

One student teacher taught while the other kept an anecdoctal record of each teaching session. I videotaped one of the six sessions each day.

As the study proceeded, the anecdotal records kept by the student teachers proved to be of little value and were not used. I concentrated on analyzing the videotaped lessons. Alternative theories didn't appear every session. I was limited to two reels of two inch Ampex tape, so I eventually copied the segments of the sessions containing the alternate theories onto a master tape. There were 35 class sessions which were taped and approximately seven alternate theories were put onto tape and transcribed onto paper for analysis. I'm not sure the tape with these episodes exists anymore. It was the property of the curriculum lab and was returned to them. The material on it didn't seem to hold much significance beyond being an aberration associated with inquiry.

I also tried to interview each student teacher on the same day as the lessons were recorded. The tape was replayed in the interview, and an audio recording was made of the teacher's comments about the lesson and, in particular, the episodes involving alternate theories. When students developed an alternate theory, the student teachers seemed to be very aware that the students were "off the track," and could generally explain how the alternate theory might have originated.

I also tried to schedule interviews with the freshman students, but this proved to be difficult. Other researchers were using the video equipment, and some interviews had to be scheduled days or weeks later. I think that the time delay affected the validity of my student interviews. I worried about the "Margaret Meade effect." Were the students saying what they really thought or what they thought I wanted to hear? I don't think this effect is as severe if the interview can be conducted very close to the time the theory was formed.

Analysis of Data

The information from the videotapes, student teacher interviews, and student interviews was transcribed, and this information became the data used to describe alternate theories. These alternate theories were explanations students created or used to explain data. These explanations weren't isolated occurrences but appeared to be parts of a continuum.

On one end of the continuum were folk theories (cf. Singer, 1957), ready-made theories, or ideas that the students appeared to possess before instruction began. They were the outdated, teleogical, or simplistic theories which fit the data and, on the surface, seemed resonable.

Toward the middle of the continuum was a second class of theories that the teacher induced, theories that were based on wrong information. There is not too much to say about these.

On the other end of the continuum were those theories students created when the teacher provided data and asked the students to create an explanation. The students created an explanation which was internally consistent and is derivable from the data supplied. Teachers often missed the consistency in these theories because they continually added their own auxiallary assumptions from the accepted theory and tried to show that students had made a mistake in logic. What the teachers missed was that the students have their own set of auxillary assumptions which make the teachers' criticism irrelevant.

As an illustration of my findings, I will present an explanation based on a folk theory. In this example, the student possesses the theory, uses an assumption provided by the teacher and demonstrates the theory's utility by applying it to a new situation.

A Theory on the Movement of Water in Plants

The students had studied how plants move water from their roots to their leaves. Several examples of moving water were given in the student text. The students had examined several models for moving water and examined cell structure and performed experiments on the movement of water; now the students were in a discussion session with the student teacher. The teacher was trying to bring ideas, experiments, and data together in an inquiry session. The teacher was asking, "Since all the data are in, what do you think is the best answer?" T is the teacher, C and K are the students in the group who enter the discussion with the teacher.

T: Where does the leaf get the water?...and its food?

C: From the roots and the water goes up into the plants.

T: The water goes up into the plants from the roots?

C: I guess.

T: How do you know?

C: I don't know, I just guessed.

T: How do you know that? How do you know the water is coming up?

The student C was being tested, pressed for an answer. The inquiry process demands that one justify positions as well as state positions. The teacher knew the reason would be given if the student was challenged.

C: Well you irrigate crops. The water always sinks down and the roots get all the water...the roots get the water...and it waters the rest of the plant.

T: OK. You can probably assume that the water is coming through the roots. How does it pump it? How does it get up here (in the leaves)? Is there a little vacuum pump in there (laughter)?

C: Well, uhmm, it just goes up.

T: Why does it go up?

K: Well there are special kinds of veins. I never remember the difference...they are either xylem or phloem, and the one brings the water and everything up and one brings it down after...

K is interrupted by C who has a burst of insight.

C: A plant breathes!!!! When a plant breathes!!!

T: How does it breathe? Does it have lungs? (T seems amused but she isn't sure how to follow up on the student comments).

C: No!!!...No!!!...See!!!...Well, I don't know how it breathes...the water comes up...and it is just like in a body, when you breathe the blood goes up. It has to!

T: The blood goes up when you breathe?

C: Still has some force.

K: The heart is pumping it...

C: Something like that.

Analysis of Session

As I stated earlier, I was interested in correcting teacher errors and finding examples of poor teaching. This episode could be considered an example of what not to do. The teacher has posed an open-ended question to a poorly prepared group of students and must now deal with the consequences, including a student who is enthusiastically explaining an incorrect theory which has very little to do with the scientific principle that the teacher is trying to teach.

Th teacher could have easily avoided this problem by offering the students a limited freedom of choice as they engaged in the inquiry. One does not leave an inquiry open and allow the students to manipulate the data in the inquiry process without first positing possible explanations.

In this view of inquiry, the teacher assists in the selection process by pointing out reasons why certain data are important, others are trivial or insignificant. These reasons often are auxiliary assumptions that derive from the theory to be achieved in the inquiry. In other words, to get from data to theory, assumptions from the theory are necessary. It is presumptuous to assume students will know what these necessary assumptions are, so the teacher needs to supply these and have the students make informed choices. This method will enable the teacher to avoid many of the problems that arise from student alternate theories. However, what might be lost when students don't express their alternate theories?

Analysis - Are These Ideas Worth Avoiding?

I suspect that this method of modifying the inputs to achieve or generate the desired outcomes is seen by many as an acceptable method for controlling classroom inquiry. The advantages are obvious: By controlling the inputs the teacher maintains the integrity of currertly acceptable ideas and maintains the myth that scientific ideas derivable from data. The integrity of the inquiry process is somewhat damaged. The more able students may sense something is wrong and will recognize the teacher has used something that wasn't available to them to create an answer. Whether they recognize what has happened or not is a moot point. When discussion is limited, we have closed down the inquiry process and we prevent students from participating in true inquiry. What if the teacher in the lesson above had limited discussion--what would have been the result? Note the quote below;

> Among early Greek writers...Empedocles (c. 80 B.C.) of Acragas in Sicily...took the folk belief "the blood is life." It recurs in many authors...pneuma was equivalent to both soul and life, but it was something more. It was identified with life and breath, and the pneuma could be seen rising as shimmering steam from the shed blood of the sacrificial victim--for was not the blood its natural home? There was pneuma, too, that interpenetrated the Universe around us and gave it those qualities it was thought to possess. Anazimenes (c. 560 B.C.), an Ionian predecessor of Empedocles had defined these functions of pneuma with this phrase: "As our soul, being air, sustains us, so pneuma pervades the whole world..." (Singer, 1957, p. 10).

Normal science teaching masks alternate theories. The theories are there, the theories make sense, and the theories probably seem more reasonable to many students than the acceptable theory. When students advance a theory that happens to be historical, I don't think that they are going through some kind of genetic recapitulation, but that the theory has a basis in common human experience. As I looked at the example cited above and others like it, I wasn't sure of their significance. I accepted them as valid outcomes of inquiry, but at the time, I didn't know what to do with them other than catalog their occurrence.

SECOND STUDY

What Happens to the Water Level When an Ice Cube Melts?

When I returned to teaching, I continued to work with alternate theories, but I quickly discovered that one has to do something with the theories, not just let them arise in some random fashion. Quite by accident I found a useful technique for working with the theories. It is as follows: As the theories arise, one asks for a justification of ideas. The students explain what they see and then offer the reasons--the theory, if you will, behind their explanations.

This technique developed one day when I was working with a group of eighth grade students. I had asked them a fluency question. I asked them to describe all the things they could see when an ice cube melted. Things were going along nicely until one student stated that the water level rose as the ice cube melted. At that point another student disagreed and said that the water level stayed the same. Not to be outdone, another said it dropped, and another it fluctuated. This gave me an opportunity to challenge the students' ideas. I asked them to produce a defense of their ideas. If the water level rose, stayed the same, dropped, or fluctuated, then it should be possible to offer an explanation why. Why would the water level rise, stay the same, drop or fluctuate? What scientific principles were operational that made things happen? This is what the students wrote:

Proposed Explanations Before Experimenting

Students said the water level remained the same because:

A. As water freezes, it expands. This makes the ice float and explains why, when ice melts, the water level remains the same.

B. Ice has a crystalline structure. It is dense, but lighter, so it floats. (The term dense means hard to this student).

C. Ice has a crystalline structure that has air to help it float. Gradual melting releases air and maintains a constant water level.

Students said the water level rises because:

D. The part of the cube sticking out of the water melts and pours into the water, raising the level of the water.

E. The floating of the cube is related to the amount of air trapped in the space of the cube. The air has negative weight (with respect to the ice) and buoys up the ice cube.

Students said the water level drops as the ice melts because:

F. As the cube melts, it loses air, which is part of the weight pushing the cube into the water and the water level must drop.

Students couldn't develop reasons why the water level fluctuates, so there was no one to defend that view.

I suggested that experimentation could show which explanation was correct. The students agreed to experiment and establish which was the correct explanation. Implicit in this agreement was the assumption that all the views but one would be shown to be wrong.

Most students recognized that the original experimental setup was too primitive and couldn't provide a definitive answer. Therefore they designed their own experiments. It was interesting to watch the students set up their experiments, for it was evident that they designed their experiments to elicit the effects that they were predicting. If their assumptions depended upon air being present, air was added by blowing into the water or putting an aquarium pump to work aerating the water. If water wasn't supposed to have air in it, students boiled the water to remove the air or used distilled water (assuming distilled water wouldn't have air in it). Many students who maintained that the water level didn't change didn't worry about the shape of the container. Those who needed a measurable change used Florence or Erlenmeyer flasks. These have a large volume of water, but the area of measurement (in the neck) is limited. Elongated ice cubes produced the apparent effect of having more ice out of the water. Students demonstrated their adherence to the rules of objectivity, just like real grownups.

Explanations for Change/No Change in Water Level Based on Observations

Further experimentation proved nothing. Students didn't change their minds too much. A few switched, but, as the statements below indicate, not many of them were swayed by data. That is, they accepted the data only if the data seemed to confirm their position.

Students whose experiments supported the idea that the water level remained the same reported the following conclusions.

A. As water freezes, it expands. The amount of air in the cube (is) directly related to the amount the cube is out of the water.

B. The water level remains the same since an ice cube is larger in volume for the same amount of water--takes up more space--particles are farther apart.

C. Ice is dense (meaning hard) but lighter, so it floats.

D. Ice freezes, expands, and forms a crystalline pattern. There is space in the patterns which makes it float. As it melts, it displaces less water.

E. Since water is released at the same time, it is decreasing in volume. All equals out. Air makes no difference.

F. When things become cold they contract, thus when the cube cools the water, it (the water) would shrink. But the melting of the cube "expands the size" of the frozen water so an equilibrium is reached. The level would not change.

G. If the ice cube had no air, it would sink. The more air, the more it would stick out.

H. The displacement of the ice compensates for the added water when it melts.

I. I do not believe my results, but they can be explained. I measured too soon and too frequently which accounts for the water level not going down because drops of water are melting are keeping it the same. Still, some fits in spaces in the water to keep it from going up. The effect is equalizing.

Students defending the position that the water level rises said:

J. Two thirds of the experiments failed.

K. Two fifths of the experiments were successful.

L. Air floats the cube, therefore the water rises as it melts and loses air.

M. Air has negative weight compared to the water and the cube.

N. The water level falls or stays the same.

O. The number of bubbles affect the amount it drops.

P. As the ice melts, oxygen and hydrogen are released at the same time. Water is released, the water level would not move because when the air escapes, the ice would float lower, but because additional water is present they offset each other.

Students said the water level drops becauae:

Q. Air spaces make a cube float higher (than a boiled cube). Aerated cubes produce large drops in water level. Boiled cubes have no drops.

R. Air floats the cube. Part of the cube sticking out makes the cube float.

S. Water replaces air lost, and the water level rises.

T. It's heavier, but less dense because of the crystalline pattern.

U. A piece of clear ice was put in water. It stuck out a little. There was no sign at any time of the water rising.

Analysis of Student Explanations

There are a number of interesting observations about the students' experiments and conclusions. The students may generally agree on a particular conclusion even though they don't always have the same reasons. I think it's important to find this out. How many kids are spouting correct answers and possibly are not able to justify their answers? I suspect our testing procedures certify many kids as knowledgeable when they are, in fact, not.

The behavior of students believing that the water level remains the same was interesting. Most students holding this idea didn't modify the procedure for measurement too much. A beaker with a scale on it was sufficient. They hadn't noticed any change and weren't looking for any--so why tempt fate and have data that might not fit the explanation?

It's apparent that the concept of density is understood in different ways. Ice is "lighter/heavier" because of crystalline structure, space or air. One way or another, air figures in many explanations--could this be the elusive pneuma rearing its head again? I think it's obvious that students are creating models based upon experience and they are falling back upon folk theory related ideas.

Some of the students are applying scientific knowledge, but imperfectly. Explanation F notes correctly that water contracts when it cools, but then adds that the melting ice makes up for the decreasing volume of water. This person is a recent graduate of the school of thought which affirms that the water level rises, as is the person who wrote the conclusion in I.

The students who advocated that the water level rose had the most difficult time with experimentation, as evidenced by their explanations. Most of these students had included air in their reasoning: If the water level failed to rise, it was because the water was making up the space taken up by air in the cube. Experimentation for these students was difficult. I tried to help them think of ways to show the water level rises, but none was too effective. The closest most students could come to demonstrating a rise in the water level was to heat the water as the cube was melting to speed melting of the cube. The water cooled to begin with and as the water warmed, it would show some change in level.

The students who said the water level drops had the best experimental data. If a lot of ice is put into a large flask (500 to 1000 ml) that has an elongated neck, there is a measurable drop in the level of the water. Most of the drops in the water level were again attributed to the presence of air in the cubes. The students in this group spent considerable time and effort devising ways to introduce or eliminate air from the cubes. Their data seemed to support their contention: Air's presence was important to keep the cubes afloat, and as the cube melted and released air, the air's space was occupied by water.

The number of different explanations is interesting to see. What was more interesting was how students in the classroom reacted to different opinions of their classmates. Students went about their business of conducting experiments, at times looking over other students' shoulders. They didn't seem to find a contradiction that others' results were different. I think students recognized that the work of others was generating data questioning their studies, but to them that meant the problem needed further study.

Often students recognized a need for perfecting their equipment or making better measurements. It was apparent that both of these judgments were true, yet better measurements still have errors. Error, however, was defined by the students in a very narrow sense of the word. Often, the students would say, "I've made an error in measurement that needs correction, a refinement in technique, or better equipment." It almost never meant being wrong and having to switch to another view. Data did not appear to be a hinderance the search for what one believes to be true, somewhat like the real world of research.

Conservation of Matter and the Data

Most of the students had a great deal of difficulty observing this experimental set up of ice melting. The experiment violates--visually, at least--the idea of conservation of matter. The apparent quantity of ice and water looks like it is diminishing as the ice melts back into water. As conservers, some students would expect the water level to rise if the concept of conserving matter is to hold. Thus, these students had reasons based on both theories and experience for expecting the water level to rise. This logical conclusion based upon experience would force an observer of this experience to conclude: The experimental observations are wrong. Matter must be conserved, and the water level must rise. That is what student "I" was referring to when he said, "I do not believe my results." Then he added the auxillary assumption, air was accountable for the experimental error. Possibly conservers are better scientists then we have previously suspected.

Students who argue that the water level remains unchanged are arguing from several points of view. Some conserve matter (water) by saying the amount of matter is the same, whether it's all water, water and ice, or all water again. Others argue that matter is conserved because air has to be part of the explanation; air escapes as ice melts. Some hypothesize that there is a crystalline structure with empty spaces that disappear when ice melts. The "holes" are filled with water.

Finally, we have the people with the best data; those who saw the water level drop. They don't seem to be considering conservation of matter until one sees their auxillary assumption about volume. Their assumption depends upon air to add weight and escape. Their thinking is different. One has some difficulty with these students because they are operating from and being misled--to some extent--by their observations.

In addition to problems associated with the conservation of matter, students brought up the idea of air again. I have no proof or data to show that students are thinking of pneuma, but air seemed to be the all purpose auxillary assumption to prop theory. Air has weight, buoyancy or almost a kind of vitality necessary to explain the discrepencies students found in their data. This looks like a problem for further study for those who have the time.

IMPLICATIONS AND CONCLUSIONS

The experiences described above and other experiences as a classroom teacher have led me to believe that we need to change our science curriculum. I would like to see the development of a model for classroom science that reflects the thinking that occurs in the world of science.

Kuhn (1962) had described the world of science as a place in which scientists engage in an activity called normal science. They have theories that allow them to devise experiments, generate data and operate successfully with the ideas of science. Their day-to-day activities are involved with solving the puzzles suggested by their theory. It is only when they cannot solve their puzzles and have a large number of anomalies cropping up in their work that scientists will consider changing their basic ideas. Kuhn describes these periods of uncertainty, when scientists question the validity of their basic assumptions, as revolutionary science. A scientific revolution ends when a new consensus is established and a new set of assumptions forms the basis for another period of normal science.

I believe that normal science teaching, including normal inquiry teaching, is very much like normal science. Students are trained to believe that certain assumptions and certain procedures are acceptable, whereas others are not. Under these conditions current scientific theories seem to emerge from the data as irrefutable fact, and the circularity of the reasoning (since the theories are the source of the acceptable assumptions and procedures) is hidden from the students.

As an alternative, I would like to propose a curriculum more reflective of the whole of science as described by Kuhn. The practice of normal science, operating under theory, can be the pattern. Those students who advance alternate theories can be considered to have introduced anomalies into the normal science pattern. However, one has to be careful not to dispute or argue these ideas by using ideas of established theory. Much of the time those arguments are irrelevant because they involve assumptions that have nothing to do with the students' ideas. What has to be done is to understand the students' viewpoint, create assumptions and challenges from the students' view. These can be used to test ideas. If they produce a change, then that is one for our side. If they don't, it may also score one for our side. If we accept students' viewpoints, they can be asked to examine ours and may try to accept ours.

I think some of the students' ideas, called alternate theories, are ones that will change with time. As the students develop, their minds will mature and they will be able to accept many of the "correct" ideas of science. However, by allowing students to look at ideas and data from different vantage points, we may be preparing them someday to discover something that has been there and that we haven't seen because our theories tell us it isn't there.

I believe that this type of tracking is especially important for the nonscience students and the creative students who often advance alternate theories. They are sensitive to "correction" of their ideas. I see my task as not to put myself in the position of the one who "corrects" and loses these students but help them understand science by using their ideas. If I didn't do my job right, these students would soon hide their ideas and become science dropouts.

There are, of course, some students who are convinced of the utility of science instruction as it exists. I think many of these students are well on the way to becoming candidates for operating in the world of normal science and will be the solid citizens of science. I'm not sure there is much reason to expose them to alternate theories. I suspect they reject them as nonsense, just as most science teachers do. Too much exposure to working with alternate theories would have them fleeing science. Even these students, though, may benefit from the knowledge that science isn't always as certain or as logical as it appears!

I find that when I admit to the existence of alternate theories, this opens one more avenue of communication with my students. As the students have the opportunity to engage in inquiry, they know that they can use the scientific method (whatever that is) to generate data and form conclusions. They also know that their ideas may be different from what others have discovered, and they know that they have the obligation to show they have a reasoning process to back up their ideas. One thing I think they should gain from this kind of teaching is a tolerance for other people's ideas, including mine. If I achieve this, then I have a place for alternate theories, nonscience students, and science students in a classroom that reflects in a reasonably candid manner what inquiry in science is all about.

REFERENCES

Hanson, K. "A Comparison of Alternate Theories Formed by Students in the Classroom and Those Held by Student Teachers." Unpublished doctoral dissertation, University of Illinois at Urbana, Champaign-Urbana, 1970.

Hanson, N.R. Patterns of Discovery. Cambridge, NJ: The University Press, 1969.

Inhelder, B. & J. Piaget. The Growth of Logical Thinking From Childhood to Adolescence. New York: Basic Books, 1958.

Kuhn, T. S. The Structure of Scientific Revolutions. Chicago, Illinois: University of Chicago Press, 1962.

Piaget, J. The Psychology of Intelligence. Totowa, NJ: Littlefield, Adams & Company, 1968.

Piaget, J. The Child's Conception of the World. Totowa, NJ: Littlefield, Adams & Company, 1969.

Schwab, J. J. Biology Teacher's Handbook. New York: J. Wiley & Sons, 1963.

Selze, H. From Dream to Discovery. New York, NY: McGraw Hill, 1964.

Singer, C. A Short History of Anatomy and Physiology From the Greeks to Harvey. New York, NY: Dover, 1957.

Singer, C. A History of Biology. London: Abelard-Shuman, 1959.

INTRODUCTION TO CHAPTER THREE

Like Keith Hanson, James Minstrell is a public school teacher, and he is interested in students' alternate ways of understanding science content.

In this chapter, Dr. Minstrell investigates the preconceptions that students bring to high school physics classes and the nature of teaching strategies that can help students to change those preconceptions. He recounts several years of teaching experience, during which he became increasingly proficient at helping students to understand Newton's First and Second Laws and their applications. He closes the chapter by suggesting ways that other practicing teachers can begin practical research programs of their own.

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TEACHING FOR THE DEVELOPMENT OF UNDERSTANDING OF IDEAS: FORCES ON MOVING OBJECTS

James Minstrell

INTRODUCTION

During my early experiences in the teaching of physics, I heard students argue in reasonably coherent ways for their ideas to explain the phenomena of the world. Their ideas were counter to the course content which I had been trying to teach. It was out of a frustration with my seeming ineffectiveness in teaching certain ideas that I began to systematically observe my instruction and its apparent effect on conceptual understanding.

In this chapter I will begin by briefly describing the phenomena of alternative student conceptions. I will continue with a description of a line of research, observations, and instructional actions which appear to have improved my students' understanding of motion. Although the description is from an area of physics, I believe many of the implications in this content area could be applied to the teaching of other science concepts as well. Therefore, I will conclude by suggesting some guidelines that can be of use to anyone who is interested in getting started on a similar investigation in his or her own classroom.

COGNITIVE SCIENCE RESEARCH ON STUDENTS' UNDERSTANDING

Cognitive scientists in various subject matter areas are identifying "alternative" conceptions that students are bringing with them to the classroom. In science, especially physics, much progress has been made in developing a list of these "naive" beliefs. These beliefs are alternative in the sense that the conceptions are different from those that the scientist and the science teacher use to discuss scientific ideas and solve related problems. For example, some students seem not to have differentiated the idea of two objects having the same speed from two objects having the same position, and they have not separated the ideas of acceleration, average velocity, instantaneous velocity, and change in velocity from each other (McDermott and Trowbridge, 1980a and 1980b).

I have generalized these researchers' results to the high school physics classroom where I've found as many as 50 percent of a group of students believing that when objects were at the same position they were traveling at the same speed. This difficulty exists in a live demonstration with balls rolling along tracks (fashioned after the apparatus used by Trowbridge) as well as in paper and pencil questions involving pictures or those involving graphs depicting motion.

These results lead me to believe that students sometimes have a conceptual confusion, perhaps a lack of differentiation between related ideas. Since students seem to confuse speed and position regardless of the mode of representation (live demonstration, pictures, or graphs), I conclude that the problem is one of understanding the ideas as well as a problem of understanding the form in which the problem is represented.

In my physics classes composed of eleventh and twelfth grade college-bound students, I find their conception of gravity is quite different from that which I am trying to teach and use. When confronted with a hypothetical situation involving the removal of air for idealization purposes, about 15 percent to 20 percent of the students initially believe that would also mean there would be no gravity, "like in space, with no air there is no gravity." Near the surface of the earth, depending of the context of the question, between 40 percent and 75 percent of the students believe that when heavy and light objects are dropped or thrown horizontally, the heavier one will reach the ground in less time, often proportionately less time (Minstrell, 1982a).

The list of alternative, pre-instruction conceptions is growing progressively more extensive with recent concentration from research groups. Students exhibit difficulties in distinguishing between heat and temperature; between length, area, and volume; between mass, volume and density; between impulse, work, force, momentum, energy, velocity, and acceleration. Students have genuine difficulties visualizing relative motion from alternative frames of reference. They have great difficulties understanding and using the electrical ideas of flow of electricity, electrical potential, and resistance to flow of electricity. The roles of mirrors and lenses in the production of images are confusing. In virtually every area of content in a physics course, it appears that students enter with, or generate very early in instruction, alternative ideas for organizing the phenomena of the world.

Another significant result from this research is that many of these alternative conceptions exist after instruction as well (Clement, 1982; Lawson, Trowbridge, and McDermott, 1980; McCloskey, Green, and Caramazza, 1980). Without instruction carefully and properly designed to deal with these pre-conceptions, change in students' understanding of ideas is left largely to chance. Telling the student that his answer is wrong and lecturing on the "correct response" often have very little effect. The student may be able to answer the same context question again, but typically the idea has not transferrred in a way that the student can apply correctly in new contexts. Apparently the student's conceptual structure, the internal mental organization of observations and ideas, has not changed. Without a change in that conceptual structure, the student soon forgets the apparently meaningless idea which was probably memorized by rote, not internalized.

USING INFORMATION ABOUT PRE-CONCEPTIONS TO TEACH IDEAS

During the past few years, I believe I have learned some strategies that aid my students in their development of understanding of ideas. When I use these strategies I am more successful at changing my students' conceptual understanding in a lasting way. In this section I will describe chronologically some of the classroom observations that led me to infer these instructional strategies.

Evidence for Conceptual Change and Relevant Instructional Factors

Consider a book resting on a level table. To explain the "at rest" condition of a book on a table, the students infer that gravity is acting downward on the book, but about half suggest that the table is not, cannot, exert an upward force (Driver, 1973; Minstrell, 1982b). In my instruction I helped students articulate their initial ideas including their idea that the table was not exerting an upward force.

Students have difficulty accepting the reality of forces they cannot feel or otherwise readily experience. So I structured other experiences in which an object was still at rest but in which students were more willing to explain the situation by postulating an upward force, e.g. a book on the outstretched hand, and also a book hanging from a spring. Also, I included experiences that demonstrated the springy bendability of the table. I reflected a light beam off the table onto a wall, so that when a heavy object (I stepped up on the table) was placed on the "rigid" table, it bent slightly. Thus, it acted like a stiff spring. Finally, I pressed the students to resolve the differences between their explanations for the book on the hand (or spring) with their explanations for the book on the table. Although the table had seemed quite different at the start, it now seemed reasonable to the students that the goal was to seek an explanation that would be simple, yet sufficient; an explanation that was consistent across various forms of the "at rest" condition. After the approximately one hour of demonstration and discussion most were willing to hold, at least tentatively, the necessity of postulating an upward force by the table in order to have consistent arguments for all of the "at rest" situations. (See Table 1.)

It appeared to me that (a) the awareness of their initial conception, (b) the juxtaposition of several experiences related to the initial conception, and (c) the encouragement to resolve discrepancies between their initial conceptions and their explanations in various contexts helped students change their conception of what pushes and pulls are necessary to keep an object at rest. At least they were willing to hold tentative the hyoothesis of balanced forces as a consistent way to explain the various forms of "at rest." This apparent change was achieved without the need for the teacher to tell the "right" answer. There were other important ingredients to this lesson, but these seemed the most clearly needed and perhaps generalizable instructional factors.

TABLE 1

Change toward force exerted by the table

Sequence of events	Number of students: Believing downward force only	Undecided	Believing upward force by support as well.
Discussion of what force is, introduction of use of a vector to represent it.			
Book on table (poll taken)	14	1	12
Book on hand (poll taken)	13	1	13
More books added to hand			
Book on hand (poll taken)	6	1	20
Book on spring (poll taken)	1	1	25
Book on table (poll taken)	9	3	15
Reflect light beam off table with instructor standing on, then off the table, and hang light weight ruler on sprint.			
Book on table (poll taken)	1	1	25

Sequencing of Instruction can be Important to Change in Conceptual Understanding

Earlier research conclusions were ambiguous about the necessity of firsthand experience with laboratory equipment (Bates, 1978). I believe the results of the investigation of the explanations for the book remaining at rest demonstrate that certain kinds of firsthand experiences, those which are related to students' initial conceptions, are necessary. In this section I describe how I came to conclude that a sequencing of experiences is also important in the development of understanding.

Consider a frictionless wheeled cart rolling with a constant velocity across a horizontal, smooth table top. What are the forces, the pushes or pulls, necessary to explain the motion of the cart? Typically, prior to instruction, in excess of 90 percent of the students will claim, among other forces, that there must be a constant force in the forward direction that is not balanced by any other forces. There must be an excess force, or net force, in the direction of motion. Similar results have been found at the university level (Clement, 1982; McDermott et. al., 1982; and Viennot, 1979) and at the secondary level (Champagne et. al., 1980). The physicist and the physics teacher suggest that once the cart is moving with a constant velocity, no unbalanced forces are necessary to keep the cart in motion.

This is essentially Newton's First Law of Motion: An object in motion will keep moving with a constant speed in a straight line unless it is acted upon by a force, a push or pull, that is not balanced by another force in the opposite direction. The only forward force needed is just enough to compensate for resistive forces in the backward direction. Newton's Second Law of Motion states that when an unbalanced force acts on a body, it accelerates at a rate proportional to the size of the unbalanced force. (See Figure 1.)

After teaching Newton's Laws, at the end of the approximately two-week-long unit, I administered a paper and pencil version of a test on the Laws of Motion containing qualitative questions asking students to draw diagrams of forces acting on moving objects. The percent of students giving answers consistent with Newton was 62 percent for the acceleration cases and 36 percent for the constant velocity cases. (See Table 2, line 2.)

I was convinced I could do better. During the first year of systematic investigation I carefully redesigned the instruction to make the students aware of their initial conceptions about forces on moving objects, to have them experience some typical sorts of laboratory activities (that relate to Newton's Laws), and to use rational argument to show what forces are necessary to explain the motions. Throughout the unit, foremost in my mind was an awareness of the difficulties students have with Newton's Laws, particularly the First Law, and whenever opportunity existed, I recycled rational arguments in favor of Newton's Laws. With this instruction reflecting a keen awareness of difficulties students have in understanding

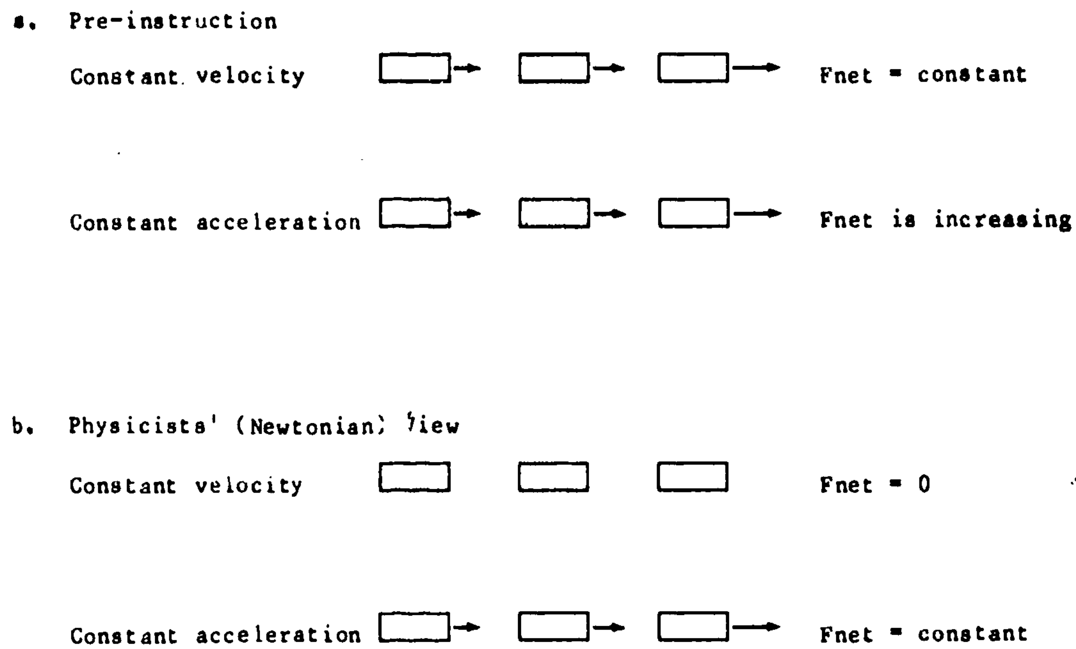

Figure 1: Forces Explaining Motion

a. Students' pre-instruction conceptions of forces needed to explain motion.
b. Physicists' (Newtonian) conception of the forces needed to explain motion.

Newton's Laws, the percentage of the class displaying a Newtonian view on the semester test (three months after the unit) was 71 percent in the acceleration cases and 67 percent in the constant velocity cases. These results were satisfying, but I was hoping for even higher percentages. When I looked at the cumulative results for all related questions for the school year, I noted 69 percent success for the constant acceleration cases and 43 percent for the constant velocity cases. (Table 2, lines 3 and 4) That represented a considerable "fall back" in the constant velocity situations.

On reflection of these data, I noted that, in every class, on every test, the proportion of the class giving Newtonian answers for the accelerating cases was greater than that for the constant velocity cases. Why were the accelerating cases easier for the students to handle? Piaget's theory (1958) suggests that reasoning from the concrete to the abstract is easier than from the abstract to the concrete. The concrete firsthand experience in the instruction dealt with situations involving acceleration, Newton's Second Law. It seemed logical that the constant velocity case, involving Newton's First Law, should be taught as a logical consequence of the acceleration case. But virtually all major physics curricula deal with the First Law first and then the Second Law, with constant velocity and then acceleration.

That next year I made a major change in the sequence of my instruction. I began by systematically engaging the students in investigating accelerated motion. Then I posed the question of how to explain the constant velocity situation. I deliberately presented the Second Law situations before those of the First Law.

I started the investigation with a "pre-instruction quiz" which asked the students to draw arrows indicating the pushes or pulls which would be necessary in order for a body to move with constant velocity and to indicate, in a similar manner, the forces necessary for accelerated movement. Results were consistent with those in line 1 of Table 2. These class ideas were summarized in a discussion and the diagrams left on the board as a record of the students' thoughts at that time.

The next activity was a laboratory activity, the objective of which was to determine the effect of an unbalanced force (an excess in one direction) on the movement of a wheeled cart. (See figure 2.) The experiment involved a low friction cart with a spring scale attached, which was pulled across a smooth level table top by a string-pulley-weight system. The cart towed a ticker-tape through a dot-maker to record time. In addition to some specific single observations, students were to analyze the motion of the cart while it crossed the table (it accelerated uniformly), and to describe the unbalanced pulling force while the cart was in motion (the spring scale reading was constant.)

It was exciting to watch student reactions while they were doing the experiment. Several came to me and suggested "something's wrong, my experiment isn't coming out like we said it should," referring to their

TABLE 2

Percent of Students Displaying a Newtonian View of Unbalanced Forces Acting on Moving Objects

Instruction before test	In Constant Acceleration Cases (Newton's Second Law)	In Constant Velocity Cases (Newton's First Law)	In Both Cases
1. Pre-instruction	3%	3%	2%
2. "Typical" Teaching Lecture, discussion, and demonstration of Newton's First Law Fnet = ma experiment for Newton's Second Law Text reading and problem. for application	62	36 (end of unit test results)	29
First year of research			
3. "Aware" Teaching Same as "typical" plus pre-instruction quiz and special care with logical argument for the constant velocity case	71%	67% (semester test results)	58%
4. Summary of arguments for relevant problems all year	69	43 cumulative results for year)	41

TABLE 2 (Continued)

Second year of research Use of Modified Sequence of Instruction			
5. Pre-instruction quiz, acceleration proportional to unbalanced force experiment - no discussion of implications of results	50	22 (During instruction quiz two days into unit.)	22
6. Same as above but including a discussion of implications of acceleration experiment on their initial conceptions	96	35 (During instruction quiz three days into unit.)	30
7. Same as above plus "aware" teaching strategy	94	88 (end of unit test)	88
8. Same as above plus integtration into network of related concepts	81	95 (end of semester test)	79

FIGURE 2

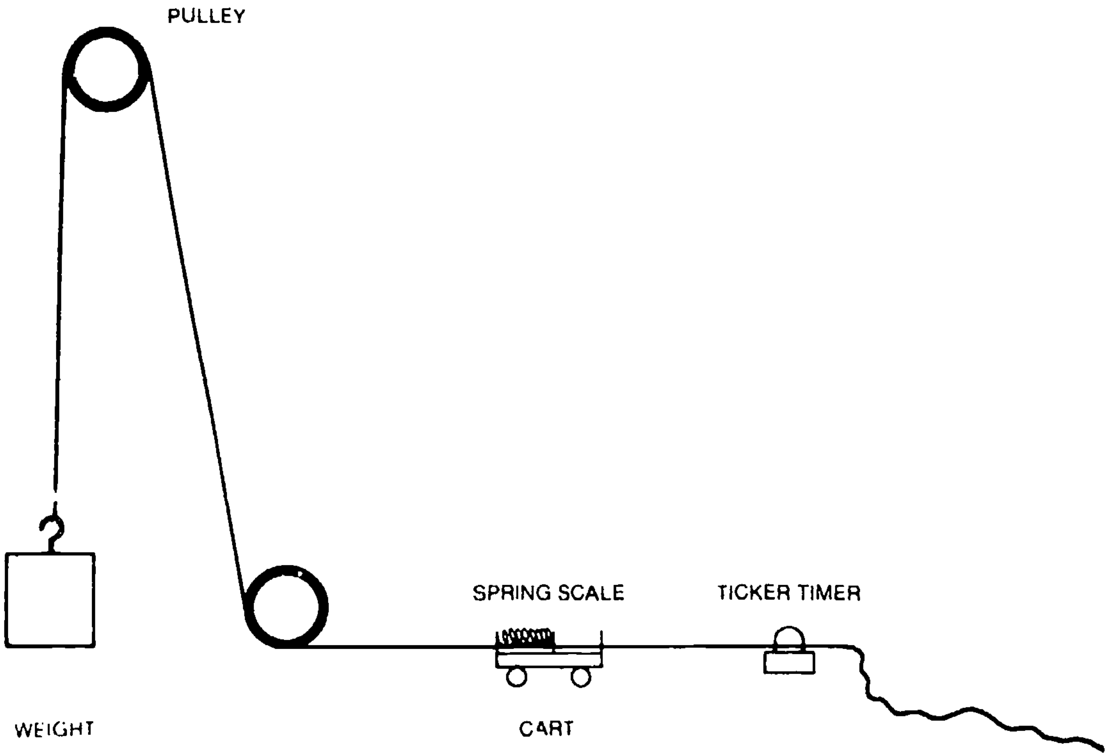

Figure 2: The first experiment involving motion under the influence of an unbalanced force.

pre-instruction ideas that a constant unbalanced force should result in constant velocity. Others were quick to maintain confidence in their experimental results and suggested "what we wrote on the board was wrong, a constant extra force produces a constant acceleration, not a constant velocity." Without any general discussion, I asked again for their answers to the same pre-instruction questions. Fifty percent of the students favored a Newtonian explanation for accelerated motion, and 22 percent explained constant velocity by implying r unbalanced force was necessary to keep that constant motion. (See Table 2, line 5).

The next activity involved a post-lab discussion to clarify and generalize our observations and analyses of motions of the carts and the forces involved. The second and probably major purpose was to discuss the implications of these experimental results for the students' ideas about both accelerated motion and constant velocity motion. During the discussion, most students were quick to conclude that a constant unbalanced force would produce a constant acceleration. I asked about the implications of this conclusion for the constant velocity case. Although several initially voiced preference for a constant force to produce a constant velocity, others quickly pointed out that that couldn't be because of the specific results of the experiment. I figured the class would now have to conclude that no unbalanced force was necessary. I was surprised to find that for many the next conclusion was "constant velocity must be explained by a decreasing force." Similar results have been found at the University of Washington in an interview format (Lawson, Trowbridge, and McDermott, 1980). It appeared that the students were reaching this conclusion by indirect argument. "It can't be constant force because of the results of our experiment. It can't be an increasing force, that just wouldn't make sense. That leaves a decreasing force." But when groups compared the results of having different weights hung on the end of the pulley system, they observed that a greater weight made the string force greater but still constant. Some argued, "the resulting acceleration was greater but still constant (which it was). So, a decreasing force would make a decreasing acceleration, not no acceleration." Among nervous laughter some students then suggested, "once it's moving maybe we need no extra force beyond a force to balance friction to keep it going at a constant velocity." This seemed a possible conclusion from the experiment to most students, but it was still hard to believe. After this discussion 96 percent of the class agreed with a Newtonian explanation for the accelerated cart, but only 35 percent agreed that no unbalanced force was necessary to keep an object moving with a constant velocity. (Table 2, line 6)

At this point I read Newton's First and Second Laws aloud to emphasize that at least part of the class was coming to an "accepted" view. There came a deluge of concerns about specific, common, everyday experiences. Probably the most popular was "What about the car? I hold the gas pedal at a certain point. At first the car accelerates. Then, it reaches a constant velocity and stays at that constant velocity." I guided them, suggesting that the forward force exerted by the road was being held constant. But, as in the case of putting your hand out the window as the car moves faster and faster, the resistance force of the wind increases up to a considerable force. How big? It increases until it matches the forward force and the forces are balanced. What if I put the pedal down further? or take the foot off the pedal? It appeared that the students needed an opportunity to think and talk through several examples or "What about the situation where..." before Newton's First and Second Laws were accepted as viable explanations for straight line movement of objects. It appeared to me that this activity helped put "hooks" of understanding into several other concepts and contexts that students relate to forces.

The remainder of the experiments, problems, and other activities in the unit on straight line motion were typical of the PSSC and Project Physics curricula. On the end of unit test I now had 94 percent of the acceleration questions and 88 percent of the constant velocity questions answered in ways consistent with Newton's Laws (Table 2, line 7).

During the remainder of our study of mechanics, I took many opportunities to revisit our former arguments and discussions. For example, in projectile motion, is a forward force necessary after the object has left the edge of the table? In circular motion, is a forward force necessary? Why or why not? On the end of semester exam 81 percent of the students' explanations for accelerated motion and 95 percent of the explanations for constant velocity were consistent with the taught notions of Newton (Table 2, line 8). These results were a source of personal satisfaction for me as a researcher and especially as a teacher.

The Importance of an Integrated Network of Ideas

I wondered whether the instructional process was usable by other teachers with other students, since the results described before were achieved only by me. At Mercer Island High School there were two physics teachers, each teaching two regular sections of physics. The other teacher agreed to see if he could get similar results by using the special instructional sequence for teaching Newton's Laws derived from earlier research and briefly described in the previous sections (including (a) engagement of initial conception, (b) firsthand experiences relating to their initial conceptions, (c) treating the concrete constant acceleration case before the abstract logical consequence of the constant velocity case, and (d) the discussions encouraging rational thought to resolve discrepancies between initial ideas and firsthand experiences.) Since I was also concerned whether differences in outcomes resulted from what had been taught before this unit (kinematics was taught for the one month prior to the beginnings of dynamics), the two teachers involved in the experiment each taught the special instructional sequence to one of each other's classes as well as one of his own. The special instructional sequence was designed to focus on developing the Newtonian ideas; it occupied the first four days of the total unit which lasted about twelve days.

The results of the investigation indicated that the special instruction could be used by other teachers, and similar results could be expected. On the unit test, the differences in success between my classes and those of the second teacher were not statistically different on the questions directly related to the ideas taught in the special sequence. Results were comparable to those achieved by my classes the previous year.

On the semester test, the percentage of students answering the constant positive linear acceleration and constant velocity questions successfully showed some increase for my classes and some decrease for the second teacher's classes. These differences were not statistically significant. But, on questions that asked students to go beyond the four day development sequence as taught, e.g. for curved motions and negative acceleration, my classes did significantly better. Apparently the second teacner's students' understandings were regressing, and they were not as able to generalize their understanding beyond the conceptual context in which they were taught. This suggested to me that there was something else different in the instruction, subsequent to the specific unit, that was showing up over time and generalization.

At least part of the difference may be explained by instruction in my classes wherein some of the old arguments used in generating Newton's Laws we revisited in the development of understanding of other conceptual ideas. For example, later in a unit on circular motion, students were asked, "When an object is traveling in circular motion at a constant speed, is it necessary to have a forward force to keep it going? -a force away from the center of the circle? -a force toward the center of the circle? Under the influence of each of these forces, what would be the resulting motion?" Earlier, while developing ideas about forces on moving objects, the introductory physics students could understand and could occasionally even initiate the logical conclusion that no unbalanced force is necessary to keep an object moving with a constant velocity. They could even use it in most other situations involving straight line motion, but the power of the idea and longterm changes in behavior were enhanced by repeatedly facing new situations and new contexts, having to explain them, and coming to one's own realization that no forward unbalanced force was necessary for circular motion, projectile motion, or constant velocity against resistive forces, etc.

These results suggest that students' conceptions are integrated in a network of relationships. When instruction assists students in differentiating between concepts in the development of new ideas, it appears necessary in subsequent development of other new ideas to guide the student in the total reorganization of many concepts and their interrelationships.

This hypothesized integrated network of concepts helps to explain two common phenomena of the classroom, i.e. non-generalization and regression of understanding. Suppose that instruction results in changing the understanding of one concept for a student. If that change exists in isolation from changes in other related ideas, then the student may be able to apply the new concept in the specific context in which it was taught, but in other situations where other naive concepts also are involved, the student's interpretation of a problem may be based on the naive integrated structure rather than making use of the new concept. The student fails to generalize. It may be that the student's one conception is changed temporarily, but within the existing network of related concepts, it tends not to make sense. Perhaps, as the students self-regulate, they reintegrate their total structure of concepts, and since the rest of the structure is more functional in daily use than the new concept by itself, the new conception gives way to their earlier explanations which were in greater concert with the total existing conceptual structure. The student's understanding regresses.

The Intellectual Limits of Students

I wondered about the applicability of the special instructional sequence with student groups with lower levels of intellectual maturity. Piaget (1958) suggested that formal operational thought required a higher level of intellectual maturity than concrete operational thought, and that the latter required greater maturity than preoperational thought. Some research suggested that higher levels of understanding of some concepts are attainable only by those students who have reached at least a certain level of logical mathematical reasoning. (Selman et. al., 1982)

My experience in teaching about forces on moving bodies with ninth grade physical science students at Mercer Island High School also suggested that the influence of the instructional sequence is dependent upon intellectual maturity. In their respective science courses, my 9th graders and 12th graders were both exposed to the same firsthand laboratory experience involving a cart under the influence of a constant pulling force (see Figure 2). The initial conception of both groups involved "constant force gives constant velocity" and "increasing force is required for increasing velocity, i.e., acceleration". The answers to the observational questions posed to both were the same. When they were looking at the ticker tape, they described the motion as "accelerating." When watching the spring scale, they described the pulling force as constant.

However, they interpreted their observations quite differently. When asked to describe what they had observed in the experiment, most of the 12th graders were able to describe the two observations simultaneously, i.e., "the cart accelerated and the force scale reading held constant while the cart was moving." But most of the 9th graders reported either "the cart accelerated and the force reading got bigger" or "the force scale stayed the same during the motion and the motion of the cart was a constant speed." It appeared that the 9th graders were so driven by their initial conception that most were incapable of holding the two experimental observations in their minds at the same time. Consequently it was very difficult for them to note the discrepancies between their initial conception and their observations from the experiment. For these less mature students, the instructional sequence was not nearly as successful.

Summary of Important Instructional Principles

The inferences from this series of investigations can be summarized in the form of six instructional principles that can be generalized to many situations in which teaching for conceptual change is the goal. These principles are as follows:

1. The students' initial conceptions should be engaged. Both teacher and students must be aware of, and verbalize, the students' initial ideas.

2. Students should have several laboratory activities, demonstrations, or other experiences directly related to their initial conceptions. If possible the experiences should be firsthand and as concrete as possible. If an experience is consistent with their earlier ideas, it will help to confirm them. But if it is not consistent with their initial conception, the experience can serve as a stimulus to rethink those ideas.

3. Discussions should encourage students to resolve discrepancies between their initial conceptions and their observations from experience. Although some students spontaneously will rationalize discrepancies between their initial ideas and the experience, many will need encouragement and guidance to resolve the discrepancy.

4. The sequence of instruction for development should begin with a focus on ideas accessible through concrete experiences and gradually build toward ideas that require more abstract or logical thought. In some cases this may involve restructuring existing curriculum, as in the example of teaching Newton's Second Law of Motion before the First Law.

5. For more lasting conceptual change, students should have repeated opportunities to reuse the arguments that led to the new idea and to review those arguments and apply them in new contexts, especially those involving development of related ideas. In this way the students will not have learned an isolated idea but a network of ideas conceptually interwoven and logically consistent with each other.

6. Students differ not only in initial conceptions but also in logical reasoning ability and information processing capacity. Successful instruction must work within these limits.

CONCLUSION: HOW CAN YOU GET STARTED?

As you've just read, there is increasing evidence that students are entering our science classes with ideas about the world that are different from our own as science teachers. Further, implications from research suggest that to increase our effectiveness in teaching concepts, our instruction should specifically be addressed to identifying and treating those "alternative" conceptions. A necessary first step for addressing alternative conceptions in your classroom is for you and your students to know their initial conceptions before commencing a particular unit of study. If you are interested in finding out what understanding your students have about the world, I recommend the following guidelines:

1. Start by listening to your students. By listening carefully and trying to understand their explanations, reasons for predictions, or even the motivation for their questions, you can gain insight into their present understanding.

2. Ask questions that are qualitative. Avoid questions that require the manipulation of formulae and/or technical words unless you specifically want to find out whether they can correctly pick and grind a formula or to find out what a particular word means to them. I believe questions that ask for a qualitative explanation or comparison can be used effectively to probe understanding of ideas.

3. Ask questions that are relevant to common situations. There is a tendency to try to think up some bizarre situation to "trap" students into displaying their "alternative" conceptions. This isn't necessary. In fact, it appears that many students who have alternative conceptions have more trouble describing or explaining a common situation, probably because it is so similar to situations for which the initial conceptions were developed.

4. Ask questions that require inferential thinking. Once I know my students clearly know the observations, I want to know how they structure the phenomena to give them meaning. I typically ask for a prediction, a generalization, or an explanation. "If you do this, what will happen to that? Explain why you think that will happen." "You've now made several observations of . . . what can you say in general about the situation? What do all the observations together tell you about the nature of . . . ?" "Explain how . . . happens." "We see that . . . happens. How would you interpret that; what does it tell us about nature?

5. Clarify the observation first. Prior to probing their organization of thought (conceptual understanding) you may want to ask for their observations. Frequently I find their perceptions (what they sensed directly) were different from mine. In other

words, before you ask them to explain or interpret what they saw, you may want to find out whether they saw the phenomenon as you did.

6. Listen (or read) carefully in a non-evaluative way to the answers given by your students. This is probably the most difficult aspect of this suggested "prescription." As teachers, we are prone to jump in and steer the students straight by telling them what to think. Students are prone to look to teachers for feedback as to whether they have the "right" answer. Fight this, if you want to know what they think. Be neutral in your comments about what the student says. Help the students clarify their ideas, but do not evaluate those ideas yourself. Get them to evaluate their own or each other's ideas. Students will be more willing to say what they really believe if they are not graded on their specific answers early in the development of their ideas. There will be time for grading later after the ideas have been developed and used. When you are reading quiz or test results, rather than simply classifying answers as right or wrong, try classifying them as to the type of argument. What I find is that students often get the wrong answer for very good reasons, and they sometimes get the right answer for very weak reasons.

Conducting these investigations in the classroom has changed the nature of my instruction. The focus is now on developing the understanding of ideas and applying ideas, ideas that are related to the students' own thinking. We are not marching through a textbook interpreting the ideas of some distant authority; we are building our own ideas. For me there is more emphasis on the ideas and processes of physics and less on the memorization of facts or manipulation of mathematical formulae. Our physics enrollment has increased, our graduates are happy for their experience when they take Introductory Physics at the university level, and teaching physics is a continual challenge to me as a teacher. It is a challenge which, when met successfully through classroom observations and inferences about instruction and learning, can promote measurable development in students' understanding of ideas.

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REFERENCES

Bates, G. "The Role of the Laboratory in Secondary School Science Programs." In M. Rowe (ed.) What Research Says to the Science Teacher. Washington, D.C.: National Science Teachers Association, 1978.

Champagne, A., L. Klopfer, C. Solomon, and A. Cahn. "Interactions of Students' Knowledge with their Comprehension and Design of Science Experiments." Pittsburgh, PA: Learning Research and Development Center, University of Pittsburgh, 1980.

Clement, J. "Students' Preconceptions in Introductory Mechanics." American Journal of Physics. January, 1982.

Driver, R. "The Representation of Conceptual Frameworks in Young Adolescent Science Students." Unpublished doctoral dissertation, University of Illinois. Urbana-Champaign, 1973.

Lawson, R., D. Trowbridge, and L. McDermott. "Students' Conceptions of Dynamics." A paper presented at the January meeting of the American Association of Physics Teachers, 1980.

McCloskey, M., D. Green and A. Caramazza. "Curvilinear Motion in the Absence of External Forces: Naive Beliefs about the Motion of Objects." Science. 1980.

McDermott, L. and D. Trowbridge. "An Investigation of Student Understanding of the Concept of Velocity in One Dimension." American Journal of Physics. 48, 1020, 1980.

McDermott, L. and D. Trowbridge. "Investigation of Student Understanding of the Concept of Acceleration in One Dimension." American Journal of Physics. 49(3): 242-253, 1980.

Minstrell, J. Conceptual Development Research in the Natural Setting of the Classroom. In M. Rowe (Ed.). Education for the 80's: Science. Washington, D.C.: National Educational Association, 1982a.

Minstrell, J. "Explaining the 'AT REST' Condition of an Object." The Physics Teacher. 1982b.

Piaget, J., and B. Inhelder. The Growth of Logical Thinking from Childhood to Adolescence. New York: Basic Books, 1958.

Selman, R., M. Krupa, C. Stone, and D. Jaquette. "Concrete Operational Thought and the Emergence of the Concept of Unseen Force in Children's Theories of Electromagnetism and Gravity." Science Education 66(2): 181-194, 1982.

Viennot, L. "Spontaneous Reasoning in Elementary Dynamics." European Journal of Science Education. 1. 1979.

INTRODUCTION TO CHAPTER FOUR

This is the last of four chapters that focus on students' ways of understanding science. Maja Apelman's critical barriers, Keith Hanson's alternate theories, James Minstrell's preconceptions, and Kathleen Roth's misconceptions are all similar in nature. These four chapters document their occurrence, and their effects on classroom teaching and learning, at all levels of the educational system.

Ms. Roth's perspective, however, is different from that of the first three chapter authors. Rather than being an actor in the drama, she sees classrooms as an outside observer. She is not a disinterested spectator, however, because she seeks to improve student understanding by developing curriculum materials that help teachers teach more effectively and students understand science better.

Ms. Roth has taught science to both middle school and adult learners. She is currently a graduate student in science education at Michigan State University.

USING CLASSROOM OBSERVATIONS TO IMPROVE SCIENCE TEACHING AND CURRICULUM MATERIALS

Kathleen J. Roth

INTRODUCTION

This chapter describes part of a continuing research program with which I have been associated for the last two years. The chapter begins with the description of a study in which I participated under the direction of Edward L. Smith and Charles W. Anderson and continues with a follow-up study in which I am the principal investigator.

The Problem of Teacher Effectiveness

Describing the essential characteristics of effective teaching has been a major problem for educational researchers for many years. By the late 1970's a number of major studies had produced consistent results describing the behavior of effective teachers. These studies used classroom observations to identify teacher behaviors that correlated with student learning outcomes as measured by posttests. Through such research a list of teacher characteristics that are statistically related with student achievement was generated. Some of the identified classroom characteristics associated with greater student learning (Rosenshine, 1979) are:

1. More student time spent engaged in academic learning tasks.

2. Less disruptive behavior by students.

3. Assignment of classroom activities by the teacher, rather than allowing students free choice.

4. Concentration of small group or large group instruction rather than individualized instruction.

5. Relatively high rates of factual questions and many opportunities for controlled practice.

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Smith and Anderson began their study in 1980 with a belief that, while necessary for effective teaching, these characteristics were not sufficient. They argued (Smith and Anderson, 1980) that there were many classrooms in which teachers were doing everything advocated by Rosenshine, yet science was not meaningful to either students or teachers.

When I joined the project in 1981, it had become clear that Smith and Anderson's concerns were justified. A year of classroom observation and testing of student learning had revealed that meaningful learning simply was not occurring for most students. For example, in a study of five teachers using a popular science textbook unit on light and seeing (Blecha, Gega, and Green, 1979), only 22 percent of the students ended the six-week unit with the key understanding that we see because light is reflected off objects to our eyes. The students of nine teachers using an activity-based approach to instruction on photosynthesis (Knott, Lawson, Karplus, Thier, and Montgomery, 1978) showed a similar failure to learn.

In order to understand what was going wrong, we realized that instead of focusing only on observable behaviors (such as questions asked, teacher wait-time, etc.), we began to think about the unobservable mental life of teachers and students. What are teachers thinking about as they plan and teach? What implicit theories of learning guide their teaching? What are students doing with information they receive during instruction? How does their thinking change as a result of classroom events?

Studying student and teacher thinking is a challenging research problem. From our attempts to tackle this problem, however, we have become convinced that such specific knowledge about the cognitive life of students and teachers is needed before significant improvements in science teaching and curriculum materials can be achieved. Such knowledge will help us to understand learning failures, as well as help us to determine the instructional strategies that are most likely to be used successfully by students.

The Cognitive Life of Students

To trace students' thinking during instruction, we have used a variety of methods to follow students through instructional units: Classroom observations of teacher behavior, focused classroom observations of targeted students, interviews with targeted students before, during and after instruction, and written pre- and posttests of all students. Such detailed observations of over 500 fifth grade students over the last three years have convinced us that students interpret instruction in terms of their own "theories" about scientific phenomena. Very early on, children begin forming their own theories to explain how the world works. These naive theories are built from children's everyday experiences with phenomena such as light, vision, plants, motion, etc. Although these naive theories are adequate for getting along in daily life, they are usually quite different from theories held by physicists, biologists, and other scientists. From the scientists' point of view, these naive theories represent critical misconceptions in the students' understanding.

Our own research and that of others demonstrates that students often fail to understand instruction because they do not give up the misconceptions. Instead of making major changes in the way they view the world, students stick with their comfortable, commonsense notions as they sit through lesson after lesson. In the language of cognitive psychologists, the students fit new knowledge into a faulty schema, or theoretical framework. They do not aba[illegible] their original incorrect schema. Thus students' misconceptions [illegible] highly resistant to change and make learning scientific views difficult.

The Cognitive Life of Teachers

Because these misconceptions are critical in students' interpretation of instruction, teachers need to consider students' misconceptions in their planning and teaching. Posner, Strike, Hewson, and Gertzog (1982) have suggested that teachers would be more successful if they viewed science instruction as a process of changing students' misconceptions to more appropriate scientific conceptions. Three critical features of the Posner et al. model of instruction are:

1. Students' misconceptions must be elicited and challenged; students must become dissatisfied with their misconceptions.

2. An explanation of the scientific conception must be intelligible and plausible from the students' perspective.

3. Students must see the wide applicability of the scientific conception.

Such a conceptual change view of teaching and learning would require teachers to think about:

1) The students: What misconceptions do the students hold about the topic?

2) The content: What is the scientific conception or theory and how is it applied to specific phenomena?

3) Classroom Activities: What activities will demonstrate to the students the limitations of their naive theories and help them see the reasonableness and the wide applicability of the scientific view?

Teachers' implicit theories. During the first year of the study, Smith and Anderson interviewed teachers before and after an instructional unit, conducted stimulated recalls of videotapes of teacher planning and observed teachers throughout a unit of instruction. They did not find any teachers who were successfully integrating their thinking about all three of these variables during planning or during instruction. Instead, they observed teachers operating (unsuccessfully) from three very different implicit theories of learning and teaching.

1. Activity-driven teaching. "What are we going to do in science today?" This is the kind of question that drives the planning and teaching of one group of teachers we observed. Typical of this group of teachers, Ms. Ross's thinking focused on the planning and doing of a series of activities with plants (Smith and Sendelbach, 1982). A great deal of thought went into planning how 30 students would use a variety of hands-on materials and complete assigned tasks within allotted 40-minute time blocks. Thus, Ms. Ross's thinking was limited to classroom activities and management concerns. She did not think about the incoming knowledge her students would have, and she did not think very much about the intended learning outcomes.

2. Didactic teaching. Ms. Rosa[1] serves as an example of a practitioner of didactic science teaching (Slinger, Anderson and Smith, 1983). She viewed the textbook as a source of facts and information about science to be presented to the students. She tried to present these facts in a clear and logical manner, and she enriched her presentations with a variety of activities that made her classes fun and interesting for her students. She thought about appropriate strategies and activities for presenting the content to students. However, Ms. Rosal sought no information about her students' understanding of light, and she never became aware of her students' misconceptions. Both she and her students ended the unit feeling that all had gone well, although posttests and clinical interviews revealed that students' misconceptions persisted.

3. Discovery teaching. In contrast to Ms. Rosal's didactic teaching style, an "inquiry" or "discovery" approach to science teaching has been advocated by many science educators. They have argued that science education would be more effective if, instead of being told about the theories of other people, children were allowed to develop their own theories through direct experience with concrete materials. Ms. Howe was an example of a teacher who tried to implement these recommendations (Smith and Anderson, in press). Prior to instruction, she thought carefully about the activities she would provide. During instruction, she thought about students and their thinking. From such a focus on her students' thinking during instruction, Ms. Howe (unlike Ms. Rosal) knew that her students were not developing the scientific concept. Because of her belief in discovery learning, however, she had put little thought into how to present the scientific content to her students. She had assumed the activities would lead students to an understanding of the content.

All three of these teachers were experienced teachers with good classroom management skills. Rated according to a list of effective teacher behaviors, all would have been classified as effective teachers. And yet, their students' misconceptions were not changed or abandoned as a result of instruction.

The importance of cognitive overload. Although the teachers described above were operating on the basis of inadequate theories, their difficulties could not be attributed simply to lack of training or information. These teaching failures can be understood by looking at the cognitive load required for successful conceptual change teaching. In practice, it is too much to expect a teacher to be able to think about the students' misconceptions, the content, the appropriate activities, and management concerns all at once. In computer language, the information-processing capacity of the teacher is exceeded. The teachers we observed survived by reducing the cognitive demands. Ms. Ross selected activities as a focus, Ms. Rosal focused on activities and content, and Ms. Howe focused on students' thinking and activities. Since the conceptual change model of instruction depends on all three, ways must be developed to help teachers reduce this cognitive load if student learning is to be improved using this model of instruction.

Curriculum Materials

An important tool that can help teachers reduce this cognitive overload is curriculum materials. Curriculum materials can give teachers (1) knowledge about student misconceptions, (2) explanations of the scientific content, and (3) descriptions of appropriate activities and strategies to help students give up their misconceptions in favor of more scientifically appropriate conceptions.

The curriculum materials being used by the teachers in our study, however, failed to give teachers all three of these kinds of information. Most importantly, these materials, and others that we have reviewed, failed to give teachers any information about students' probable misconceptions, and as a result, the curriculum materials (in both text-based and activity-based programs) failed to address and challenge student misconceptions.

We believe that knowledge of students' misconceptions about specific topics in the science curriculum can be used to improve teaching and curriculum materials. Our most recent research has tested this idea by developing curriculum materials which addressed student misconceptions. We examined the effects of such materials on classroom teaching behavior and on students' cognitive processing of instruction.

In the next section we offer, as an example of this kind of work, a case study describing our three-year relationship with one fifth grade teacher and her students. This case study traces our attempts to identify particular misconceptions and then use this knowledge to develop curriculum materials that would help the teacher become a conceptual change teacher.

THE CASE STUDY: MS. KAIN AND HER STUDENTS

Ms. Kain is an experienced fifth-grade teacher in a middle class school district that is adjacent to a large state university. Her students are predominantly children of professional parents, but there are also working-class students. A minority of the children are black. She teaches science in the afternoons to three groups of students in a team teaching, open-space classroom situation.

The curriculum used by the eight elementary schools in the district is the activity-oriented program of the Science Curriculum Improvement Study (SCIIS; Knot et al., 1978). Ms. Kain had been using the SCIIS Teacher's Guide and materials kits for two years before she became involved in our study. Although she did not have a strong background in science, she came to enjoy her science teaching assignment. While other teachers in the district have many complaints about the SCIIS curriculum, Ms. Kain is an enthusiastic supporter of elementary science teaching and of the SCIIS program.

Methods

During the first year of our study, Ms. Kain was one of nine teachers who agreed to let us observe the teaching of Part I (Producers) in the SCIIS Communities unit. This unit is designed to help students understand plants' role as producers in the ecosystem. Chapters 3-6, the focus of our study, consisted of a series of experiments with plants and related class discussions that investigated photosynthesis as plants' source of food.

One focus of our observations during Year One was on understanding the cognitive life of the teacher. We were particularly interested in the relationships among science program materials, teacher planning and classroom behavior, and student learning of science concepts. The following section describes the observation and interviewing procedures used to understand the teachers' thinking and the influence of program materials on their thinking.

Preparation for observing. We wanted to know as much as possible about the program materials, the teacher, and the students before beginning classroom observations. In order to be able to recognize how the teacher was using/modifying the curriculum materials, we first did a propositional analysis of the SCIIS Teacher's Guide using procedures described by Landes, Smith, and Anderson (1980). We identified every proposition that was an intended learning goal of the unit. Each of these was coded so that it could be easily referred to in the narrative reports of actual instruction.

Another preliminary step was to interview each teacher before he or she began the unit. The purpose of the interview was to probe the teacher's attitudes and beliefs about teaching and learning and to get some ideas about how each teacher planned. Teachers were also videotaped as they planned a lesson. After each planning session, the tape was played back to the teacher and used to stimulate recall of what the teacher had been thinking during planning.

We also gathered pre-instruction information about the students' understanding by using a researcher-designed test. The test was designed to distinguish among different possible student conceptions of plants' source of food and the role of light in plant growth. The test included multiple-choice questions, true-false items, and questions requiring written answers. This test and the analysis procedures are described elsewhere (Roth, Smith, and Anderson, 1983). Briefly, the students' answers were first coded using defined features of the responses. These codings were then used to compute scores reflecting the strength of students' belief in the goal concepts of the unit or in alternative inaccurate conceptions (misconceptions).

Observation procedures. A classroom observation scheme was developed that began with detailed observer notes of classroom events. We later reviewed these notes in conjunction with audiotapes of observed lessons to develop detailed narratives of the lessons. In these descriptive reports, lessons were broken down into a series of student tasks, each of which was described in detail. In addition, certain features of each task (including time, materials used, corresponding proposition number in Teacher's Guide) were coded in shorthand form (Hollon, Anderson, And Smith, 1980).

At the conclusion of each observed lesson, the teacher completed a quick questionnaire about his or her perceptions of how the lesson went and about the planning that had been involved. The observer often also had opportunities to talk with the teacher informally after some lessons.

Post-instructional procedures. At the end of the unit, the teacher was interviewed again. Students were given a posttest that was identical to the pretest.

The following sections describe what happened as Ms. Kain taught the unit in each of three successive years.

Year One

Curriculum materials. From our analysis of the SCIIS Teacher's Guide we found that, unlike most elementary science programs, the targeted unit presented a teaching strategy compatible with a conceptual change model of instruction. Consistent with Posner et al.'s (1982) first criterion for conceptual change instruction, the guide identified for the teacher likely student misconceptions. For example, the Background Information section mentioned that students may believe that plants get food from the soil or that fertilizer or water is food for plants.

The Guide then prescribed a series of hands-on activities and discussion questions designed to challenge these misconceptions. For example, the students observe that grass plants will live in the light and will sprout, but then die when left in the dark. The guide suggests that the teacher pose questions that are intended to confront students with the inadequacy of their beliefs. At one point, for example, the Guide tells the teacher to point out that both the plants in the dark and plants in the light had the same soil. The teacher should then ask the students to explain why the plants in the light lived and the plants in the dark died if they both had the same soil.

After the students' misconceptions are challenged, the Teacher's Guide calls for the teacher to explain that plants get their food by using light, air, and water to make their own food in a process called photosynthesis. This step fits Posner et al.'s (see page 3) criterion that the students be given a reasonable and plausible explanation of the scientific conception.

Finally, the SCIIS Guide allows students to apply this new knowledge in two ways. One is a "Brainteaser" problem that students write about and discuss. The other is a final experiment in which students make predictions about what will happen to bean plants placed in different conditions. After the plants are grown, the results are discussed in terms of photosysthesis.

Thus, the instructional strategy given in the SCIIS Teacher's Guide was consistent with Posner et al.'s conceptual change model. It calls for eliciting and challenging students' misconceptions (that plants get food from the soil), it provides a teacher explanation of the scientific conception of photosynthesis, and it gives two occasions for students to apply the new knowledge they have about photosysthesis.

<u>Ms. Kain's thinking and teaching</u>. In her planning and classroom instruction, Ms. Kain did not use a conceptual change view of learning. Instead, she interpreted the guide as presenting a discovery orientation to learning. Consistent with this approach, her planning time focused on setting up activities that would help students figure out how plants get their food. She did not think at length about how to present the scientific concept of photosynthesis to students, since it was her belief that the experiments and discussions described in the Teacher's Guide would lead students to the appropriate conclusions.

Consistent with this view of learning, the majority of class time was spent in actually doing experiments such as planting seeds and measuring and recording plants' growth. Discussion sessions primarily involved describing observations and exploring students' explanations of the observations. The following sections from a classroom transcript presents the typical discourse pattern of the classroom:

Teacher: Where do they (plants in dark) get their food?

Bob: Sun isn't everything that makes a plant grow. They've got the dark, the water and they've got the cells inside them that give themselves food. And the dirt gives them food and stuff. So they don't just need sun to grow. They have other things to help them grow.

Teacher: Un huh. Ok. Anything else?

Kristen: Maybe it's something in the air helps them grow, a chemical in the air.

Teacher: They're beginning to die, don't you think?

In this discourse, the teacher provides a structure that encouraged students to think about their observations and to generate their own explanations for these observations. Ms. Kain did not give out information, nor did she give evaluative feedback to students to indicate which kind of thinking is most appropriate. She listened to students' ideas, sometimes repeated ideas, and then moved on, asking for other ideas or changing to a new question. Students' answers were all received with neutral acceptance by Ms. Kain. They were neither praised nor rejected. Although the quality of answers varied, all ideas received equal treatment.

When it came time for the teacher to present the concept of photosynthesis, Ms. Kain gave her students a brief explanation of the concept. This explanation came toward the end of a lesson and was followed up by student discussion not directly relevant to this issue. The teacher then used questioning to review the plants' sources of food. The ideas mentioned by students that she approved as sources of food were "the cotyledon" and "the sun." The role of the sun in photosynthesis did not come up again until a brief review on the last day of the unit. Ms. Kain's presentation of photosynthesis was done in a cursory fashion, as if she felt she were betraying the intent of the program.

The teacher's class time, then, consisted of procedures for experiments given by the teacher, experiments carried out by students, and class discussions that focused mostly on students' observations. When reasons for observations were discussed, it was the students' ideas which were elicited. The teacher did not provide explanations or clarifications, nor did she probe students' explanations.

It took eight weeks for Ms. Kain to complete the unit, with lessons being presented about three times per week. At the end of the unit, Ms. Kain had some frustrations. She complained about the length of time it took to get the plants grown, about her short class periods, and about her feeling that things were fragmented. She described a number of difficulties she was having with the Teacher's Guide. Her planning time was consumed with figuring out what activities were to be done, when they were to be done, what materials and procedures were to be used and when they were to be used. She was not sure why the last experiment (a complex one involving growing bean plants in the light and in the dark, with cotyledons removed and with cotyledons intact) was included and what students were supposed to have gotten from it that they had not already gotten. As the unit had progressed, student behavior had deteriorated. She believed that students' behavior was a reflection of their frustration with the repetitive measuring and recording of plant growth. In her final lesson, she asked students, "How many of you feel that this has been a long unit?" She followed the question with another: "How many of you feel we could have learned just as much in less time and doing less experiments?" The majority of her students raised their hands.

Student learning. And what did tne students learn? Our posttests clearly revealed that Ms. Kain's students had not given up their belief in a number of fundamental misconceptions. Only 11 percent understood the goal conception that plants get their food only by making it themselves.

Students' main source of information had been the experiments, and they interpreted these experiments in terms of their own preconceived notions about plants without recognizing the intended dissonance between their own ideas and the experimental results. For example, many students' interpretation of the grass plants dying in the dark was merely that plants need light to grow, an idea that most of them had believed prior to instruction. They did not, as intended, use the concept of photosynthesis to explain the experimental results.

At best, students who began instruction with the miscnception that plants get food by taking it in from the soil interpreted photosynthesis as merely an additional food source for plants. They often thought of the light itself as the plants' food, believing that plants take in food from the soil and from the sunlight. Thus, students assimilated the information into their misconceptions without making a basic change in their misconceptions. They still viewed plants' food as raw materials coming from an external source. Because they did not give up the idea that plants take in their food, students failed to make a fundamental distinction between plants as producers of food and animals as consumers of food. That distinction is the basis for understanding the remaining sections of the Communities unit following the Producers section.

Year Two

The plan for the second year of our project was to use the knowledge we had gained about the interactions among teacher thinking, curriculum materials, classroom instruction, and student learning to develop curriculum improvements that would provide teachers with the knowledge about content, students, and teaching strategies they need to become conceptual change teachers. That is, we hoped to use curricular changes to influence teachers' implicit views of learning. We wanted to make teachers aware of particular student misconceptions and of the importance of challenging these misconceptions in addition to providing scientific explanations that would appear reasonable to students.

For Ms. Kain and other teachers in our study using the SCIIS curriculum we rewrote the SCIIS Teacher's Guide (Smith and Anderson, 1982) based on the difficulties we had observed teachers having with the original guide. Our aims were: a) to simplify and clarify the procedural details for the activities, b) to highlight the intended learning goals, and c) to highlight students' probable misconceptions. We hoped that this would free up some teacher thinking time, previously focused on activities and procedures and allow teachers more time to think about how instructional activities should change students' misconceptions.

Ms. Kain used this Revised Teacher's Guide when she taught the Producers unit during Year Two. To pursue our study of teacher thinking, we continued to use teacher interviews and stimulated recalls of teachers' planning while using the new guide. Classroom observations remained a primary source of information. During Year Two, however, we used some new strategies to probe student thinking during instruction more deeply. In addition to the administration of pre- and posttests to all students, four students in Ms. Kain's class were selected for detailed observations. These students sat at one table, and a special microphone was placed above their table so that transcripts of all their conversations could be made. During most class periods, two observers watched each lesson. One focused on the behavior of the target group of students, and the other surveyed the entire class. When only one observer was present, videotapes of the target group were made. The target students were interviewed before and after the unit of instruction and at four strategic points during the unit. With the new guide focusing the teacher's attention on students' misconceptions, we had hoped to be studying these students in the process of conceptual change, moving from their misconceptions to more acceptable scientific views.

Ms. Kain's thinking and teaching. Throughout the unit, Ms. Kain was enthusiastic about the new Teacher's Guide. She commented frequently about how helpful it was to her in long-range planning and as a daily instructional guide. Overall, the feature that most impressed her was the improved organization of the guide--things were easy to find which was a big timesaver for her. Unlike the frustration she felt at the end of the unit in Year One, Ms. Kain ended the unit in Year Two with a feeling of satisfaction that she attributed to the improvements in the Teache s Guide.

Although Ms. Kain reported in the final interview that she had felt things had gone much more smoothly during the second year, it is clear from her teaching and from talking to her that there had not been significant changes in her views of learning or in her ways of interacting with students. The guide heightened her awareness of student misconceptions, but this did not become a central issue for her in her teaching. It was more an interesting observation than something critical to instruction. As a result, she did not change her discovery orientation to attack these misconceptions more forcefully, even when she was aware that students still were thinking that plants get food from the soil as the end of the unit approached. In discussions with Ms. Kain after the posttest analysis was completed, she hypothesized that perhaps fifth grade students were not able to think abstractly enough to ever "get" this concept.

The following segment of classroom discourse was typical of both Year One and Year Two lessons. This interchange took place at the conclusion of the grass plant experiment, Year Two. Students had seen plants die in the dark and live in the light. The teacher had not yet given the students the concept of photosynthesis to apply to this question. Instead, she elicited students' explanations based on their observations. In this segment, the students used a lot of common sense thinking and human analogies. The teacher's role, as in Year One, was to make sure she heard and understood what the students were saying without any evaluative feedback. When a number of ideas had been expressed, she ended the discussion by moving on to a new question.

Teacher: What do you think about now about what light does for a plant? What do you think it does for a plant? Jeff?

Jeff: Well, I think that it gives its, the, ah, rays of the light gives, gives the plant the extra food it needs to produce the chlorophyll...

Teacher: ...What do you think light does for the plant? John?

John: Well, I'm not sure....it's like us. If we stay outside a lot and you get sunburned. It's sort of like what the sun does to us.

Teacher: Okay, looks healthier maybe. I'm not sure if we can make that analogy. Okay, any other comments about that? Andy?

Andy: Well, you know the sun in the summer most of the time and the winter you feel like you don't want to be active and run around all the time. People just don't want to sit down but in the summer you like to lay there in the shade so I think it's more of the heat.

Teacher: We're talking about the light now. Aren't we?

Andy: The heat.

Teacher: The heat from the light you're saying?

Andy: Yeah, the....grabs all the light in and uses all the heat.

Teacher: Uh-huh, okay. Melanie?

Melanie: Well, I think kinda, maybe it gives it a little bit more food. I mean not like food but ah like it gives it like a green. Green looks more healthy.

Teacher: Okay. One more. Heidi?

Heidi: Like we're healthy, like we're healthy from being in the sun and stuff, we've got the sunshine but like other people who don't have the sunshine like, ah, maybe they wouldn't be like, like they probably might be greener? I don't know but might be sick or something. Without light you would probably get pale and you could also change colors. I mean, I wouldn't say to a dark green or anything but I mean you could get really pale.

Teacher: Okay, what we're saying here is that light is important. We can say that, can't we at thia point? That light seems to be important for plants to be able to grow. But can you explain why plants grew in the dark for a while?

This pattern did not change much even after the concept of photosynthesis had been presented. Students stated ideas that reflected major misconceptions, but the teacher did not force the students to see the inadequacy of their misconceptions. She often asked follow-up questions, but these focused more on helping clarify what the student was saying rather than on trying to help them see the conflict between their explanation and the concept of photosynthesis. If the students persisted in spite of her follow-up questions, she let the issue drop, unresolved.

Thus, the revised Teacher's Guide did not alter the way Ms. Kain listened to and respnded to her students during Year Two. Instruction continued to reflect a discovery rather than a conceptual change orientation. Lessons continued to consist primarily of teacher-given procedural directions, the doing of experiments, and loosely structured discussions of students' observations and ideas.

Student learning. The posttests given to all of Ms. Kain's students and the detailed study of the four target students revealed that student learning was not significantly improved as a result of the use of the Revised Teacher's Guide. While a number of factors contributed to this instructional failure, our continued analysis of students' misconceptins during this second year convinced us that we had been attacking the wrong misconceptions. While the SCIIS strategy had been focusing on the misconceptions at a factual level (i.e., plants take in food from the soil), we found that there were deeper, more fundamental misconceptions that concerned students' ways of thinking. The students' common-se se ways of thinking were in conflict with the scientific ways of thinking that the Teacher's Guide and Ms. Kain anticipated students would "naturally" use.

One of these deeper level misconceptions concerned the students' ideas about the nature of explanations. The scientist is continually trying to make sense of the world by seeking functional explanations for observable phenomena. The scientist does not expect to physically see the answers to most questions by looking at experimental results. On the contrary, the scientist is constantly thinking about unseen events that can explain observations.

The fifth graders, on the other hand, often did not think beyond what they could see. When interpreting a phenomenon such as plants growing in the light and dying in the dark, they did not think about functional explanations for this phenomenon. They did not think about anything happening to the light inside the plant. Instead, they were content that the observation or "facts" were enough to explain the phenomenon: Plants need light because they'll die without it.

Students also differed from scientists in their way of defining the term "food." The scientist attaches a precise meaning to this term: Food is organic material that provides energy for life processes. On the other hand, the students used common-sense notions of food as they interpreted instruction. Rather than thinking of food in precise functional terms, they appealed to analogy: Plants need food like people do. Thus, plants need food to live just like people do; plants must also have many different kinds of food like people do. Since people take in food, plants must also take in food. These common-sense notions and analogies provide explanations that make sense to students. As a result, they were very powerful. satisfying explanations from the students' perspectives.

Curriculum materials. These deeper level misconceptions about students' ways of thinking were not recognized or challenged by the SCIIS instructional strategy as presented in either the original or the Revised Teacher's Guide. The instructional sequence failed to break this cycle of ways of thinking about plants. The concept of what food does inside the plants was not emphasized. That plants have only one source of food was presented only indirectly at best. That students might have trouble thinking beyond their observations to processes occurring inside the plant was never suggested. In fact, in stressing importance of making and recording observations, the instructional sequence actually reinforces the importance of focusing on observable evidence. The bulk of the Teacher's Guide, even in the revised version, is devoted to explanations about how the students should make and record observations.

Year Three

The Revised Teacher's Guide also failed to bring about significantly improved learning in three other classrooms where the teachers used it.

Did the failures of our intervention mean that the conceptual change approach to instruction was not a useful one? Or, was it just this particular conceptual change strategy that was not working? We believed that there were three critical shortcomings in the Revised Teacher's Guide:

1. In developing the guide, we had been unaware of the existence of students' deeper level misconceptions about appropriate ways of thinking. Therefore, these misconceptions were not addressed in the guide.

2. There were not enough opportunities during the unit for students to apply new concepts.

3. The rationale for suggested teacher questions was not always made explicit. In particular, when a question was designed to test whether certain misconceptions were persisting, we did not alert teachers to this function.

We decided to give the conceptual change model a further test, believing that this concept of photosynthesis could be understood by fifth graders. Using the deeper analysis of students' misconceptions and our study of the difficulties that had been encountered by both teachers and students using the photosynthesis unit, I developed a student text/workbook and an accompanying Teacher's Guide that were designed to help students relinquish their misconceptions about food for plants in favor of the scientific concept of photosynthesis. Thus, the text was written to induce conceptual change in students rather than just to present scientifically correct information. The text (Roth, 1983) was written to overcome the weaknesses of the Revised Teacher's Guide listed above; thus, it attacked both factual and deeper level misconceptions. There were many application questions included. The Teacher's Guide version of the text gave the teacher information about a) the purposes of each question, b) appropriate scientific explanations of questions, and c) likely student responses and ways to spot misconceptions revealed in these responses.

This text was used by Ms. Kain during the third year of study. In addition to classroom observations and pre- and posttests for all students, six target students were selected for focused observation and study. They were interviewed before, during, and after the instructional unit.

<u>Ms. Kain's thinking and teaching</u>. Ms. Kain began the third year with doubts that fifth graders were developmentally ready to comprehend an abstract concept such as photosysthesis. However, she was willing to give it another try with whatever new materials we could provide to help her. When I first handed her the text I had written, I was concerned that she might feel uncomfortable with the text since its approach clashed in many ways with her discovery orientation to science teaching. Ms. Kain, however, was enthusiastic about the text from the beginning, and before long, her initial lukewarm attitude towards teaching the unit had changed to a determination that the students would "get it" this year. At the

beginning of the unit, Ms. Kain moved back and forth between the new text, which she used to structure all class discussions, and the SCIIS Revised Teacher's Guide, which she used for giving procedural directions and planning the experimental activities. As the unit progressed and the experiments were underway, Ms. Kain came to rely almost exclusively on the Teacher's Guide to the new text for her planning and teaching of lessons.

Before describing changes in Ms. Kain's thinking and teaching that can explain the improved student learning, it is important to note that many things did not change in Year Three. The students were of similar academic ability, although they were a more "social" group and posed more discipline problems for Ms. Kain. She still faced the problem of short science class periods and frequent requests to give up science time for special activities. She was, in fact, under pressure to finish the unit by a certain date, which forced her to finish the unit in fewer lessons in the third year. There were still the distractions posed by the physically open classroom space, with other groups of students working close by. The giving of procedural directions and the doing of experiments still dominated actual instruciton time, expecially at the beginning of the unit. Except for the elimination of students' individual record keeping in favor of class graphs and for the "drylabbing" of the final bean experiment, procedures for the experiments remained the same. Even the discussions held in the early going of the experiments were practically identical to those of earlier years, with the teacher eliciting and accepting students' observations and ideas without leading the discussion to any closure or consensus. As in prior years, she also tended to call on the children who volunteered to speak, so the non-volunteers virtually never participated in class discussion. In short, there were not significant changes in the teaching characteristics that have been defined as "effective" by correlational research described earlier in this chapter (Rosenshine, 1979).

However, there were fundamental changes in Ms. Kain's explicit and implicit views of teaching and learning. Once she made the commitment that the students were going to "get it" this time, Ms. Kain adopted the new attitude that she was going to have to be more hardhitting and direct in her approach. She recognized how difficult it was going to be to help students give up their comfortable common-sense notions in favor of more abstract, invisible concepts. From interviews with the teacher and observations of her behavior during instruciton, it is clear that she was thinking a great deal about how to present the content so that students would find the concept of photosynthesis reasonable and more acceptable than their misconceptions. Whereas in the past Ms. Kain's thinking had focused on getting the activities to go smoothly and on encouraging students to think about their own explanations of their observations, her thinking during Year Three concentrated largely on two issues: a) how to present the content so it seemed reasonable and b) how to confront students' misconceptions. The flow of activities was much less a concern than in previous years. Although Ms. Kain did not describe her own thinking as being dominated by these issues, these changes in her thinking were reflected in her ways of presenting content and in her ways of confronting student misconceptions.

1. Ways of presenting content. In attempts to make the concept of photosynthesis seem sensible to students, Ms. Kain tried a number of different presentations of the concepts. While in Years One and Two the presentation of photosynthesis consisted of a brief teacher explanation during one class session, in the third year Ms. Kain explained the concept during four separate lessons. Each time, she tried to explain it in a different way--one time talking about photosynthesis as a chemical reaction with molecules being rearranged, at another time describnig it as a combination of light, air, and water taking place inside the plant. In addition to hearing the teacher explanations, the students read and discussed explanations of the concept in the text. Ms. Kain also hung up posters summarizing the main points of the process and had students take notes from the posters.

Ms. Kain not only spent more time explaining photosynthesis in different ways and through different media, she also explained other ideas related to the main concept of photosynthesis that she thought would help students understand. These concepts had not been explicitly explained at all in the past. Thus, for example, the teacher explained the scientific definition of food, how raw materials get into the plant, that all seeds have embryos and cotyledons, and that excess food produced during photosynthesis is stored in the seed. Each of these concepts was presented by the teacher briefly at strategic points during instruction. Ms. Kain did not become a lecturer; class time was much more typically in a discussion format. But she did not hesitate to explain concepts she thought would be helpful to the students in understanding photosynthesis. Sometimes these explanations served as a summary of a discussion, to make sure that students understood the main point she was trying to develop.

Not only did students hear and see main ideas explained and repeated in different ways, they were also provided many opportunities to use the new ideas. An overhead transparency showing plants at different stages of growth was used to discuss plants' sources of food at each stage. A newspaper article that included drawings of plants was used for a similar review discussion. Finally, Ms. Kain used every application question in the student text, having students write out answers to the questions before discussing each one in class.

2. Ways of confronting misconceptions. During such discussions Ms. Kain was clearly focusing on any evidence she heard that a misconception was persisting, and this represented a second key difference in her behavior during the third year. In general, she kept discussions more sharply focused on the main issues, she was clearly attentive to students' misconceptions, and she began to provide evaluative feedback to students. She more frequently challenged students' explanations, not just to clarify what the student was saying as she had done in the past, but to try to change students' thinking. The following classroom excerpt provides an

example of this type of questioning pattern. In this discussion, Ms. Ksin does not just accept the answers given by Leanna, Eric, and Brad. Rather she tries to help each of them focus in on the critical issue that the cotyledon provides food for the plant. Although this dialogue occurs at the same point in the instructional unit as the one from Year Two, a sharp contrast between the two discussions is evident:

Question: Why did the grass plants grow in the dark?

Leanna: Light isn't the food so it can grow without the light--it had water and stuff.

Teacher: I'm sorry, Kate, it's Leanna's turn; if you would like to speak, I would like you to raise your hand. Leanna, I couldn't understand you.

Leanna: The light isn't the food so it can grow without the light.

Teacher: Yeah, so we're talking though about how it is that it grew in the dark...

Leanna: It had the water and stuff.

Teacher: It had its food?

Leanna: Well, it had the cotyledon and everything.

Teacher: Why was that important? ....that it had its cotyledon?

Leanna: It's its food.

Teacher: Okay! Eric?

Eric: They all need water, the reason those (in the light) look better is because the sun gives it its color and it also helps make those stay healthy.

Teacher: I want to know why the grass grew in the dark. I don't want to know about ....

Eric: Okay, the cotyledon...helped it for a while.

Teacher: So it needed what?

Eric: Cotyledon and water.

Teacher: Why did it need its cotyledon?

Eric: Because it's the food.

Teacher: It's the food. Okay, Brad, what did you put?

Brad: I put the grass grew in the dark because the cotyledon helped it grow until it could (inaudible).

Teacher: What is the cotyledon?

Brad: It's, ah, ah, ah, it's the food.

Teacher: It's the food. OK. The cotyledon is the food which gives the young plant the energy to grow, right?

In addition to probing to guide the students' thinking toward goal conceptions, as the above passage illustrates, Ms. Kain also provided more evaluative feedback for students, letting them know if their comments were acceptable or not. Unacceptable answers were generally received with probes, as in the sample above, intended to improve their answers. Acceptable answers were approved with comments such as the following:

Jason: They no longer have food that they need to continue living and growing.

Teacher: (Enthusiastically.) They do not have the food! They do not have the food to continue growing. They don't have the food to provide them with the energy to continue growing. Okay? That's why they died. They don't have the food to give them the energy to continue growing. That's <u>very</u> important.

. . . .

Laura: Well, it shows that after a while the seeds fall off the plant. They have some food from the cotyledon for a while but then they have to make their own food.

Teacher: All right, they have their own food for a while, just like it shows there, the little embryo did, but pretty soon the little young plant has to begin to make its own. That's the accurate part of the cartoon. You said that well, Laura.

. . . .

Anuja: It would start making its own food!

Teacher: All right!

An important focus in Ms. Kain's concern about students' misconceptions during Year Three was her attempt to pick up on the idea of deeper level misconceptions that were addressed in the student text. The text, for example, explains the difference between scientific and everyday definitions of terms like "food." Not only did students read about this in the text, Ms. Kain explained the idea to her classes. Throughout the unit she constantly reminded them of the scientific definition of food.

She also repeatedly encouraged students to think about what they had learned and to apply this in developing scientific explanations. She stressed that scientific explanations should tell why and not just report observations. She reminded students periodically to think about what is going on inside the plant. On two occasions when students were going to be writing answers to application questions, Ms. Kain had posters hanging up with main concepts listed on them. The class would read over the list aloud together, and then Ms. Kain would tell the students to use these concepts in writing their explanations. The following is one example of an occasion when the teacher was attacking students' deeper level misconceptions about how to think about experimental results.

Teacher: What do you think will eventually happen to this?

Lisa: That was the plant that used to be in the light?

Teacher: Started in the dark and it's been in the dark the whole time.

Lisa: It might start dying.

Teacher: Why do you think it will die?

Lisa: Well, it looks unhealthy.

Teacher: Yeah, that's an observation. Remember that a scientist will go beyond that and explain <u>why</u> you think. Why do you think? She's saying that she thinks it's going to die. Because it looks unhealthy. Let's go beyond that and explain <u>why</u>.

In this and other instances, Ms. Kain was clearly trying to give students information about the features of a scientific explanation and the shortcomings of the students' explanations.

Ms. Kain's overriding concern throughout the unit that students give up their misconceptions was reflected on the first day of the unit. The class was discussing how their initial ideas about food for plants that they had written down at the beginning of the unit had changed. Andy stated, "When I did it, I said that water was food. And so I changed it now to that water was not food." Ms. Kain replied with evident relief and enthusiasm, "Water is not food. Oh, I am <u>so</u> glad to hear you say that, Andy."

Thus, Ms. Kain's thinking and behavior were quite different during Year Three. They were much more consistent with a conceptual change approach to instruction. Her instruction addressed each step in Posner et al.'s (1982) conceptual change model of instruction: she elicited and challenged student misconceptions, thought carefully about how to present the goal concepts so they would appear reasonable to students, and provided numerous opportunities for students to apply new concepts. Her careful guiding of student thinking was thoroughly consistent with a conceptual change view of learning, although this was not a change that she was able to verbalize at the end of the unit. She did recognize, however, that she had made significant changes in her teaching and that she was no longer operating from a discovery view of learning. She ended the unit with guarded enthusiasm, afraid that the posttests would belie her gut feeling that the students had "gotten it" this time.

Ms. Kain attributed the changes in her teaching to two factors: a) the text and accompanying Teacher's Guide, and b) her experiences and frustrations with the unit in the past. Partly because she was more familiar with the activities this year, she was able to allot more time to thinking about content and students' misconceptions. The activities did not require so much of her concentration. The thinking she did during this newly freed-up time was shaped by the content and philosophy of the text and Teacher's Guide.

Student learning. During Year One, Ms. Kain had asked the students in frustration, "How many of you feel we could have learned just as much in less time and doing less experiments?" In the third year, the students showed that they could learn more in less time. Although the instructional unit was cut down from 23 lessons in Year Two to 16 lessons in Year Three, the students in Year Three developed significantly improved ideas about photosynthesis. Although the test data analysis is not yet complete, improvements are clear. For example, in answering the question, "What is food for plants?", only 7 percent of the students in Year One used the goal concept that plants get their food only by making it (photosynthesis). Most students listed raw materials such as fertilizer, water, sun, etc. On the Year Three posttest, 79 percent of the students answered this question by referring only to photosynthesis or plants' making of food. Interestingly, another 15 percent of the students in Year Three answered the question by defining food: Food is anything that gives plants energy.

The students' answers to the application question described below in Table 1 provide an example of an important kind of improvement evident on the Year Three tests. Table 1 compares pre- and posttest frequencies between Year One and Year Three of the study (The results in Year Two were nearly identical to those for Year One and therefore are not included.) Sixty-five percent of the students using the text in Year Three correctly predicted that the seeds would begin to grow, then eventually die, compared with only 30 percent the first year. The improvement in students' explanations of their predictions is even more striking. In past years, students' explanations on the posttest did not use the scientific concepts that they had been taught: a) Young plants can get food from the cotyledon in the dark, but b) they need light to make their own food when the cotyledons are used up. Instead, students' explanations had been based on their observations during the experiments: The plants will live, then die, because plants can begin to grow in the dark but will eventually die if they don't have light. During Year Three the idea that the plant can get food from the cotyledon was mentioned by 41 percent of the students; 52 percent used the concept of photosynthesis, that plants need light to make food. An additional 15 percent said that plants need air, water, and light for food but did not explicitly mention photosynthesis.

Table 1

Question: A man wanted to have an early garden. He planted some tomato seeds in small boxes. He kept the boxes in a closet where it was warm and dark. He watered them whenever the soil started to get dry. What do you think happened to the seeds? Why?

	Pretest		Posttest	
	Year One	Year Three	Year One	Year Three
Correct prediction: Plants will begin to grow but eventually die in the dark.	2%	6%	53%	60%
Explanation states that plants can get food from the cotyledon.	1%	0%	22%	41%
Explanation that plants need light to make food.	0%	0%	2%	52%

Summary

Over the three years of our work with Ms. Kain and her students, as well as the other teachers and students who participated in the study, we learned a great deal about the cognitive life of teachers and students and about the role of curriculum materials in science instruction. We become convinced of the critical role that students' misconceptions play in science learning. While this awareness of students' cognitive lives led us to favor a conceptual change view of instruction, our study of teachers' cognitive lives made us realize that the conceptual change model puts tremendous demands on teachers. It requires them to think in some depth not only about scientific content but also about the students' thinking and about the appropriate strategies to use to guide student thinking.

In Years Two and Three, we provided curriculum materials that we believed would give Ms. Kain much of the information she needed to become a conceptual change teacher. Our first attempt, the Revised Teacher's Guide, proved not to be enough. It did not change the cognitive lives of the teacher or the students in the intended ways.

In our most recent attempt, we succeeded in influencing Ms. Kain's thinking and teaching which resulted in improved student learning. We believe that this success was a result of an instructional strategy outlined in the text that attacked both factual level and deeper level misconceptions about students' ways of thinking. In addition, much more specific guidance about the reasons questions were posed and about how teachers should use the questions to diagnose and remediate persisting misconceptions was a second important feature of the text. Finally, a third critical change in the strategy in the third year was the inclusion of more application opportunities so that students had enough practice using new concepts so that they could see the wide applicability of the scientific conception.

IMPLICATIONS

From our work with Ms. Kain and other teachers, we believe that science teaching and science curriculum materials can be improved by using knowledge of student misconceptions about particular science topics to develop conceptual change instructional strategies. Materials like the text on photosynthesis that was based on a thorough knowledge of students' misconceptions can provide enough information to help teachers improve their effectiveness. Thus, teachers like Ms. Kain can use knowledge about their students' thinking to improve instruction if they are given the crucial information about expected student misconceptions.

Classroom observations and investigations of students' and teachers' thinking during instruction were critical elements in our research efforts. If we had not entered the classroom to watch Ms. Kain and her students in action, we would not have been able to understand why the students were failing to learn. Without such knowledge, we would have had to approach any curriculum development efforts using the traditional "best guess" approach, knowing only that the existing program was not working. Once we had information about why students were failing to learn, it was clear what kinds of changes had to be made in instruction and in curriculum materials.

Our research suggests the need for a new curriculum development model that focuses on how students learn in classroom settings. Such a model would take the developer into classrooms before curriculum development begins to identify and catalogue common student misconceptions about particular units of study in the science curriculum. The developer could then put together strategies and materials to help teachers move their students from their misconceptions to more scientific views. Evaluation of the success of the strategies would again take the developer into the classroom. Catalogues of common misconceptions and field-tested strategies to overcome them would be gradually accumulated for each topic in the science curriculum. Through such a patient and systematic approach to curriculum development, guided by knowledge of the realities of classroom teaching, important findings about the learning process can be used to improve teaching and curriculum materials to more effectively help students make sense of science instruciton.

It will not be an easy task to convince those clamoring for immediate solutions to students' science learning difficulties that such a curriculum development policy is necessary if we are going to significantly improve student learning. It took us three years to make significant progress on the topic of photosynthesis. We found that it was a difficult and time-consuming task to uncover students' misconceptions, expecially those crucial deeper level misconceptions. However, we beli that in the future this research ' development cycle can be str ined so that new knowledge and curri a materials can be generated 'mely manner, particularly if researchers build on each of ndings. In this regard, there is a growing body of research c s s' misconceptions about various science topics that has not yet been used in attempts to improve teaching and curriculum materials.

Besides requiring a more gradual implementation than traditional curricula, this conceptual change approach to science teaching and curriculum development also raises an important question about what constitutes "meaningful" learning in science. There are those who would argue that Ms. Kain's students in Year One and Year Two were learning something more critical than the concept of photosynthesis They were involved in the processes of science, and they were facing issues that scientists face (cf. Hanson, Chaper 2). From the many open-ended opportunities to think like scientists, they were learning about the nature of scientific inquiry and developing an understanding of science in general. On the other extreme, others would argue that Ms. Kain could have covered many more concepts in the five-week period. They might argue that young students are not yet capable of thinking like scientists, and the best thing we can do for them is to expose them to a lot of concepts and facts about science. Later on, students will learn more sophisticated ways of thinking about these concepts.

I believe that neither of these extremes--the discovery or the didactic approaches--will result in meaningful learning for the majority of students. It is difficult to support the contention that the students in Ms. Kain's classes in Year One and Two, who received heavy doses of discovery teaching, were learning anything meaningful about scientific processes. They began and ended an eight-week unit using the same kinds of naive ways of thinking about experimental results. They did not find the processes of observing, measuring, recording, and thinking about the results useful, because the processes did not help them develop an improved understanding of plants. Using the processes was an empty exercise, because students ended instruction clinging to the same misconceptions they had at the beginning. On the other hand, the didactic approach ignores what we know about students' thinking. Students can memorize lots of facts from didactic teaching, but these facts are quickly forgotten and are not used by students in approaching new problems. The students do not incorporate the new facts into their ways of thinking. This approach does nothing to help students urderstand how scientists think and go about their work.

The conceptual change model, as used during Year Three in Ms. Kain's class, represents a middle position between the extremes of discovery and didactic teaching. In Ms. Kain's class, students were initially given opportunities to do some free thinking about experimental observations, but la er they were given guidance about how scientists think. The inadequacies of their own ways of thinking were pointed out. Facts were given to students at strategic points to help them see that scientific ways of thinking could help them develop new understandings of plants. At the end of the unit, students applied new ideas to new problems both as part of instruction and on our posttest. By coming to understand a scientific principle that could be used to explain a number of observations, students were leaining that the processes of science were useful tools for understanding phenomena.

While this chapter describes only one topic being taught at the fifth grade level, this method of using classroom observation to develop curricular improvements is one that holds promise for improving science learning of students on a wide variety of topics and all grade levels. If knowledge about students' misconceptions and knowledge about teachers' needs is properly used to improve science teaching and curricular materials, then more atudenta can experience meaningful learning in science classrooms.

References

Blecha, M. K., P. C. Gega, and M. Green. Exploring Science, Green Book (second edition). River Forest, Illinois: Laidlaw Brothers, 1979.

Hollon, R., C. W. Anderson, and E. L. Smith. A System for Observing and Analyzing Elementary School Science Teaching: A User's Manual. (Institute for Research Series No. 90). East Lansing, MI: Institute for Research on Teaching, Michigan State University, 1980.

Knott, R., C. Lawson, R. Karplus, H. Thier, and M. Montgomery. SCIIS Communities Teacher's Guide. Chicago: Rand McNally, 1978.

Landes, N., E. L. Smith, and C. W. Anderson. The Task Features Analysis System. (Research Series No. 89). East Lansing, MI: Institute for Research on Teaching, Michigan State University, 1981.

Posner, G. J., K. A. Strike, P. W. Hewson, and W. A. Gertzog. "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change." Science Education, 66(2): 211-227, 1982.

Rosenshine, B. V. "Content, Time, and Direct Instruction." In Penelope L. Peterson and Herbert J. Walberg (Eds.) Research on Teaching. Berkeley: McCutchan, 1979.

Roth, K. J. Food for Plants Teacher's Guide. East Lansing, MI: Institute for Research on Teaching, Michigan State University, 1983.

Roth, K. J., E. L. Smith, and C. W. Anderson. Students' Conceptions of Photosynthesis and Food for Plants. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada, 1983.

Slinger, L., C. W. Anderson, and E. L. Smith. "Studying Light in the Fifth Grade: A Case Study of Text-Based Science Teaching." Paper presented at the annual meeting of the National Association for Research in Science Teaching, Fontana, WI, 1982.

Smith, E. L. and C. W. Anderson. Planning and Teaching Intermediate Science. Research proposal submitted to the Research in Science Education division of the National Science Foundation. Michigan State University, 1980.

Smith, E. L. and C. W. Anderson. "Plants as Producers: A Case Study of Elementary School Science Teaching." Journal of Research in Science Teaching. (In press.)

INTRODUCTION TO CHAPTER FIVE

There are far more male than female scientists, and boys tend to be more successful than girls in science classes. Can anything be done about this problem? Are we discriminating against girls in the way we teach science?

These are questions addressed by Susan Melnick, Chris Wheeler, and Barbara Gunnings, in their case studies of two teachers who are conspicuously successful in teaching science to <u>both</u> boys and girls. Their findings suggest that some common prescriptions for "sex-equitable" science teaching may not be entirely appropriate and that "equity and excellence go hand in hand."

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CAN SCIENCE TEACHERS PROMOTE GENDER EQUITY IN THEIR CLASSROOMS? HOW TWO TEACHERS DO IT

Susan L. Melnick*
Christopher W. Wheeler*
Barbara B. Gunnings

INTRODUCTION

Over the past decade, a growing body of literature has emerged confirming the pervasiveness of differential role expectations and treatment in schooling experiences for males and females. Much of the research in the area of sex-discrimination in the classroom has centered on such issues as failure of females to succeed in science and mathematics (Kistiakowsky, 1980; Parson, 1982), sex stereotyping in textboks and other curricular materials (Frazier and Sadker, 1973; Women on Words and Images, 1975), and differential teacher feedback (Blumenfeld, Hamilton, and Bossert, 1979; Bassert, 1981; Dweck, Davidson, Nelson, and Enna, 1978).

If one looks at science in particular, evidence of differential success which might, in part, be attributed to schooling tends to be fairly convincing. In 1979, for example, women holding doctorates in science and engineering comprised 7 percent of those employed by business, academia, government, and the medical profession; 5 percent of those holding doctorates awarded to women in the various subfields of physics rose from 1.9 percent in the period from 1960 to 1969 to 3.5 percent from 1970 to 1976 (Kistiakowsky, 1980). While enrollment figures for graduate studies project continued increases for women in the coming decades, it will take seventy-five years, at the current rate, for women in the physical sciences to receive degrees on a par with men (authors' calculations of Vetter's data).

Explanations for such underrepresentation range from discrimination in employment to childhood experiences where role perceptions are shaped by family and peer expectations (Kistiakowsky, 1980). Recent research, however, has shown the special role junior and senior high school experiences play in creating these disparities. For example, while

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occupational stereotypes are formed quite early (Maccoby and Jacklin, 1974), it is only at a later age that actual performance in academic subject areas and preference for certain subjects become clearly differentiated. Thus, at age nine, boys and girls demonstrate almost identical achievement levels in science, mathematics, and social studies, but by age thirteen, female students have begun to slip behind males (NAEP, 1975, 1978). The gap continues to widen through high school and into adulthood. Moreover, as Hardin and Dede (1975) report, interest inventories show negligible sex differences in seventh grade preferences for science, but significant differences by eighth and ninth grades. In sum, according to Kahle (1983), "girls [come to] have poorer attitudes toward science, enroll less often in science courses, demonstrate lower achievement levels in science, and have fewer experiences with the instruments or materials of science" (p. 1).

Such findings, however, do not mean that females reject science altogether. Rather, studies show that girls, as they grow older, come specifically to reject the physical sciences, which is later translated into enrollment disparities (Fox and Denham, 1974; Hansen and Neujahr, 1974; Koeische and Newberry, 1971). In short, while enrollment patterns in high school science indicate that females take fewer science courses than do males overall, such disparities are particularly evident in the "hard" sciences, for example, physics.

Given the critical nature of junior and senior high school for influencing who goes on in science, it is important to ask what role, if any, teachers play in shaping attitudes and subsequent enrollment patterns. Numerous studies at the elementary level, for example, indicate that boys receive more extended converstion, direct instruction, and praise than do girls (Sadker and Sadker, 1982). Moreover, a recent study by Dweck et al. (1978) suggests that boys receive more praise and girls more criticism for the academic quality of their work. Such differential treatment, it is argued, contributes to a feeling of "learned helplessness," where failure is perceived as insurmountable and attributed to factors such as ability, which one cannot control. According to Dweck et al., girls exhibit this feeling more than do boys.

While similar studies of teach student interaction at the junior and senior high levels are unavaila such patterns are nonetheless likely to exist in subject areas tradition viewed as masculine. Such a belief is strengthened by national and cross national studies indicating that females demonstrate lower levels of achiev ent in coeducational science classes than in sex-separated classes (Finn, 1980; Kelly, 1979; Vockell and Lubonc, 1981). According to Kelly (1979), such findings in physics classes result, in part, from the fact that girls receive more faculty encouragement and peer support for achievement in a sex-separated environment (cited in Kistiakowsky, 1980, p. 37).

While inequitable results have been amply documented, the majority of these studies have tended to rely on frequencies of female presence or absence in non-traditional areas, standardized measures of achievement outcomes, or, as Bossert (1981) has noted, global ratings of teacher behavior consistent with the process-product paradigm of teacher effectiveness. Given the discrimination focus of most studies, little is known about sex-affirmative teaching practices which contravene traditional social norms and the results which occur. The purpose of this chapter is to describe two case studies of teachers who successfully promote gender equity in their classrooms and in the process accomplish outcomes that differ from the typical patterns in terms of female enrollment, participation, achievement, and interest in pursuing additional courses in science.

Sex-Affirmative Teaching

In an effort to determine teacher behaviors that might promote gender equity, the researchers reviewed relevant literature to determine characteristics of sex-affirmative teaching practices. According to Sadker and Sadker (1982), sex-affirmative teaching is

> ...an active and intentional process of incorporating into daily instruction those books, audiovisual materials, discussions, research projects, field trips, enrichment activities, learning centers, and lesson plans and units that teach girls and boys about changing roles and widening options (p. 137).

The Office for Sex Equity (1981) in the Michigan Department of Education provides examples of what sex-affirmative teaching looks like in the following excerpts from an evaluation of a local school district's efforts to promote sex equity:

> One teacher, in addition to encouraging students to look at all career possibilities, invites community workers in nontraditional jobs to speak to the class. An administrator requires that both boys and girls move chairs after an assembly. A secondary staff member, to give visible support for the principles of sex equity, teaches students about sex role stereotying and job choices with materials designed for that purpose (p. 55).

The report concludes that such efforts are affirmative not only because they are designed to eliminate sex bias but also because they "...purposefully counter the biased expectations that students, their peers, parents, etc. hold. The intent of these efforts is to remediate" (p. 55).

With respect to science in particular, Cohen and Cohen (1980) suggest a number of classroom activities to exercise awareness of sex-role stereotyping. Such activities include rewriting sexist employment ads; making collages of traditional and non-traditional careers for men and women with special attention to the role of science and math in career preparation;

reviewing classroom materials, popular songs, and prime time television programs for bias; value voting about sex-appropriate expectations at home and work; reading about men and women who had non-traditional careers; studying professions requiring firm science and math backgrounds; and inviting people of both sexes to classes to speak about their careers. Button and Brown (1980) supplement this list for science teachers by suggesting they set up a "Women-in-Science Resource Program" in their schools where books and other materials on the scientific accomplishments of women can be made accessible to students. Kahle (1983) adds to these suggestions the encouragement of girls to enroll in courses designed to enhance the development of spatial abilities, for example, mechanical drawing; the structuring of laboratory groups to ensure that girls work with science apparatus; and the provision for extra-curricular science activities to augment science education for girls.

In her description of affirmative programs, Bornstein (1981) argues that the purpose of efforts such as those described above is to promote increased levels of participation in all areas of school activity by underrepresented groups, such as girls and young women, because more equal participation at this level will ultimately translate into more equal participation in the job market.

From the foregoing review, the researchers tentatively concluded that sex-affirmative teaching can be characterized as follows:

1. It is an active, intentional process of bringing into daily instruction content about changing sex roles;

2. It remediates by purposefully countering biased expectaions; and

3. It promotes increased participation by girls and young women in curricular school activities.

Although these characteristics emerge from a prescriptive rather than an empirical context, they were used as the basis for initial data gathering in the classrooms of the two teachers described below.

METHOD

Subjects

The subject of one case study was a black-female middle school science and mathematics teacher, while the other was a white-male high school physics teacher. The two teachers taught in districts of comparable size and were similar in terms of preparation and years of teaching experience. These subjects were purposefully selected for study because they had reputations among their peers, school administrators, and students for pursuing sex-affirmative teaching practices in their classrooms.

Research Questions

The primary questions for these case studies were as follows:

1. Were sex-affirmative teaching practices evident in these classrooms?

2. If such practices existed, how might they be described?

3. Did these practices positively influence student attitudes toward science and interest in future science courses?

Data Sources

For each of the case studies, data sources consisted of intensive classroom observations over a three-month period, in-depth interviews with each teacher, reviews of relevant documents (e.g., curriculum guides, instructional materials, course descriptions), and interviews with students, teaching colleagues, counselors, and school administrators. In an effort to identify and describe what these teachers do to make instruction sex-affirmative, particular attention was paid to daily teacher-student interactions, ecological characteristics of the classroom, teacher views about their subject matter and personal views toward gender equity, and confirming or disconfirming perceptions of significant others.

Findings

The goal in analyzing the naturalistic data for these studies was to describe sex-affirmative teaching practices. The following sections describe the two teachers' practices.

Mary Jenkins' Seventh Grade Science Class*

The physical structure of Jenkins' classroom provides an appropriate setting for the variety of teaching strategies she uses: small group work, lecture/discussion, and individualized projects. The classroom has three rows of single desks in the middle of the room. Along the three outer walls are lab stations. The teacher's station is at the front of the classroom and consists of a table and lab set-up which is used for demonstrations. The lab stations house the traditional general science equipment such as Bunsen burners, tools, beakers, pipettes, dissecting materials, and variety of science-related equipment. Evidence of previous

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*The names of the subject teachers have been changed to guarantee anonymity.

student projects, such as a working model of a volcano displayed under a laboratory hood, can be seen at various locations around the room. A gerbil plays on its wheel in a cage at one lab station, while a white mouse maneuvers a maze at another station. Near the entrance to the classroom is a large aquarium with a variety of fish. A snake rests lazily in a cage nearby (see Figure 1).

The atmosphere in Jenkins' classroom is busy, varied, sometimes noisy, and reflects a general mood of excitement and involvement. A synopsis of one particular class period is presented here to capture the varied interaction patterns between teacher and students, as well as among the students themselves.

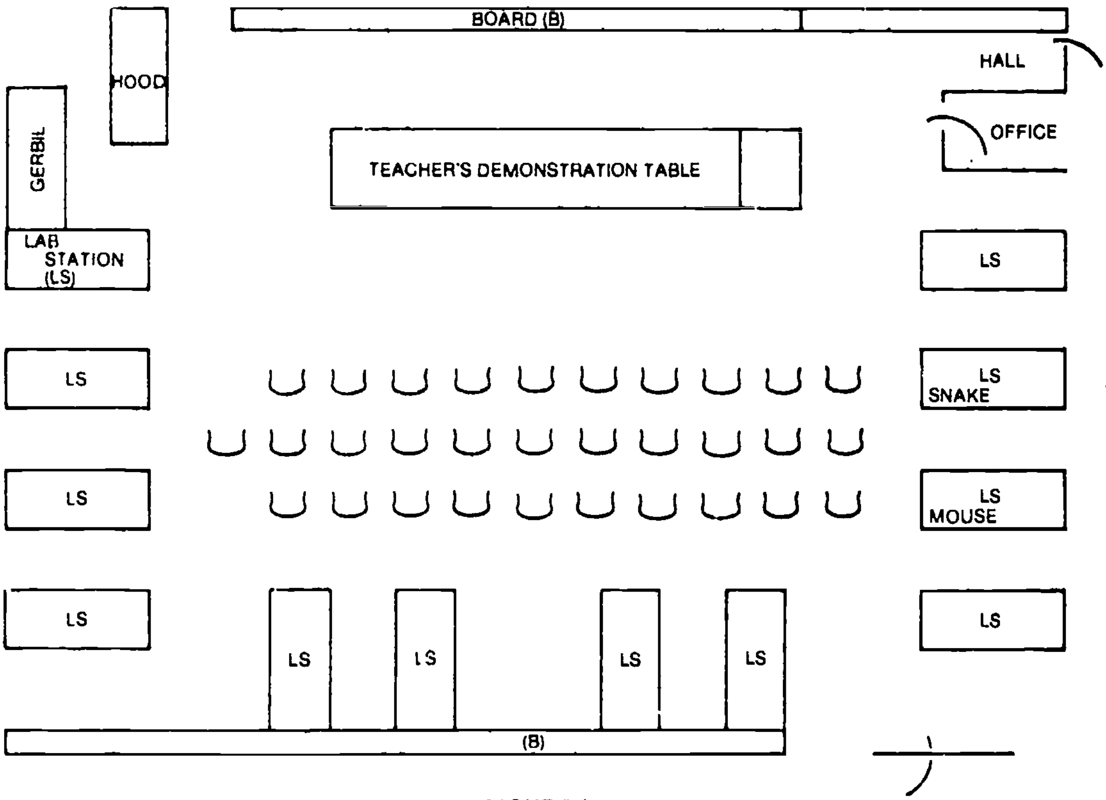


FIGURE 1

As the students entered the classroom, Jenkins stood by the entrance and greeted them, making individual "small talk" as they entered. For example, she recognized the return to school of one male student who had apparently been absent because of illness, telling him that he "looked no worse for wear." As the students moved into the classroom, they interacted socially among themselves--a male and female who were an obvious couple sat in a corner and talked; a female student rushed over to check the gerbil, took the animal out of its cage, and showed it to a female friend; a couple of male students tussled with each other, while a group of about five males and a female gathered around the aquarium (which was an apparent new addition to the classroom) to observe and comment on the fish and plant life. Other socializing occurred around the classroom, and the noise level escalated as the bell rang, signaling the beginning of class.

The teacher left the entrance and blinked the lights three times signaling students to take their seats. They chose their own seating with no intervention from the teacher. The result was a pattern that coincided with the social relationships that existed before the class began. There were a few instances of gender mixing, but the basic pattern was one of same-sex seating. The teacher moved to the front of the class and took care of some preliminary activities, such as noting a student was absent and mentioning two students who would be celebrating birthdays during the week. She led the class in applause for these students.

Jenkins then began an overview in the form of a mini-lecture. Most of the day's work was to be spent in individual projects. She described in general terms how projects were to be written up and noted that she would talk with students on a one-to-one basis as they completed their experiments. She then became much more specific about how to do the experiments, emphasizing the importance of developing an hypothesis, establishing proper controls, taking care of animals and plants, and avoiding certain pitfalls when drawing conclusions. At various times in her lecture, she asked individual students to restate points she had made as a way of giving them added emphasis. For example, she asked a female student to explain why "controls" are important when conducting a scientific experiment. This lecture lasted about fifteen minutes, and students then worked on their experiments for the remainder of the class.

During work time, students worked individually or in groups at various lab stations. Most were on-task, but a few avoided any real work. For example, the "obvious couple" who had moved to their lab station remained noticeably more interested in one another than in their science project.

As the other students moved to their lab stations, two male students came to the front to discuss their computer project with the teacher. They explained how they planned to use graphs to chart the results of their experiment. The teacher talked with them for about three minutes and complimented them on their progress thus far.

Jenkins then moved around the classroom, observing student progress, asking questions, and helping to unsnarl problems. Thus, for example, two female students were encouraged to go deeper into an issue because they were making such rapid progress. Jenkins then went over to a young man who was reading at his desk. She found he was getting background information for his project and complimented him. She subsequently visited each lab station and talked with every student or group. The groups were generally sex-segregated, and most seemed to work effectively.

About three minutes before the period ended, Jenkins told the students that it was time for clean up. This brought on a flurry of last minute activity and socializing as the students put away their work, made last minute conversation, and got ready to leave for their next class.

Jeff Garrett's High School Physics Class

Upon entering Garrett's room (see Figure 2), one is initially struck by two things: it is clearly a busy place, and it is unlike the typical high school classroom in many respects. A double-size classroom specifically designed as a physics lab when the school was built, the front portion contains desks arranged in lecture format, while the back contains tables and stools, sinks, and counter-tops for experiments. Both sides of the room are lined with either bookcases scattered with materials, or cabinets and counter-tops laden with a melange of beakers, test tubes, Bunsen burners, pulleys--the range of equipment necessary for physics experiments.

The room includes a variety of learning settings, which is consistent with Garrett's views on teaching an individualized course (a point discussed in greater detail below). Students sit where they wish within the lecture format of their desks, or work at various tables or counters when doing their experiments and textbook exercises. They work alone, in pairs, or in groups, and in a given class period they often do all three. Some even work in a storeroom connected to the back of the room, although this area tends to be reserved for independent study students working on special, and often large scale, projects.

Throughout a class period there is considerable coming and going of students, and there is an equally constant hum of noise as they do their individual activities and talk to each other and/or their teacher. Garrett is accessible to all students during the class period and seems to be in motion the entire time. After taking roll at the beginning of class, he typically spends the remainder of the period answering questions on a one-to-one or small group basis. He appears to reach every student during each period, but during our observations, he was never observed in lecture-type activity. While he was overheard repeating the same explanation to various students, it was when they were ready for a given point, not when it was convenient for him to request total group attention to a topic.

One particular class period is presented here to capture the nature of Garrett's interactions with students. After taking roll and making one "housekeeping" announcement about an upcoming school event, Garrett spent the next eight minutes helping one female student and then a second one get started on their individual experiments at their lab stations. After a three-minute explanation to the first student, he handed her a pair of pliers and a bottle, "Here, do that." He then moved on to the second female student and spent four minutes explaining how to set up a sensory needle and chalk graph.

Garrett then moved towards the front of the room and was intercepted by a male student who was working on a series of questions from a text chapter on Newton's Third Law. After provinding a brief verbal explanation, Garrett gently shoved the student's right shoulder and then discussed the student's physical resistance as an illustration of an equal and opposite reaction to the initial action. Several minutes later, when he returned from the storeroom where he helped two students set up another experiment on velocity, Garrett was asked the same question about Newton's Third Law by a female student. He provided the same verbal explanation initially and then demonstrated the concept with a roller skate and the formula for computation of energy used in pushing and pulling.

During the next nine minutes, Garrett answered questions from two females, seven males in a row, and then two more female students. He then moved to the back of the room and talked with one of the female students working on her experiment. When she showed him the chalk graph, he said, "Ah, now I understand. Good." He then moved toward the front of the room and stopped at a table to look over one male student's answers and discuss a sentence the student was having difficulty understanding. The second female student who was doing an individual experiment then stopped Garrett and told him about the results. He said, "Something's wrong. This one [answer] is either too high or too low. I'm not sure." The student then explained some of the things she had done, and Garrett indicated what he thought might account for the problem. He then moved to one of the tables where two males were discussing a chapter they were working on. One of the students described a problem he was having in understanding the chapter, and Garrett gave him a clue for approaching it. He remarked further, "When I first tried it, I couldn't figure it out either. Then a student showed me how to do it. This a real gee-whizzer of a problem. You'll really enjoy solving it." Garrett then turned to the next table and discussed the concerns of two students working together. A few minutes later, the student who had been working on the gee-whizzer announced to the whole class, "Hey, Garrett-man, I'm done." He showed his solution to Garrett who said, "Good. That's an interesting diagram you've developed." Garrett then began to move toward the front of the room and the bell rang, signaling the end of the fifty-minute period.

This same class period provides an equally appropriate context to shift perspective and examine student-student interactions. As Garrett began to take role at the beginning of the period, students at the various tables and desks talked quietly in pairs or groups as they got out their materials. For the most part, the students began their work as Garrett proceeded to set up the experiments for the first two young women mentioned earlier. Within eight minutes all students, with two exceptions, were engaged in tasks related to their work.

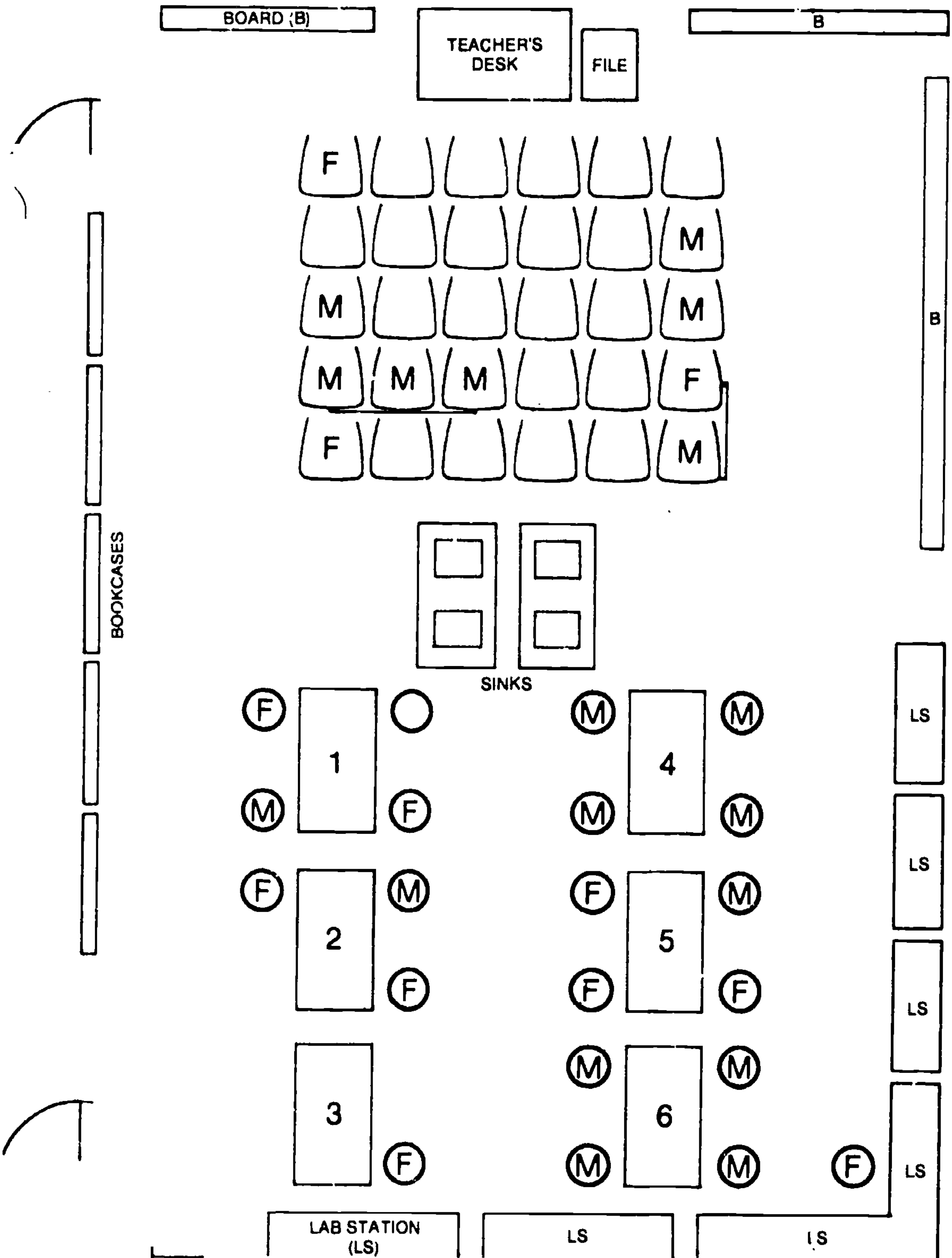
As we looked around at the various tables, students were reading quietly by themselves, writing answers to textbook questions, talking with each other, or working on their experiments. Figure 2 depicts the varied seating arrangements, which may be best characterized as self-selected, cross-sex and same-sex grouping. As a total group, the students were using four different textbooks (designated by color) assigned by level of difficulty within Garrett's individualized program. Each of the five tables seemed to have a mix of orange, white, green, and black books in use.

During this class period, the following student-student interactions occurred:

> Table 4: A male student read a sentence out loud and asked the other three students at the table to help him understand what it was supposed to mean.
> Table 6: One male student asked the others at his table, "Is this how we are to figure it out graphically?" One student shrugged, so he leaned over to one of the girls doing an experiment and asked her the same question. She responded by saying she thought so.
> Table 1: One of the males who had been working in the storeroom re-entered the classroom and started talking with the students at the table. They exchanged a few social pleasantries and one of the students seated started teasing the newcomer about the way he was dressed. The conversation then shifted to a discussion of what the two students were doing in the storeroom, and one student got up to go look at the project.
> Table 5: Three female students and one male were engaged in a social conversation about an upcoming dance and securing rides since the beginning of class. During this conversation, a male student sauntered up and started kidding one of the female students. One of the male students at Table 4 leaned over to one of the female students at Table 5 and asked, "How many chapters have you done?" She replied, "I've done 4 1/2." He responded, "How much do you want for them?" and joined in laughter with the rest of the students at the table.
> At the front of the room, one female and male student who had been working independently started comparing answers and then ultimately moved their chairs so they could work together on a common chapter exercise. Three males who had begun their work seated side-by-side eventually moved their chairs to work as a small group.

If one looks at this class period retrospectively, there appears to be a definite rhythm. For the class as a whole, there was an initial period of readying and socializing, then a period when time on task increased and socializing decreased, and finally, toward the end of class, socializing seemed to increase considerably. During the time on task, there was a great deal of variation among students at the various tables. Those on-task worked on chapter exercises and experiments and, when they needed

FIGURE 2


BOARD (B)
TEACHER'S DESK
FILE
B
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BOOKCASES
SINKS
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LAB STATION (LS)
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LS

help, took the initiative to seek out Garrett. Where students were engaged in more social activities during the time on-task period, there was no direct intervention by Garrett. Instead, he spent the entire period engaged in helping students set up experiments, talking with students about their individual problems, and checking the accomplishments of the students who were on-task.

In each interaction with a student, Garrett's behavior varied only with the student's problem and not with the student's gender or personality. There was no perceptible variation in his eye contact, wait time, or praise and encouragement of students. The only differentiation in opportunities to learn seemed to derive from the students' choice to be on- or off-task. Those who were on-task got his attention as they needed it; those off-task got no direct attention whatsoever.

Garrett's laissez-faire policy toward task commitment and seating might be criticized for allowing low-achieving students to "slip through the net," or for resulting in sex-segregated tables. Yet these outcomes might be more appropriately critiqued within the larger framework of an individualized instructional approach. What is more pertinent to the issues at hand is the virtual absence of differentiated behavior on the basis of gender. The only notable instance in the particular class period profiled above was physically touching a male to illustrate a concept and using a different approach to illustrate the same concept for a female student.

Discussion

The foregoing vignettes suggest that the classroom practices of these two teachers share the following characteristics: Content orientation of teachers, task orientation of students, attention to student problems, teacher praise to students, and student-student interactions. Each of these areas, is discussed in turn below. Following this, a discussion of the findings within the context of the literature about sex-affirmative teaching is presented.

Content Orientation of Teachers

Both Jenkins and Garrett understand the content of their disciplines and believe that their students should as well. As the classroom vignettes suggest, both teachers are enthusiastic about science and convey this enthusiasm to their students in multiple ways. This same enthusiasm was conveyed to the researchers during interviews. For example, Jenkins describes her own approach to teaching in the following way:

> I subscribe to the motto that "Learning Can be Fun!" But fun is not the end product.... I think my own enthusiasm for science is important [for getting students interested in science]. If the kids see that I enjoy teaching and learning, then some of my

> spirit rubs off on them.... I believe what I do is important. I'm committed to my job Some of my friends have suggested I get a job at [a local university] or in industry, but I feel I'm performing a needed service by teaching junior high kids. Besides, I like what I do.

Garrett describes his commitment as stemming from a belief that people need to understand aspects of science, and particularly physics, to function effectively as citizens:

> ...[T]here may be some things I'm not completely aware of that may be useful for [student] success in college and as citizens, [but] there are choices that citizens face that require some kind of science background: the role of nuclear energy, the role of government. The concept of whether or not you want to wear seatbelts relates quite specifically to physics rather than chemistry or biology. Whether a mandatory seatbelt law in this state would be useful. We don't have a specific question along those lines, but the kids do study topics related to that. The concept of heat conservation. Kids study about heat. They've been tinkering around with radios. Everyone uses one. The study of wave motion....

Both teachers have their degrees in the content areas in which they teach, as well as many years of experience teaching general science and physics (Jenkins, 12 years, and Garrett, 14 years).

Further evidence of their knowledge of content comes from the kind of curriculum innovations they have engaged in. Each has developed a curriculum for her/his course that specifies minimum performance objectives. This effort required each to decide which concepts were central to student mastery as well as a range of possible strategies and techniques to accomplish such mastery. Jenkins emphasizes "hands on" activities to involve students in the learning process, arguing that the developmental needs of early adolescents are best met by active learning experiences. Such an emphasis, she feels, also draws on her extensive laboratory experience (prior to teaching, she had been a researcher in microbiology at the local university). For Garrett, individualization is the cornerstone of his new curriculum. His course provides students with a wide range of objectives that respond to varying student abilities and interests.

Finally, as the vignettes show, teacher-student interactions generally occur around content issues: students seeking help in understanding a concept, approval for the start of an experiment or research project, or a critical review of findings. In these interactions both teachers consistently ask students open-ended questions which require them to develop solutions on their own, a finding which again underscores the content orientation of these teachers.

Task Orientation of Students

As the vignettes suggest, most students in both classrooms were busy with tasks to complete. After an initial period of socializing, students began to discuss assigned chapters, conduct experiments, and report findings. Then, as the period drew to a close, socializing began to increase. While a small number of students in Garrett's classes were consistently off-task and quietly socializing, these students never posed any discipline problems for Garrett nor did they interfere with students who were on-task. We believe that the amount of work to be done in both classes, the clear expectations of the teachers regarding work to be accomplished, and the role students play in deciding what level of effort they will put forth all contributed to this emphasis on on-task behavior.

Attention to Students According to Problems with Content

Reflecting their belief that science is important and students need a strong grounding to function effectively as citizens, both teachers demonstrated a commitment to students who wanted to learn. As they moved around their classrooms, students approached them with questions, problems with experiments, or results. As a rule, explanations were given to a single student or small group of students rather than to the whole class (at most Jenkins would devote 15 minutes to whole class instruction). When a student solved a particularly difficult problem or made an instructionally interesting discovery, the teacher might comment only to the student or call it to the attention of the entire class for purposes of further discussion.

Praise for Students

Students in both clases were praised for actual accomplishments and given constructive criticism to help them improve. Such behavior reflected the belief held by both teachers that honesty is important in developing a credible relationship with students. Jenkins put it this way:

> I always try to be honest with the students because they can see through a phony. When I give a student a lower grade than the student expected, I sit down with the student and try honestly to explain why that particular grade was given. I think this approach helps the student both understand and accept the grade.

Student-Student Interaction

The vignettes show that students interact comfortably with one another in both content areas and social interests. While each teacher pursued a laissez-faire seating/grouping policy which resulted in considerable same-sex clustering for experiments and projects, mixed-sex tables did exist, boys and girls were regrouped according to task and information, and results were shared across gender.

Sex Affirmative Teaching?

According to Bossert (1981), research on gender bias in schools suggests that teacher behavior is one of the most critical variables affecting girls' and boys' attitudes, behavior, and achievement. Differential treatment of females and males in terms of teacher feedback, expectations, and teacher-created opportunities to learn tend to result in discriminatory school experiences and limited future opportunities. The vignettes and summary of characteristics common to both classrooms clearly counter such suggestions of differential treatment, yet they fail to conform to our prior expectations, given the characteristics of sex-affirmative teaching practices outlined in the literature. Looking only at what is taught in these classrooms and the patterns of teacher-student and student-student interaction, we see no active, intentional effort to bring into daily instruction content about changing sex roles. Nor do we see either teacher purposefully trying to counter biased expectations. Yet Jenkins is one of the most requested teachers by parents of female students and many of these students return when they are in high school or college to report that they are taking science courses in large part because of the experience of her class. In a similar vein, Garrett, in a high school of 1,600, teaches five physics classes of approximately 30 students each, and 44 percent of these students are female. Something else must be going on. And indeed there is.

As the vignettes suggest, these teachers treat males and females equitably from the perspective of content. The patterns described in the vignettes clearly illustrate the patterns that emerge from multiple observations of these classrooms. Analysis of this larger body of data shows that teacher attention varies according to the student's problem and not whether the student is male or female. No disparities were noted in terms of whether boys or girls had more problems. Rather, over time, ability and interest rather than gender seemed to determine who received more attention from the teacher. As many girls as boys in each class seemed interested in the material; as many girls as boys had problems solving a particular problem, understanding a concept, or completing an experiment. As many girls as boys ranked high or low in terms of grades on the grading scale.

It appears that both teachers pursue an individualized approach to teaching, albeit one that differs from the common perception of individualized objectives and activities as the overriding concern. Both focus on teacher-student interactions from the perspective of creating effective content learning. When an individual student fails to understand a point, each teacher responds in a similar fashion to each student, regardless of gender. What we know of differential teacher treatment of boys and girls is not evident in these classrooms. Instead, attention, help, criticism, and praise is <u>content focused</u> and <u>gender neutral</u>.

Jenkins and Garrett argue that this is the kind of interaction they seek to create--precisely because they are sensitive to the issues of gender discrimination. In terms of their major focus, science content, they see their reponsibility as distributing knowledge equitably among all students, regardless of gender. As Jenkins said:

> I definitely believe in sex equity, but I don't make any special allowance for girls beyond getting them interested in science.... I try to make [the class] an interesting, fun-loving, learning experience for all students

In their emphasis on treating students equitably, each teacher recognizes, however, that stereotypes and the cumulative efforts of past discrimination can detract from an environment in which male and female students feel that interaction with the teacher and with each other can occur on a basis of equality. Thus while no "special allowances" are made for girls in terms of number or type of interactions, each teacher engages in activities that benefit both boys and girls but probably have more salience for girls.

Consider role modeling for example. Jenkins is sensitive to fears boys and girls may have and helps them overcome qualms of various sorts. Thus early in the year, a student, almost always a boy, will bring in a snake or some other creature to show the class. When this happens, Jenkins makes a point of holding it to show any girls or boys who might be uncomfortable doing so that she is not afraid. She then has different students handle it. She believes that this modeling effort is especially relevant for girls but is probably important for some boys as well. She notes that later in the year, when students have a chance to work on independent projects that involve reptiles, insects, or animals, girls will be seen working comfortably with such creatures.

Jenkins believes any role model effect for students is simply a means to help accomplish her end goal of creating an exciting learning experience for all students, regardless of gender. Thus, female (and black) students, she believes, are more likely to do well in her class and to take science classes later in high school if a competent black woman teaches them and treats them the same as boys or whites than if a black woman singles them out for special attention simply because they are female or black.

The approach pays off, given the number of females who return after high school or college to tell Jenkins how their decision to take more science or to enter medical school was in part an outgrowth of their experiences in her class. In addition, as noted earlier, the parents of almost every student in her classes requested her as a teacher.

Garrett, too, takes additional steps to promote an environment conducive to equal treatment of boys and girls in terms of content--steps which derive from his belief in the importance of physics for all students but which may have more salience for girls than boys.

In contrast to seventh-grade science which is required of all students, physics, in Garrett's school, is an elective and is usually taken after other courses which meet the science requirements for high school graduation. This means that recruitment could be a problem, especially given the declining high school recruitment for the past few years. But class enrollments have never been a problem for Garrett, at least since he revised the curriculum a decade ago.

During the 1971-72 school year, Garrett's teaching load consisted of two physics and three electronics classes. His teaching style was quite traditional. As he put it:

> I [taught] physics in a traditional fashion where all the kids listened to lectures and discussions, had labs, had a quiz every Friday--or a test; they all took the same test.

At that time females made up, at most, 25 percent of any physics class.

Garrrett's desire to see more students take physics (ideally all students, so they could function more effectively as citizens) led him in 1971 to participate in a year-long inservice program sponsored by the National Science Foundation at a nearby university. This experience gave him the tools to completely revise his course by individualizing it; seed money awarded competitively by the school district for R & D gave him time to make the changes over the summer. Garrett described the changes in the following way:

> Basically I set up the course in terms of behavioral objectives. . . . What I tried to do was describe what students would be able to do if they read or participated in certain activities . . . so that there would be no surprises [to them] on questions on quizzes. . . . Test and quizzes were an important part of the grade, as in most high schols, but . . . I wanted . . . to describe completely or as much as possible what the kids were expected to know and be able to do. [This developmental process] would also allow me an opportunity to . . . develop objectives that kids who were not real strong in math backgrounds could do and feel successful at--feel that they were accomplishing something in physics.

When he was through, Garrett's individualized course had a wide range of objectives reflecting a range of responses to varying student abilities and interests. Individualizing his course also provided him the chance to eliminate a major barrier to female participation in physics--the trigonometry requirement. He described his decision to eliminate this barrier in the following way:

> Traditionally, at least when I came to this school, the kids [who enrolled in physics] had to be taking Trig and be . . . seniors. . . . It seemed to me that there [were] kids who weren't seniors who could just as well take physics when they're juniors or even some kids when they're sophomores. . . . They possess maybe not

the math background, but they have the math skills . . . that could be successful. The other thing was that . . . I felt that there were things that kids could do and I hated to see kids who were 12th graders not have an opportunity to take physics because of some deficiency in their math background. In designing the course I could appeal to them because there were things maybe they couldn't do [like] the Trig stuff, because they hadn't got that far in math. But for whatever reason it was, there were some things in physics that they could do and learn and they were going to be citizens and so on. So for that I could appeal to them and say, 'Listen, even though you haven't had Trig . . . I'm going to ask you to do what I think you can do with the idea of hopefully getting you [to] feel successful in completing the assignments and objectives.'

Modifying this requirement did not mean that Garrett felt math was unimportant: on the contrary, he felt strongly (and still does) that math is critical, perhaps even more so than physics:

There's a clear message and that is the kids should be taking math and often I tell the kid I'd rather, if somebody came up to me and said, 'Garrett, I only got room for one class and that is either physics or math.' I'd tell them there's got to be a good reason why they shouldn't be taking math. Even though I don't know if it does, it might cost me a student because the math thing is like a skill. I mean they can always pick up physics as a science class in college, but the math thing is that entry level and the kinds of classes that they can take are super difficult to overcome if they have not been exposed all the way through Trig in high school. And to the extent that they've got an opportunity to take calculus, I boost them to take calculus.*

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*While Garrett feels that he would boost males and females equally in terms of math, his major successes have been with females. One in particular who initially said she hated math ultimately enrolled in Honors Trig:

I'd been on her almost the whole year and she says, 'I hate math, I'm not taking it.' And I'd been on her left and right, and I think the found out she could do the things that I was asking her to do and she knew that they were just things that I was asking kids in calculus to do, and she's just breezing through it, man. She came in and she didn't have to show me her schedule 'cause she wasn't taking another science class, and she said, 'Here, I'll show you my schedule. You win! You win!' She'd signed up for Honors Trig, which is a higher level than the college prep Trig.

Garrett's next step after individualizing his course was recruitment. With permission from the principal, he visited other science and math classes to explain his "new" physics course, had his current students help him make up posters and "plaster them all over the school," and rewrote the course description and circulated it widely.

During the 1972-73 school year, Garrett's physics courses increased from two to three; the following year he taught four physics classes; and since 1974-75 he has had five each year. Since 1978-79 enrollments have increased in his classes each year from 110 to 150. Correspondingly, the percentage of female students has grown steadily from 25 percent to 44 percent in ten years. Meanwhile, total school enrollment has declined during the past five years. In addition to his success in increasing enrollments, Garrett also counts among his accomplishments the fact that students score high on the state assessemnt in science and that three recent graduates, one of whom is female, are currently enrolled at MIT.

While Garrett's recruitment efforts have led to an increase in female participation in an area of science where they are traditionally under-represented, the context of recruitment, it should be remembered, is Garrett's desire to see more students, regardless of gender, take physics. As with Jenkins, we see an activity carried out that benefits both boys and girls but has the effect of being more relevant for girls than boys.

Garrett, in fact, claims that he does not do anything special for female students. Yet his bulletin boards seem to contradict this claim if one compares them to a typical advanced science classroom. When asked about his inclination to hang posters depicting women in science, he replied:

> [I do it because] the girls can see that there are successful girls and women. This counselor sent them down to me because he knows I'm interested in pushing girls in science and math. There's a message that I've seen girls look at it, girls especially look at those nice big General Electric posters. The other thing is for boys, I see them seeing that their careers will not be male-dominated [and] that they will be in a situation in the future that they often see in society.

In a sense, Garrett doesn't do anything "special" for his female students; he does what he does for both males and females. The same is true in the area of curriculum review. Garrett is concerned about potential bias in the textbooks he uses. Thus he periodically reviews them, recently replacing one as a result. As with bulletin boards, his concern is for the messages both males and females receive and how they may affect student attitudes toward science.

Upon further probing, Garrett did acknowledge, however, one measure of differentiation:

> The thing that I might do for girls a little more than boys is it seems like I'm getting a lot of advertisements for career seminars for girls, and I make sure I pass them on. Now I may not have announced to the whole class that there's a summer science institute at Tri-State University in Angola, Indiana. But it's a real cheap one, $30.00 is all it costs, and the kids are there for a whole week. All you have to do is provide the transportation, and I had a girl go over there last summer. There are other summer science things and I make sure that those [female students] I think would benefit from them get the brochures.

In addition to these ongoing efforts, Garrett is responsible for orchestrating a formal mechanism for rewarding outstanding female students. For the last few years, the regional chapter of the Society of Women Engineers has solicited nominations of three female seniors in a number of area high schools to receive Merit Certificates for high achievement in science and mathematics. Three years ago one of the couselors sent Garrett the announcement and a note saying, "Jeff, would you like to handle this?" Garrett accepted the task and since that time has selected the nominees in consultation with the other science and math teachers at his high school. But even in these two areas of "special" treatment for females we see the underlying theme of commitment to content, since those who get the summer school announcement or receive the awards are the ones who have achieved in science.

Conclusion

It is now appropriate to summarize how the practices of the teachers we studied compare with those generally assumed to be sex-affirmative. While both teachers share the end goal of increased levels of female participation in science elaoorated by Bornstein (1981), they pursue strategies that differ in significant aspects from those recommended in previous literature as sex-affirmative. In each case their basic focus is on subject matter content, not on gender issues, per se. Within the context of a task-oriented class, they strive to treat males and females equitably as they help them with problems and praise them for accomplishments. Within the context of trying to make science exciting or physics appealing to a wide range of students, each teacher pursues strategies that have relevance for both sexes, but given the cumulative effects of past discrimination on the attitudes young women hold towards science, probably have greater salience for them.

The practices described earlier as sex-affirmative do not have content as their principal focus, but rather emphasize bringing into daily instruction material about changing sex roles or purposefully countering biased expectations. Such a focus is different from an equitable distribution of knowledge, which these teachers provide. Instead of gender equity as an add-on, something done in addition to teaching subject matter content, it becomes an integral part of the subject matter content that is taught and the strategies for teaching that content. Moreover, strategies that have the effect of assisting girls more than boys are not adopted from a perspective of assisting only girls or purposefully remediating past discrimination, but rather from a belief that such practices will contribute to the academic goals each teacher has set. In short, good teaching and concern for equity are inseparably linked. Academic excellence and equity go hand-in-hand.

Jenkins and Garrett recognize that to create an environment in their classrooms where equitable treatment in terms of content can occur, they may have to take extra steps to provide special encouragement or support for females. For instance, both teachers make a concerted effort to remove barriers to success for all students in general, but for females in particular. These steps, however, are always oriented around content and achievement and are directed at both male and female students. Garrett's recruitment efforts are a case in point. The current course description reads as follows:

> Girls! Boys! Take physics, you'll feel better! This course is designed to calm your fears and misgivings about an 'advanced' science. You'll plan your work with your teacher on individual learning contracts by choosing learning objectives, experiments, and activities picked from a long list of suggestions for each chapter. Filmloops, supplemental readers and textbooks, programmed learning booklets and filmstrips allow you to adapt the course to your own abilities and interests. First year Algebra is a prerequisite, but you don't have to be a math whiz to do well in this class. But if you are planning to take lots of math, wait until you are taking Trig before you take physics. Come as you are; there's always room for more.

What is clear from such an invitation is that Garrett moves beyond symbolic gestures attacking biased sex role expectations to a systematic attack on the barriers to success themselves.

In summation, recommendations for sex-affirmative classroom teaching practices would benefit from studies of teachers who enjoy reputations for promoting equity in their classrooms and who in their teaching employ suggestions such as those of Button and Brown (1980), Cohen and Cohen (1980), and Kahle (1983). To date, prescriptions for what sex-affirmative teaching ought to look like represent logical deductions from problems discovered through empirical studies of discriminatory classroom practice. By purposefully selecting for study teachers who promote equity in their classrooms, such recommendations, we believe, will be more firmly grounded and, from what we found in these two case studies, will better demonstrate ways to promote the goals of increasing female participation in science courses and ultimately science careers.

REFERENCES

Blumenfeld, P., V. Hamilton, and S. Bossert. "Teacher Talk and Student Thought: Socialization into the Student Role." Paper presented at the Learning Research and Development Center Conference on Student Motivation, Pittsburgh, PA. 1979.

Bornstein, R. Title IX Compliance and Sex Equity: Difinitions, Distinctions, Costs, and Benefits. Washington, D.C.: National Institute of Education. 1981. (ERIC Document Reproductin Service No. ED 202 948).

Bossert, S. T. "Understanding Sex Differences in Children's Classroom Experiences." The Elementary School Journal, 81(5): 255-266, 1981.

Button, L. and R. A. Brown. "Women in Science." School Science and Mathematics, 3: 206-210, 1980.

Cohen, R. F. and M. R. Cohen. "Opening New Doors: Taking Sex-Role Stereotying Out of Science and Mathematics." School Science and Mathematics, 7: 566-572, 1980.

Dweck, S., W. Davidson, S. Nelson, and B. Enna. Sex Differences in Learned Helplessness: II. The Contingencies of Evaluative Feedback in the Classroom, and III. An Experimental Analysis." Developmental Psychology, 14: 268-276, 1978.

Finn, J. D. "Sex Differences in Educational Outcomes: A Cross-National Study." Sex Roles, 6: 9-26, 1980.

Fox, L. H. and S. A. Denham. "Value and Career Interest of Mathematically and Scientifically Inclined Youth." In J. C. Stanley and L. G. Fox Eds.), Mathematical Talent: Discovery, Description, and Development. Baltimore, MD: The Johns Hopkins University Press, 1974.

Frazier, N. and M. Sadken. Sexism in School and Society. New York: Harper and Row, 1973.

Hansen, R. and J. Neujahr. "Career Development of Males and Females Gifted in Science." Journal of Educational Research, 68: 43-45, 1974.

Hardin, J. and C. Dede. "Discrimination Against Women in Science Education." Science Teacher, 12: 255-261, 1975.

Kahle, J. P. The Disadvantaged Majority: Science Education for Women. (Reprint of AETS Outstanding Paper for 1983). Burlington, NC: Carolina Biological Supply Company, 1983.

Kelly, A. As cited in Kistiakowsky, 1980.

Kistiakowsky, V. "Women in Physics: Unnecessary, Injurious and Out of Place?" Physics Today, 32-40, 1980.

Koelsche, C. L. and S. L. Newberry. "A Study of the Relationship Between Certain Variables and the Science Interests of Children." Journal of Research in Science Teaching, 8, 237-241, 1971.

Maccoby, E.E. and C. N. Jacklin. The Psychology of Sex Differences. Stanford, CA: Stanford University Press, 1974.

National Assessment of Educational Progress. "Males Still Better in Science." Science News, p. 246, 1975, October.

National Assessment of Educational Progress. Science Achievement in the Schools (Science Report No. 08-S-01). Denver, CO: Educational Commission of the States, 1978.

Office for Sex Equity. The Final Report of the Sex Equity Needs Assessment: Brighton Area Schools. Lansing, MI: Michigan Department of Education, 1981.

Parsons, J. "Sex Differences in Math Achievement and Course Enrollment." Paper presented at the annual meeting of the American Educational Research Association, New York, 1982, March.

Sadker, M. and D. Sadker. Sex Equity Handbook for Schools. New York: Longman, 1982.

Vetter, B. M. "Women Scientists and Engineers: Trends in Participation." Science, 214, (18): 1313-1321, 1981.

Vockell, E. L., and S. Lubonc. "Sex Role Stereotyping by High School Females in Science." Journal of Research in Science Teaching, 18: 209-219, 1981.

Women on Words and Images. Dick and Jane as Victims: Sex Stereotyping in Children's Readers. Princeton, NJ: Women on Words and Images, 1975.

INTRODUCTION TO CHAPTER SIX

In this chapter Thomas Russell describes how teachers, knowingly or not, must deal with philosophical issues in their classrooms. In particular, Dr. Russell looks at the issue of authority in science teaching: How can we convince students that the logic of an argument should count for more in science than the identity of the person presenting it?

Dr. Russell demonstrates one approach to this question with a philosophical analysis of a science classroom dialogue. His analysis suggests that, although modeling rational arguments during science classes is difficult, it could be done more effectively by many teachers. The chapter closes with a discussion of how issues of authority and rationality arise in the relationship between teachers and teacher educators as well as between science teachers and their students.

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PHILOSOPHY AS A GUIDE TO REFLECTION ON CLASSROOM EVENTS

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INTRODUCTION

Philosophy is hardly an obvious basis from which to make observations in science classrooms. Philosophy has a reputation for being abstract, intellectual, and impractical, and these are certainly not features one would expect to attract the attention and interest of science teachers in today's educational circumstances. But those who are at all familiar with philosophy know that it strives for clear and careful thinking on fundamental, often complex topics. Therein lie its strengths. The argument that I develop here is intended to explain and illustrate how these strengths of philosophy may be used to the advantage of those who seek to improve or to understand more fully what happens in science classrooms. This approach to observation is qualitative, not quantitative, and this feature is explored at some length as a basis for more general comments about teacher education and the process by which teachers reflect on their teaching activities.

In keeping with familiar logical structure, I begin by explaining the conceptual underpinnings of this particular approach to classroom observation. Those who prefer to see examples first are invited to begin with the second section of the argument, in which I show how philosophical writings about the nature of authority in teaching and about the form of logical arguments in general can be developed into a scheme for analyzing science classroom dialogue. The scheme permits conclusions about the image of scientific authority that may be suggested to students by the argument a teacher constructs, typically by a sequence of questions leading to or using a scientific law. In my final section, I move beyond the approach and its illustration to broader issues concerning teachers, staff developers, researchers, and research reports as they come together in the processes of preservice and inservice teacher education.

ASSUMPTIONS OF THE APPROACH TO CLASSROOM OBSERVATION

My goal for this first major section is to spell out significant elements of the backing that legitimates this approach to classroom observation and research. The first attempt to describe the use of philosophical analysis to examine educational practice was published in 1975 (Roberts and Russell, 1975). By that date, Roberts* had attracted a significant number of graduate students at the M.A. and Ph.D. level, and a clear pattern was emerging in the studies those students were completing. In sharp contrast

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*Douglas Roberts was then at the Ontario Institute for Studies in Education; he is presently Head of Curriculum and Instruction at the University of Calgary.

to training in statistical procedures and construction of instruments for quantifying measures of experimental and control groups, Roberts trained students in sound conceptual analysis of issues they regarded as significant in science education. Philosophy of science and philosophy of education proved to be important resources. At the time, the familiar goal of research was finding a statistically significant difference in favor of a new curriculum package or a new teaching strategy. Under Roberts' direction, the goal became the development of an analytical scheme (or "clue structure") that would permit significant philosophical distinctions to be used to look at educational practices, such as classroom events or textbook statements. The goal of research became the demonstration that an analytical scheme could in fact be used successfully to examine practices, and the demonstration provided feedback for refinements in the scheme itself.

The result, then, is not a claim that teaching should be conducted with new materials or a new strategy but that teaching may be examined for particular issues using the framework that has been developed. The study discussed in the following section demonstrates a framework for assessing the attitude toward authority suggested by the argument a teacher constructs during teaching. The distinction between advocating adoption of an innovation and providing a sound way to examine practice has important implications for how researchers speak to and listen to teachers, and these are explored in the final section of the argument.

An mportant element in Roberts' work with graduate students was training in the procedures of clinical supervision as it developed at Harvard Un ersity in the 1960s. Goldhammer (1969) and Cogan (1973) are major references for this unique approach to the supervision of teachers. One central feature is the supervisor's role in the collection of data to be analyzed collaboratively by the teacher and the supervisor. Many types of data are possible, including frequency counts of particular events using lists or seating plans, but the most powerful type of data proved to be the verbatim transcription of classroom speech by teacher and students. Teachers rarely have access to such data, and transcripts alone can be a powerful stimulus to reflection with a view to improvement. The analysis of transcriptions to identify patterns of teacher and student behavior, separately and in interaction, adds further strength to this strategy for supervision (see Kilbourn, 1982). The power of the verbatim transcription is also the greatest liability of clinical supervision, for the production and analysis of such data is very time consuming. Training in clinical supervision served to demonstrate the potential value of verbatim transcriptions as data that might be analyzed using frameworks grounded in philosophical analysis.

Reports of research using philosophical analysis to examine practice were presented at the 1977 and 1978 annual meetings of the National Association for Research in Science Teaching. Many of those papers were revised for inclusion in a book that represents the single best source of material illustrating the use of philosophical analysis to examine science education issues and practices. Munby's introduction to Seeing Curriculum in a New

Light: Essays from Science Education (Munby, Orpwood, and Russell, 1980) is a particularly clear and concise summary of the idea of "using philosophy as a lens" (p. 5) to develop new ways of seeing educational events.

At the same time that the individuals trained by Roberts were developing career paths in educational research and gaining confidence in their shared approach to research, an important change was occurring in the way the educational community looked at its research enterprise. As case studies became more numerous and as ethnographic techniques were discussed in the literature of educational research, annual meetings of the American Educational Research Association began to give attention to the contrast between quantitative and qualitative research and to the relationship of each to the overall enterprise of educational research. At the 1981 annual meeting of the National Association for Research in Science Teaching, Roberts gave an invited address on "The Place of Qualitative Research in Science Education." This paper (Roberts, 1982a) uses philosophical analysis concerning world hypotheses (Pepper, 1942) to conceptualize significant differences between the two broad categories of quantitative and qualitative reserch. The paper simultaneously illustrates the use of philosophical analysis and draws valuable conclusions about the nature of educational research and the appraisal of its reports. Roberts locates the use of philosophical analysis within qualitative research and demonstrates its strength in examining the context of educational events. This contrasts with the strength of quantitative research in identifying correlations among educational events. Roberts argues that knowledge in science education must be seen broadly enough to include both qualitative and quantitative approaches (Roberts, 1982a, p. 291).

The term "context" is particularly significant in describing this qualitative approach to classroom observation. Quantitative research has the potential to arrive at generalizations valid across populations. Data are presented in tables that are very concise, telling us nothing about the individuals who made up the samples. Qualitative research stresses individual contexts, and the presentation of data usually requires considerable space. Rather than seeking generalizations, qualitative research seeks to permit readers to join in the interpretation of data and the evaluation of hypotheses about what is happening in particular situations. Often it is much easier for the reader to identify personally with elements of a qualitative research report, because the contextual clues permit one to judge how similar the setting is to one's own.

Munby and Russell (1983) recently developed the significance of context in a statement about "A Common Curriculum for the Natural Sciences." Typically, the search for a common curriculum in a discipline seeks to identify that core of subject matter that is essential for all students to learn. We rejected that strategy in favor of the position that all students should be introduced to the unique power that accrues to science by its specialized use of language (giving very precise and limited definitions to its concepts; see Munby, 1982). Beyond that, we argued that contextual characteristics of the individual science teacher and of groups of students should determine the specific emphasis (see Roberts, 1982b) given to the teaching of science content.

In summary, then, the use of philosophical analysis to examine science classroom practices including classroom dialogue is a recent development within the category of qualitative research. The focus of this particular research strategy is the development of an analytical framework that permits the interested teacher or researcher to examine practices from a perspective of a particular set of philosophical distinctions. The result is not a definitive recommendation for change, such as might emerge from a quantitative approach. Rather, the resulting qualitative analysis reveals contextual features of the classroom setting in the light of the chosen perspective. This may suggest possible changes, while also indicating the trade-offs that changes might require. In the following section, a specific example of the use of philosophical analysis is presented, as an illustration of the research approach. In the final section, I return to the preceding issues to extend the analysis of the place of research in teacher education.

AUTHORITY AND ARGUMENT IN SCIENCE TEACHING

This portion of the discussion develops a philosophical perspective on the nature of authority in teaching, with particular reference to the relationship of a teacher's authority to the discipline that underlies the subject matter presented. Then an analytical scheme is developed, drawing on additional philosophical analysis of the nature of argument, to permit assessment to be made of the attitude toward authority suggested in classroom dialogue. Finally, one instance of dialogue is presented in transcription form and analyzed using the scheme. Additional comments consider the potential value of such a scheme within the overall enterprise of a science teacher's work.

Rational and Traditional Attitudes Toward Authority

Peters (1967) draws a fundamental distinction between a rational attitude toward authority and a traditional attitude. He compares the distinction to the difference between "having good reasons" and "taking someone else's word" (pp. 13-24). The relevance to Western education is obvious; for we have come to regard the development of reasoning as a central purpose of schooling. Green (1971) argues that "instruction" strives to establish beliefs on the basis of reasons and evidence, while "indoctrination" is concerned only with the content of beliefs transmitted, not with the basis of beliefs. In Peters' view, the teacher's manner is crucial. He sees the authority of the teacher as having two distinct senses: a teacher is <u>an</u> authority in some aspect of our culture and <u>in</u> authority to accomplish the task of teaching (Peters, 1966: p. 240). A teacher is an authority by virtue of certain knowledge, and in authority by virtue of appointment to the position of teacher.

Most concisely, then, a teacher is an authority in authority. A teacher's authority of knowledge appears to be fundamental, the basis upon which an individual is appointed to the position of teacher. A teacher is an authority by virtue of knowledge that enables the teacher to give reasons and evidence, in short to give rational authority for arguments presented to students.

The distinction between traditional and rational authority provides a basis for classroom observation when we note that a teacher's authority of position makes it possible to present knowledge claims without reasons, an event that would suggest a traditional attitude toward authority rather than a rational one. By virtue of the authority of position conferred to enable a teacher to maintain the classroom learning setting, a teacher acquires the potential to present knowledge claims on either of two types of authority--rational or traditional. This is not to imply that a teacher would intentionally present claims on authority of position, only to recognize the possiblity of doing so inadvertently. A teacher has many elements to attend to during instruction, and the authority for an argument is neither familiar nor prominent in a list that includes discipline, pace, student attention, group dynamics, room conditions, distribution of opportunities to speak, and so on.

Among their many duties, science teachers are often charged to develop positive attitudes toward science among their students. Research (most notably, Mead and Metraux, 1957) has shown that actual attitudes toward science may contain positive, negative. and neutral elements. There are many sources of information about and images of science, not the least of which are television, movies, and cartoons (Basalla, 1976). In the science classroom, there are several reasons for teaching in a manner that suggests a rational attitude toward authority. Scientists view their discipline as rational; our concept of education aspires to rationality; and despite competing images from other influences, the science teacher may wish to foster positive attitudes toward science. Here, then, are reasons why it may be informative to science teachers to have a scheme for analyzing the attitude toward authority suggested by their teaching.

The Pattern of Rational Arguments

We need more detailed criteria for examing classroom dialogue if we are to recognize a distinction as broad as that between traditional and rational authority, between authority of position and authority of knowledge. Toulmin provides this in The Uses of Argument (1958), in which he argues that there is a single pattern common to all types of rational argument. Toulmin's argument pattern specifies six elements and the relationships among them. Four elements are of central importance: Data, Warrant, Conclusion, and Backing. (Capitalization indicates that a term is being used in the sense specified by Toulmin.) A Warrant is the rule that permits one to move from Data to Conclusion; the laws of science are Warrants. Backing expresses the conditions and assumptions that support a Warrant, the "facts" that give authority to the Warrant. Toulmin explains that Backing often remains implicit until an argument is challenged. He also notes that different disciplines use different kinds of Backing for their Warrants (pp. 103-106). Backing is particularly significant when alternative explanations (Warrants) are being considered. Famous examples of new Backing being developed in science would include Darwin's analysis of the origin of biological species and Einstein's theories of relativity that reinterpreted Newton's Laws.

The remaining two elements in Toulmin's pattern of arguments are Qualifier and conditions of Rebuttal. A Qualifier indicated the extent to which the Data fully support the Conclusion; conditions of Rebuttal are special circumstances in which a Warrant may not apply (pp. 101-103). These two elements play minor roles in the pattern, and frequently are not required for the analysis of science classroom dialogue. The pattern itself is shown in Figure 1. (The same argument pattern is used in Toulmin, Reike, and Janik, 1979; the names of some elements have been changed and the pattern has been rearranged without changing the relationships.)

```
DATA-----------------------------------So,   QUALIFIER,  CONCLUSION
                 |                                |
                 |                                |
                 |                              Unless
                 |                          CONDITIONS OF
               Since                           REBUTTAL
              WARRANT
                 |
                 |
           On account of
              BACKING
```

Figure 1. Toulmin's argument pattern (Toulmin, 1958, p. 104).

A word of caution is required concerning the special meanings of the terms used by Toulmin. In everyday science classroom setting, "data" and "conclusion" refer, respectively, to what is known at the outset and to the final result of a laboratory exercise. Often, a "conclusion" to a laboratory exercise or data analysis is a law of science, but this is a Warrant in Toulmin's terms. While in everyday language, the term "conclusion" is used to refer to the final step in a sequence of reasoning, Toulmin's use of the term specifies logical rather than sequential relationships to other parts of the argument. The episode that follows provides an example. The teacher seeks to develop a law of science, a process Toulmin terms "Warrant-establishing." In such instances, Conclusions must be available at the outset for use in the argument, and the final step produces a Warrant. Once a Warrant has been established, it can appear in "Warrant-using" arguments to make predictions (which would be Conclusions in Toulmin's scheme).

Toulmin's argument pattern gives sufficient detail to the concept of a rational argument to suggest criteria for recognizing when a teacher establishes a conclusion or a Warrant on the basis of rational authority. I make the assumption that suggesting to students a rational attitude toward authority requires providing all necessary elements of an argument, properly related to each other. This seems plausible because students would have no basis for accepting an incomplete argument, were it not for a teacher's alternate source of authority, that of position. Authority of position can bridge gaps in rational arguments, but a teacher then risks suggesting a traditional attitude toward authority. The following analytical scheme is used.

1. Does the classroom dialogue include Data, Warrant, Conclusion, and Backing?

2. Are the elements of the argument properly related to each other?

Affirmative answers to these two questions warrant the conclusion that a rational attitude toward authority is suggested. A negative answer to either or both questions produces a judgment that a traditional attitude toward authority is suggested to students.

Analysis of One Episode of a Science Lesson

In an earlier report (Russell, 1983), narrower in scope but more detailed than this discussion, I demonstrated the application of the analytical scheme to excerpts from three science lessons. Examples from three lessons permitted me to indicate more than one way in which a strategy of questioning may inadvertently lead to the suggestion of a traditional attitude toward authority. Here analysis of part of one science lesson is sufficient to demonstrate the use of the analytical scheme and to illustrate the meaning of the several elements in Toulmin's argument pattern.

The following episode is part of a Grade 9 general science lesson in which the teacher uses data collected earlier in the period as the basis for an explanation of Snell's Law for the refraction of light. The lesson was tape recorded in a secondary school in Ontario; 12 girls and 9 boys were present. The argument is concerned to establish a scientific law (Warrant), not to use a Warrant to predict an event. As such, we would expect Backing to be included in the argument. In fact, Backing is the central issue in the following segment, but the teacher does not attend to it explicitly and the absence of attention to Backing is the basis for concluding that a traditional attitude toward authority is suggested by the the argument.

For those not familiar with the refraction of light when it passes from one medium (such as air) to another (such as glass or water), the diagram in Figure 2 may be helpful. Typically, a semicircular block of glass is used, so that light is bent when it enters the block but not when it exits. Most science departments have an "optical disk" that holds the glass block and permits easy reading of the angles shown in Figure 2, which illustrates three of the seven Data-Conclusion pairs from the following episode. Angles of incidence (for incoming rays a, b, and c) are measured from a line (dotted) perpendicular to the surface of the glass block.

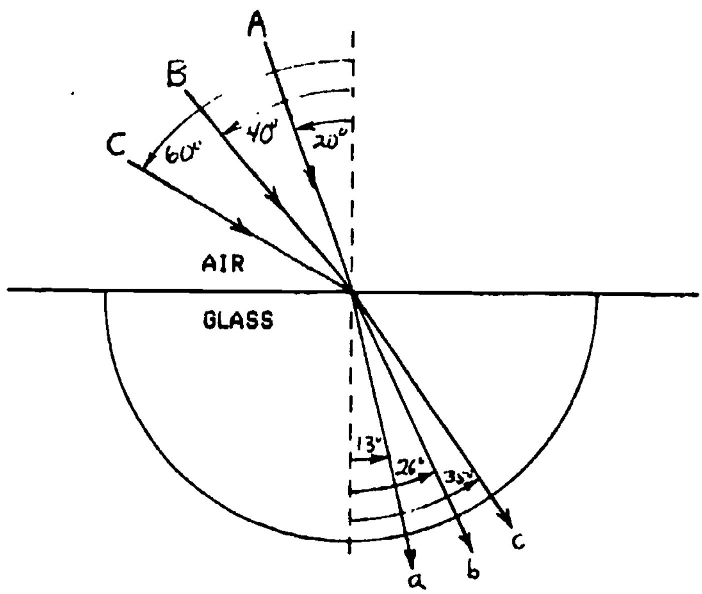

Figure 2. Refraction of light by a semicircular glass block

The episode is divided into three segments for purposes of analysis. In each of the first two, the teacher invites students to propose Warrants linking Data to Conclusions. The students do so quite readily, but both segments end with an indication by the teacher that the proposed Warrant is inadequate. In the final segment, the teacher begins a lengthy exposition of how Snell's Law permits one to predict angles of refraction from angles of incidence. In the right column, beside the left-column transcription, brief statements indicate what each speaker is doing in terms of elements of an argument.

SEGMENT 1: First request for a Warrant

Teacher: O.K., here we have our results on the side board. (The table reads:)

10	7
20	13
30	19
40	26
50	31
60	35
70	40

Left column lists Data (Angles of Incidence)
Right column lists Conclusions (Angles of Refraction)
(The goal is to find a Warrant fitting all seven pairs.)

Teacher: Can anyone see a relationship between the angle of incidence and the angle of refraction from those results? Just look at that for a couple of minutes. (Pause. Teacher writes "Snell's Law.") Susan.

Teacher requests a Warrant.

Susan: Um, when the angle of incidence increases by ten, most of the angles of refraction increase by six.

Student states a Warrant, with a Qualifier.

Teacher: That's interesting. As the angle of incidence increases by ten, the angle of refraction increases by six. Let's see: seven from thirteen is six; thirteen from nineteen is six; there's seven, there's five, there's five . . . there's four.

Teacher restates the Warrant, with Qualifier, and "tests" the Warrant.

Susan: Well, the average is six.

Student revises the Warrant.

Teacher: Oh, well, averages aren't good enough here. (Some laughter) Rick.

Teacher announces a reason why the revised Warrant is inadequate.

SEGMENT 2: Second request for a Warrant

Rick: The, er, like first of all when you increase it by ten, er, there's an increase of . . . there's a . . . first of all seven, then it goes down to six, then it goes down to five, and then it goes down to four.

Student attempts to state a Warrant.

Teacher: So what?	
Rick: If you take the difference, like, er, from six to seven you've got a difference like ten . . . like you've got of difference between thirty-six and forty. And between the thirty-one and the thirty-six, we have to have a fifty and sixty increase by ten, and then you have five. And then at twenty-six and thirty-six, and that's five. And then you go six . . . like (laughter).	Student continues to try to state Warrant.
Teacher: You're just telling me the results up here. What, what . . .	Teacher seems to say student has not provided a Warrant.
Rick: Yeah, well, er, you said, um see this five thing, when the angle of incidence increases by ten, the angle of refraction is increased by one.	Student tries again to state a Warrant.
Teacher: It is?	
Rick: Like, er, when you subtract, the difference increases by one.	Student states a Warrant.
Teacher: You mean it decreases by one.	Teacher corrects Warrant.
Rick: Decreases . . . yeah, decreases.	Student accepts change.
Teacher: All right. yes, it is decreasing by one. Can we make a prediction from those results? Can we predict what the angle of refraction will be for eighty degrees? Bill.	Teacher asks if Warrant can be used to predict an unknown Conclusion.
Bill: Forty-three degrees?	Student states a Conclusion (prediction).
Teacher: How did you get that?	Teacher seeks account of how Warrant was used.
Bill: Er, just a guess (laughter).	Student claims that he guessed.

Teacher: Er, what was your guess based on?	Teacher again asks what Warrant was used.
Bill: Er, it's going down one. Sometimes it stays the same, other times it goes down one. So, it'll be three for eighty degrees.	Student states Warrant, Qualifier, and Conclusion.
Teacher: So what made you . . . what made you think it was going to go down one this time?	Teacher asks how Qualifer is used.
Bill: Oh.	
Teacher: So, in other words, you don't know.	Teacher "discredits" argument.
Bill: No.	

SEGMENT 3: Presentation of Snell's Law (Warrant) by the teacher

Teacher: Well a person by the name of Snell came along and he looked at these angles, and he came up with a law, which we now call "Snell's Law." And the way it works . . . well, let's first draw a diagram on the board, and you'll see how it works.	Teacher presents Snell's Law, in an extended explanation of how ray diagrams are drawn. No comparison is made to students' Warrants.

Discussion of the Analysis

In an argument to establish a Warrant such as Snell's Law, one would expect the Backing to be made explicit; in subsequent uses of the Warrant, the Backing would be taken for granted. In Segments 1 and 2, the students react just as most people do to the two columns of figures, by focusing on the arithmetic differences. The teacher's questions may even be read as suggesting that the students should be able to find a Warrant by inspecting the Datum-Conclusion pairs. In Segment 3, which is not present in its entirety because of its considerable length, the teacher moves directly into a diagram. This is, of course, a very different way of "seeing" the problem, using a geometric approach based on the view that light travels in straight lines. I speculate that in this instance a brief explanation by the teacher of the difference between an arithmetic Backing and a geometric one would have made simultaneously a rational argument complete and shown the students why Snell was able, centuries ago, to see a Warrant where they could not. That the teacher did not do so is not surprising. The task of presenting Snell's Law clearly to all students in a limited amount of time is formidable indeed. But the absence of discussion of Backing leads, through the analytical scheme, to the judgment that this episode suggests a traditional attitude toward authority. Part of the argument--an important part--rests on the teacher's authority of position, and the teacher appears to assert the superiority of Snell's Warrant.

This conclusion is reached without considering the way the teacher ends Segments 1 and 2. In both instances, first with Susan and then with Bill, the teacher appears to speak somewhat arbitrarily. The teacher does not take the time to show that an arithmetic analysis works quite well, just as well as Snell's Law, through the first four pairs (10-7, 20-13, 30-19, 40-26). The ratios of these pairs are virtually as accurate as Snell's Law, which calculates ratios of the sines of the angles. (The sine of an angle is a trigonometric function available on any "scientific" calculator.) The average increase is actually 6.5 degrees for each 10 degree increase in the angle of incidence, through 40 degrees. But direct ratios and arithmetic differences fail rapidly beyond an incident angle of 50 degrees. For example, at an incident angle of 70 degrees, the 6.5 rule would predict 45.5 degrees but the observed angle of refraction is only 40 degrees. In fact, at 90 degrees the refracted angle is only 42 degrees, the highest possible value for an air-to-glass situation. Snell's Law predicts all these values very precisely, while the arithmetic analysis is accurate only for small angles of incidence.

I hope that my efforts to explicate this approach to classroom observation have not been read as suggesting that rationality of a teacher's argument should be a major criterion of good science teaching, though for some teachers it might be. The fun, the drama, the potential excitement of demonstrations and experiments are important, too. Teaching has many dimensions, and that may be one reason why good teaching is such a challenge and why all teaching is so easily criticized by those who would be critical. Each teacher must decide which dimensions take priority, personally and in light of students' backgrounds, abilities, and goals. The analytical scheme presented here may suggest to science teachers a cluster of issues not previously considered. Some teachers, particularly those concerned about student attitudes toward school and toward science, may find the issue of authority for arguments important enough to apply to their own classrooms.

To return to a previous issue, this is clearly a qualitative approach to observations in science classrooms. To judge the quality of the authority for a teacher's argument, one must work directly with the transcribed dialogue, apply the categories, and form a judgment using the analytical scheme as a guide. The analyzed transcription is informative in its own right. Science teachers may identify strongly with some of the moves made by teacher and students in the episode presented above. Once a judgment has been formed, it is then possible to return to the transcription to ask where and how changes might have been made and to speculate about the consequences of any changes.

In this final section* of my argument, I explore the assumptions about teacher education and the improvements of teaching that are consistent with the use of philosophical analysis as a basis for classroom observation. As stated previously, this approach does not result in prescriptions for changes in teaching practice. Teachers, individually or in groups, are invited to select a scheme that is of interest and to use the scheme as a new way of looking at teaching. Working alone or in groups, with or without the assistance of an observer familiar with the scheme, teachers can consider the results and explore implications for their own teaching. The position that arguments presented to teachers should suggest a rational attitude toward authority is consistent with this view of teacher education. It is a premise of this approach to observation that a teacher is capable of and interested in reflecting on his or her own teaching in some systematic fashion, and that there is value in a teacher's doing so. This is not to suggest that teachers have a great deal of time for doing so; supportive features in the local school setting are essential.

There is, however, a contrasting set of assumptions about teacher education. I associate the assumptions with the decades of quantitative research in education with the tradition of evaluating teachers in supervisory visits, and with the view that scores on standardized tests are the most important criteria for evaluating what teachers and students do in schools. These assumptions focus on the idea of controlling teachers' behavior. Our culture has a long tradition of assuming that researchers give directives to practitioners, through their development of theory and through their research findings. This may be partially correct as an account of what occurs in fields such as medicine and agriculture, but in education we have a long history of tension between teachers on the one hand and administrators and researchers on the other. There is little evidence to support the positions that telling teachers how to change their teaching--either by giving them new materials or by recommending new practices--consistently rsults in lasting changes of the types intended.

The view that quantitative research findings should be passed on to teachers for implementation has been given support by a large body of recent quantitative research that has yielded significant correlations between certain teaching behaviors and management practices and the very attractive goal of higher student achievement scores. (Good, 1979, provides a particularly clear summary.) Moving beyond teacher behaviors to the analysis of student behaviors, the Beginning Teacher Evaluation Study (B.T.E.S.), conducted in California between 1972 and 1978, generated a construct termed "Academic Learning Time" (or ALT) that correlated positively with the reading and mathematics achievement scores of students in

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*Jane Bowyer of Mills College, Oakland, CA, provided valuable comments on this portion of the argument.

in Grades 2 and 5. (See Denham and Lieberman, 1980.) In 1980, the National Institute of Education funded four school districts within the U.S. "to research and document their findings," as they attempt to develop "a cost-effective instructional management system focusing on Academic Learning Time. Student engaged rate, success rate, and opportunity to learn are the basic components of this program."* The focus is on developing "strategies for implementing Academic Learning Time Concepts," and the research is scheduled for completion late in 1985.

The names of Joyce and Showers (1981) are associated with a staff development strategy of "coaching," which includes the direct assistance of a consultant who observes teachers' attempts to use new strategies previously explained and demonstrated in a training session. Coaching is an important ingredient in the NIE-supported demonstration project located in Vacaville in Napa County, California, and Robbins and Franco** report that teachers are enthusiastic about the "coaching" they receive, at the rate of two follow-up visits for every formal training session. What this does not tell us is whether the teachers are enthusiastic about the recommended new practices or enthusiastic about the associated supportive experiences that reduce typical classroom loneliness, providing an adult who can talk about teaching and making it possible for teachers to observe colleagues within their school.

At the center of my concern about processes of preservice and inservice education is the associated conceptualization of the role of the teacher in the use of research findings. Is the teacher expected to use the findings directly and uncritically? Alternatively, is the often limited research base made clear to teachers and are teachers involved directly and actively in exploring the advantages and the stresses that may arise in the course of modifying patterns of teaching that are, in most cases, already reasonably successful? One aspect of my concern is whether teachers are presented with a complete argument, not necessarily in the form of a research report but at least in a form that frees teachers from dependence on the authority of the researcher's position. A second aspect is whether the practices recommended by research findings are seen as replacing existing practices directly or as modifiable to obtain the best fit with the existing practices. In my view, it is crucial that we eventually determine to what extent it is the research findings and to what extent it is the related staff development processes that lead to acceptance, rejection, or modification by teachers. If test scores do improve, what are the other influences--intended and unintended--on the school, the teachers, and the students? Are there principles of staff development that

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*N.I.E. brochure, "ALT--Academic Learning Time," undated

**P. Robbins, principal investigator, and J. Franco, principal, in September 8, 1983, staff development presentation at Mills College, Oakland, CA.

take precedence over the goal of increasing the number of teachers who use certain teaching behaviors?

A strategy of "interactive research and development" (IR&D) for encouraging teachers' professional growth is described by Tikunoff and Mergendollar (1983), in the recent N.S.S.E. Yearbook, Staff Development, edited by Griffin (1983). In the IR&D model, research on concerns of teachers is directed by a team that includes teachers, researchers, and staff developers; a staff development strategy is prepared as the research proceeds. The authors' goal is to remove the familiar gap between teachers and the research process.

> To counter this situation, we believe it is imperative to involve teachers in the conduct of research intended for their use. As a result of this involvement, we believe that there is greater probability that the findings will be perceived to be relevant and useful by other teachers. We believe that research skills are among the most powerful in an educator's professional repertoire. When used to analyze and adjust instruction, they provide the basis for developing a deeper understanding of the classroom environment and the process of instruction. Such understanding, we argue, ought to be a major goal of professional staff development. (Tikunoff and Mergendollar, 1983, p. 211)

Three examples of research conducted on the IR&D model are described, but the general accounts deny us insight into what happens at the level of the individual teacher. We would expect high impact among the teachers who were directly involved, but the important question remains whether the involvement of a few teachers in research that also develops training strategies will produce results that are more attractive to and more likely to be used by teachers who did not participate directly.

There is yet another important issue as we move from classroom observations and research reports to preservice and inservice teacher education. Do we know what it is that successful practitioners in the teaching profession need to know? Is it enough for them to copy the "effective" behaviors of teachers whose students had the highest achievement scores? Do teachers need to understand the assumptions and consequences of their actions? Where does the process of reflecting on one's own professional actions fit in the activities of teacher education? Alternative answers to questions such as these are indicative of alternative sets of assumptions about teacher education, and Zeichner (1983) has suggested that at least four "paradigms" of teacher education--"behavioristic," "personalistic," "traditional-craft," and "inquiry-oriented"--can be identified in recent debates about teacher education. While the personalistic paradigm focuses on the psychological maturity of the teacher and the traditional-craft paradigm is implicit in most student teaching experiences, the tension I have been emphasizing here is that between the behavioristic and the inquiry-oriented paradigms. The behavioristic paradigm stresses knowledge and skills for the current role of a teacher; the inquiry-oriented paradigm stresses not only technical skills but also the ability of teachers to analyze and reflect upon their own actions (Zeichner, 1983, pp. 4-6). While it is important to read these paradigms as indicative of emphases or major themes rather than as mutually exclusive apprаches to teacher education, they do provide a useful scheme for comparing different programs for staff development. Classroom observation using perspectives derived from philosophy falls clearly within an inquiry-oriented conception of teacher education, encouraging teachers to examine basic role assumptions with a view to approaching more closely our basic goals for educaiton.

Schon's (1983) conclusion that a process of "reflection-in-action" is central to the work of successful practitioners (in fields as diverse as architecture and psychotherapy, town planning and management, medicine, and engineering) provides a promising new perspective for those who work within an inquiry-oriented conception of teacher education. Schon argues that our basic premises about the relationships among theory, research, and practice are misleading and in need of revision, and he uses case studies to illustrate the alternative view he proposes. Two issues are crucial. The familiar view of professional practice as a problem-solving activity (using techniques derived from theory) is one that ignores problem setting ". . . the process by which we define the decision to be made, the ends to be achieved, the means which may be chosen" (p. 40). Schon stresses the importance of the practitioner's "framing" the elements of a problematic situation, and he suggests that problem <u>setting</u> may be more significant than problem solving.

The second major element in Schon's perspective is "reflection-in-action," which he sees as "central to the 'art' by which practitioners sometimes deal well with situations of uncertainty, instability, uniqueness, and value conflict" (p. 50). For Schon, reflection-in-action includes three types of experimentation. To the familiar "hypothesis-testing" of quantitative research, he adds "exploratory" experiments and "move-testing" experiments. "Exploratory experiment is the probing, playful activity by which we get a feel for things" (p. 145). A move-testing experiment is "any deliberate action undertaken with an end in mind . . ." (p. 146). The purpose of such an experiment is to determine whether the "move" produces its intended effect <u>and</u> to identify any unintended consequences of the move. This new category of experimentation seems particularly relevant to teachers who are asked to use a new curriculum or to adopt particular teaching behaviors that have been found to correlate with higher student achievement.

My goal in this concluding section is to demonstrate a need to attend to how we frame our staff development practices as we also work to frame our classroom observations more appropriately. The view that teachers should be trained or retrained according to significant correlations with student achievement reflects a "behavioristic" approach to staff development. Using quite different premises, Schon suggests new possibilities for work within "inquiry-oriented" approaches to staff development. As the tension among teacher education paradigms continues, I hope that future repo· s of staff development and the implementation of research findings will report in detail the training procedures used and the individual responses of those trained, as well as the degree of success in changing practices and increasing test scores. Then our images of the work of the classroom teacher and the ways that teaching may be improved will become more accessible to those who work within alternative paradigms of teacher education.

REFERENCES

Basalla, G. "Pop Science: The Depiction of Science in Popular Culture." In G. Holton & W.A. Blanpied (Eds.), Science and Its Publist: The Changing Relationship. Boston: D. Reidel Publishing Co., 1976.

Cogan, M. L. Clinical Supervision. Boston: Houghton Mifflin, 1973.

Denham, C. and A. Lieberman (Eds.) Time to Learn. Washington, D. C.: National Institue of Education, 1980.

Good, T. L. "Teacher Effectiveness in the Elementary School." Journal of Teacher Education, 30 (2): 52-64, 1979.

Goldhammer, R. Clinical Supervision. New York: Holt, Rinehart and Winston, 1969.

Griffin, G. (Eds.) Staff Development. Eighty-second Yearbook of the National Society for the Study of Education, Part II. Chicago: The University of Chicago Press, 1983.

Joyce, B. R. and B. Showers. "Transfer of Training: The Contribution of 'Coaching'." Journal of Education, 163: 163-172, 1981.

Kilbourn, B. "Linda: A Case Study in Clinical Supervison." Canadian Journal of Education, 7: 1-24, 1982.

Mead, M. and R. Metraux. "Image of the Scientist Among High School Students: A Pilot Study." Science, 126: 384-390, 1957.

Munby, H. What is Scientific Thinking? Ottawa: Science Council of Canada, 1982.

Munby, H. and T. L. Russell. "A Common Curriculum for the Natural Sciences." In G. Fenstermacher and J. Goodlad (Eds.), Individual Differences and the Common Curriculum. Eighty-second Yearbook of the National Society for the Study of Education, Part I. Chicago: The University of Chicago Press, 1983.

Munby, H., G. Orpwood, and T. Russell. Seeing Curriculum in a New Light: Essays from Science Education. Toronto: OISE Press, 1980.

Pepper, S. C. World Hypotheses: A Study in Evidence. Berkeley: The University of California Press, 1942.

Peters, R. S. Authority, Responsiblity, and Education. New York: Atherton Press, 1967.

Peters, R. S. Ethics and Education. London: George Allen & Unwin, 1966.

Roberts, D. A. "The Place of Qualitative Research in Science Education." Journal of Research in Science Teaching, 19: 277-292, 1982a.

Roberts, D. A. "Developing the Concept of 'Curriculum Emphases' in Science Education." Science Education, 66: 243-260, 1982b.

Roberts, D. A. and T. L. Russell. "An Alternative Approach to Science Education Research: Drawing from Philosophical Analysis to Examine Practice." Curriculum Theory Network, 5: 107-125, 1975.

Russell, T. L. "Analyzing Arguments in Science Classroom Discourse: Can Teachers' Questions Distort Scientific Authority?" Journal of Research in Science Teaching, 20: 27-45, 1983.

Schon, D. A. The Reflective Practitioner. New York: Basic Books, 1983.

Tikunoff, W. J. and J. R. Mergendoller. "Inquiry as a Means to Professional Growth: The Teacher as Researcher." In G. Griffin (Eds.), Staff Development. Eighty-Second Yearbook of the National Society for the Study of Education, Part II. Chicago: The University of Chicago Press, 1983.

Toulmin, S. E. The Uses of Argument. Cambridge: Cambridge University Press, 1958.

Toulmin, S. E., R. Rieke, and A. Janik. An Introduction to Reasoning. New York: Macmillan, 1979.

Zeichner, K. M. "Alternative Paradigms of Teacher Education." Journal of Teacher Education, 34 (3): 3-9, 1983.

INTRODUCTION TO CHAPTER SEVEN

The first six chapters suggest a variety of ways that the classroom teaching of science could be improved, but will practicing science teachers ever hear about those ways? And if they do, will they be inclined to teach differently?

James Gallagher's case study of a small school district suggests that for many teachers the answer to both questions may be "No." Neither administrators nor teachers in this district considered the improvement of classroom science teaching as a salient concern, even though Dr. Gallagher's observations suggest that it should have been. This case study suggests that if we are to understand why teachers act as they do in classrooms or if we are to improve science teaching, we must understand schools as organizations, and we must consider changes in those organizations.

Dr. Gallagher is a professor at Michigan State University. He is currently chairman of the International Committee of the National Science Teacher's Association. He has recently completed a program of training in fieldwork research methods; the research program that he has developed is discussed in this chapter.

A STUDY OF POLICY AND PROGRAM FORMULATION AND IMPLEMENTATION IN A SECONDARY SCHOOL SCIENCE DEPARTMENT*

James Joseph Gallagher

INTRODUCTION

In 1983, we witnessed much criticism of elementary and secondary education in the U.S. More than ten reports of national scope, headed by A Nation at Risk (National Commission on Excellence in Education, 1983) and Educating Americans for the 21st Century (National Science Board, 1983), gave evidence that schools are not preparing U.S. youth adequately for adult roles in our rapidly changing, technological society. Although all aspects of elementary and secondary schooling have received a share of criticism, science instruction receives heavy emphasis as authors of reports recognize the importance of ience as a basis for understanding our technological society and fulfilling adult roles as citizens and workers. The reports are critical of the quality and amount of science instruction offered in most schools. Most reports recommend modification of instructional content in science, more instructional time for science at all levels for all students, higher standards (especially in secondary science closer contact between science teachers and personnel in indust retraining of the present science teaching staff, and tougher standai in the preparation of new science teachers.

As a result of these reports, interest in reforming school science is high, but history shows us that change may not occur readily. Beginning in 1956, the federal government entered into a coalition with leading scientists, educators, and psychologists to bring about a massive reform of school science in the U.S. The purpose for the effort was to modify the character of the science curriculum from its prior emphasis on acquisition of science content knowledge by students to a new focus on inquiry as a more adequate portrayal of the character of the scientific enterprise and as more productive knowledge for students who should be life-long learners in a rapidly changing society.

The effort represented the largest intervention of government in shaping school science in U.S. history. Hundreds of millions of dollars were spent, and the reforms had the endorsement of the nation's intellectual and political leaders. The movement was publicized widely as a revolution in education which affected all fields of schooling, including science, social studies, mathematics, and English (Goodlad, 1974).

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*This chapter is based on a paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Dallas, Texas, April 6, 1983.

Twenty years later, in 1976, the National Science Foundation, which was the chief sponsor of the reforms in social studies, science, and mathematics, commissioned three major studies to assess the effects of the movement on school practice (Helgeson, Blosser, and Howe, 1978; Weiss, 1978, Stake and Easley, 1978). These studies produced voluminous data. Ten interpretive studies were commissioned to analyze the results from the perspectives of major professional organizations, including those representing science, mathematics, and social sciences education (National Science Foundation, 1980). Among the findings, four are of special interest to this writer and form a foundation for the study which is reported. These are:

1. In spite of massive infusion of money and effort, school science has not changed significantly during the last two decades. Instructional programs designed in the 1960's and 1970's are not widely used in schools. Inquiry teaching is not occurring to any extent nor is inquiry an operational goal of science instruction in schools.

2. Although some students are receiving excellent science instruction, the majority of U.S. school students are not receiving science instruction that is adequate for informed participation in our technological society.

3. Science instruction is largely text-centered and emphasis is placed on preparation of a small portion of students for careers in science and engineering; science for citizenship in a technological society receives little attention.

4. Teachers are the key "policy makers" in that they determine the nature of the science courses in which students participate, the standards which are set, and who is admitted (Stake and Easley, 1978).

Data from the three major National Science Foundation studies show that infusion of money, innovative materials, and scientific training of teachers did not bring about the reforms in school science that were sought in the 1960's and 1970's. Therefore, an obvious question appears to be:

> In response to recommendations for changes contained in current reports, how can we bring about the transformation of school science so that youth are prepared for effecting participation in our scientific and technological society?

The massive, "top-down" approach had less success than was desired in achieving the reform from content teaching to inquiry teaching. Today, with far fewer resources being offered by government, how can the reforms in school science be achieved that are recommended by leaders in the field--reforms that many feel are essential if our nation is to maintain its leadership and our people are to continue a high quality of life (Hurd, 1982)? To answer this question, it is necessary to know more about the internal workings of school science departments. It will be necessary to know how school policies regarding science instruction are established and implemented. Given the central role which science teachers play in determining the character of school science programs, it will be necessary to learn where science teachers acquire new information about science, about its role in society, and about new instructional approaches. Moreover, it will be necessary to explore the value systems which influence teachers' thinking and actions and who influences these values. It will also be important to learn how administrators, parents, and students influence school science as well as the reasons that students are placed in, or elect, particular science courses, especially at the junior and senior high school levels.

The purpose of the research described in the report was two-fold. One goal was to test techniques to investigate how school policies and programs are formulated and implemented within a local school district. Second, the study aimed to discover and describe the perspectives of science teachers and school administrators in formulating and implementing policies and programs relating to school science. Thus, the roles and viewpoints of science teachers and school administrators were of special interest to the researcher. Considerable attention was given to values and belief systems of school personnel and how these affect their search for, reception of, and utilization of new information as part of their continuing professional development. Atttention was also given to the interactions among teachers and students and to how values and belief systems influenced interaction.

The approach used was ethnographic. That is, the techniques of anthropologists were applied, using a school district as the culture under study. The study included a wide variety of techniques including interviews, analysis of written documents, classroom observation, participant observation in classes and laboratory sessions, and informal conversations as techniques for "teasing out" information on actions, values, attitudes, and beliefs of teachers, administrators, and students (Agar, 1980).

RESEARCH QUESTIONS

The research questions were directed toward learning about the internal workings of school science departments. The major questions addressed by this study were:

1. How are policies and programs regarding school science formulated and implemented in the district?

2. How do the values, belief systems, knowledge, attitudes, and commitments of teachers affect selection of content, methods of teaching science, and classroom intereactions with students?

3. From what sources and by what means do science teachers and administrators acquire information on new scientific and technological developments and instructional approaches, and how does this information affect the science program?

Each of these questions is complex and each has a broad potential for eliciting a rich response. In the pages which follow, each question will be dealt with, first in the literature review and then in view of data gathered through ethnographic procedures.

The readers should keep in mind that this is a report of a pilot study which tried simultaneously to test techniques for learning about the internal operations of a school science department and to carry out a substantive study of a department. Thus, the findings are tentative and may not generalize to other districts. It is the researcher's intent to replicate this study in other districts as a means of providing answers to the questions that are more generalizable and less idiosyncratic than those which might be obtained from a study of just one district.

LITERATURE REVIEW

Few studies of school science have been conducted using field work as an approach. Because of the heavy emphasis on hypothesis testing and quantification which characterizes the natural sciences, and because most university science educators have been trained in the natural sciences, statistical studies and hypothesis testing have been the favored styles of research. Field work has been eschewed as "pre-scientific." As recently as 1977, ethnographic studies were routinely rejected by the Program Committee of the National Association for Research in Science Teaching because they did not conform to the accepted statistical/hypothesis testing paradigm.

The investigations of science, mathematics, and social studies programs in 11 school districts, reported by Stake and Easley (1978), represent the best known attempts at employing ethnographic techniques in exploring school science. The studies provide a rich description of the three subject areas in 11 districts of varied size, geographic location, population characteristics, fiscal resources, and dominant values. Even though they provide useful descriptions of the state-of-the-art in school science, mathematics, and social studies, they suffer somewhat from superficiality since too much was studied in too short a time. Moreover, not all observers were adequately trained in field work.

Stake's and Easley's report contains many useful observations and interpretations. For example, they showed that:

1 The text book is a dominant factor in shaping instructional content in most classrooms with more than 75 percent of classwork and 95 percent of homework being derived from the text.

2. A wide variety of instructional philosophies, approaches, and choices of content exists in schools with individual teachers being highly autonomous in decision making regarding what is taught to students.

3. The classroom behavior of most teachers implies that the substantive content of instruction is of secondary importance to the inculcation of the "work ethic." In science, mathematics, and social studies classes, students are taught to perform work on time, to follow instructions, to keep busy (or even just look busy), to accept delayed gratification, and to complete tasks that some day may make sense.

In a more recent study, Korth and Cornbleth (undated) showed that middle school teachers they observed over one year demonstrated a small number of direct instructional activities and that these were of short duration. Instead of teachers teaching students by helping them to clarify understandings of subject matter content, teachers spent most of their time giving assignments, going over completed homework assignments, and supervising students who were completing study guides and work sheets. They also observed that middle school teachers kept students busy on assigned tasks for a very high percentage of the class period. Korth and Kornbleth questioned the impact of this experience on children's understanding and enjoyment of the subject matter they are studying.

To date, no studies appear to have been reported on processes by which school science policies and programs are formulated in a local district. Little appears to be known about how requirements for science are established. For example, it is not clear why most schools require one year of science in high school, four years of English, and three years of social studies. Further, it is not clear why some schools require two years of high school science while most require only one. In addition, the processes of text book selection are poorly understood even though Stake and Easley's work underscores the importance of text books in science instruction.

An area of growing concern among scientists, educators, industrialists, and governmental officials is the lack of "scientific and technological literacy" of the vast majority of students graduating from high schools (Hurd, 1982; National Science Foundation, 1980b). Our schools appear to be educating the top 10 or 15 percent of our students quite well. However, the other 85 to 90 percent of our youth appear to be receiving inadequate education in science and mathematics.

Thus, there is a growing commitment to redirect school science so that we may educate that segment of the school population who are not now receiving an adequate education in science and mathematics. It is recognized that profound changes are needed in the content, resources, organization, goals, and approaches for teaching young people science and mathematics if a substantial portion of the bottom 85 to 90 percent of students is to learn these subjects.

Clearly one important issue regarding any substantial redirection of school science concerns teachers' ability to understand and develop a commitment to the need for change and then to find ways of altering the content, organization, goals, and approaches of their own instruction. This issue implies the second and third research questions raised in this paper (i.e., information sources and belief systems of school personnel).

To date, no studies have been reported regarding how secondary school science teachers acquire and process new information. However, some work has been done by Wirzup in contrasting subscriptions to professional journals by American and Russian secondary science and mathematics teachers. He showed that paid subscriptions to pedagogical journals on sciences (chemical education, physics education, etc.) in Russia equals about 90 percent of the number of science teachers while the number of paid subscriptions in the U.S. equals about 10 percent of the number of American science teachers (Wirzup, 1981). In a personal discussion, Hurd also pointed out that American science teachers do not read professional journals on either new science content or new pedagogical developments. Thus, these two observations tend to present a dismal image of secondary teachers' ability to engage in continuing professional growth through reading of professional literature in science or education. However, no systematic studies appear to have been conducted on other strategies for self improvement which are widely used by teachers, including attendance at professional meetings, inservice programs for teachers conducted by local county-wide school districts, and further study at colleges and universities. Further, little is known about the values, belief systems, attitudes, and commitments of science teachers and how these influence their choices regarding professional growth, selection of content, and interactions with students.

* * * * *

Schools also may be viewed as organizations in which supervisors and subordinates (administrators and teachers as well as teachers and students) interact to carry out specific roles and functions. Thus, the literature of organizations and their administration is important to this study. This literature is vast, and it is relatively new to this author. However, four pieces appear to have considerable relevance. First, Melman (1958) has shown that cooperative decisions between managers and workers in industrial settings can result in improved attitudes of workers and increased productivity. Second, Simon (1961) emphasizes the important position of administrators in coordinating actions of individuals so that adaptation of behaviors takes place which will result in attainment of stated goals. Even after cooperative decisions have been made, individuals frequently need assistance and directions so that effective actions will be maximized and ineffectual ones reduced. Third, Kaufman (1973) studied behavior of supervisors in governmental agencies and found that supervisors were not knowledgeable about subordinates' behavior because they were not inspired to learn about it, or they avoided acquiring this information because if they knew about subordinates' inappropriate behavior, they would be obliged to take corrective actions. Kaufman also showed that the incentive structure in governmental bureaus tended to foster laissez-faire supervisory behavior. As a consequence, subordinates were left with little or no supervision and their behaviors tended to regress to whatever levels the individuals chose (1973). Fourth, Shibutani (1978) examined the results of acute disruption of organizational functions among a demoralized military group. In this study, Shibutani reported on disruptive behaviors of Nisei soldiers (Japanese-Americans) who viewed the military training requirements imposed on them as useless and wasteful of their time and energy because they were being trained for combat while their assignments were to be as key individuals in the occupation force in Japan. The soldiers recognized that they needed to improve their Japanese language skills and their understandings of how to deal with people of their own ethnicity as an occupation force, but their training was not preparing them for the assignment. As a consequence, the group memebers began to vent their frustrations by engaging in a wide array of unproductive, anti-social behavior which resulted in the imposition of increasingly stern and repressive disciplinary actions against the group. In the final analysis, the group became demoralized and efforts to rebuild them into an effective group were unsuccessful.

In the closing chapter of the book Shibutani examines demoralization as a social process and identifies characteristics, symptoms, and principles of demoralization. While demoralization may be too strong a word to describe the attitudes of people in this study, some students and even some staff members may be exhibiting some of its preliminary symptoms. For example, Shibutani states that one of the characteristics of demoralization is doing only the "acceptable minimum" on an assigned task or on the job. He further points out that disruptive behavior may signify that individuals have not "bought into" the goals and related actions of the leader, and that this is an "early warning sign" of demoralization. And then leaders ignore the early warnings, subordinates feel that the leaders are insensitive or inept and the process of demoralization continues at an accelerated pace.

The points raised by Melman, Simon, Kaufman, and Shibutani may be considered as having some applicability to the interactions that occur between both teachers and students and between administrators and teachers. In both cases, decisions must be made, goals set, action plans established and implemented, feedback gathered, and corrective actions taken. In short, the concepts of management of organization can be a useful tool for comprehending the interactions between administrators and teachers and between teachers and students in school settings.

THE SETTING

The study was conducted in a community which shall be called Fairfield in order to maintain its anonymity. It is a heterogeneous, mid-western suburban community with a population that includes a mixture of faculty and other employees of a large state university, farmers, employees of state and federal government agencies, factory workers, industrial management people, and people from many other occupations. Homes in the community show considerable diversity as well. There are many middle-class and upper middle-class homes, apartment complexes, and condominiums in the community. There are also some homes that are very modest. However, the middle-class and upper middle-class homes are more prevalent.

In driving through the community, the writer was impressed by its newness and its well-ordered character. The schools, stores, and shopping centers are modern, attractive, and well maintained. The apartment and condominium complexes have been designed aesthetically with thoughtful preservation of "greenspace." Ponds, parks, lakes, biking trails, play grounds, and other recreational features are abundant. Many private homes are set on large lots, and they are well landscaped and maintained. All together, the community appears to be a pleasant place to live--in some ways it exceeds the "great American suburban dream."

The community is not large. Its schools have a total enrollment of 1850 students K-12. Of these, 796 are K-5, 408 are in middle school (6-8), and 646 in high school (9-12). About 40 percent of the residents of the district have school-age children, due in part to the large number of apartment complexes which house single persons and young couples without children.

The people who live in Fairfield are generally very pleased with their schools. In a recent survey conducted by a public opinion research group, 405 residents of the community were asked how they would rate Fairfield schools on a scale from A-E (like school grades). Sixty-five percent rated the schools A or B with eighteen percent indicating that they were not able to rate the schools. Only one and one half percent of the respondents rated the schools D or E. In a nation-wide Gallop Poll, only thirty-five percent of the sample rated schools A or B, and in a state-wide survey conducted by the Michigan Department of Education, forty-five percent of Michigan residents surveyed gave schools A or B ratings.

The survey showed that people were satisfied with the teachers, administrators, programs, and resources which comprise the schools. When asked what they disliked about the schools, 60 percent of the respondents gave no criticisms. Replies to the question regarding points of dissatisfaction included:

Some teachers	9%
School's poor discipline	9%
Student attitudes and school behavior	5%
Weakness in curriculum	6%
Lack of basic skills	4%
Board policies	5%
Bus transportation	3%
Administration	3%

The schools appear to get good financial support from their public. Clearly, the high level of confidence in Fairfield schools shown by the survey of residents is a major factor in continuing financial support. Also, the community has grown in recent years due to construction of apartments and condominium complexes. As a result, student enrollments have declined only slightly, whereas many communities in Michigan have experienced sharp declines in school-age population as declining birth rates 5-18 years ago, coupled with migration of Michigan residents to other states, have significantly reduced the number of school-age children. According to the superintendent, confidence in schools and stable school populations have made it possible for school budgets to keep close pace with inflation and few teachers have been laid off in the district.

Initial observations showed that the schools were well equipped, well maintained, well staffed, and class sizes were relatively small, with many classes in middle and high school having about 20 students. The science department chairman also has been able to obtain adequate supplies for instruction and for lab equipment, due to his effectiveness in obtaining a favorable share of the school supplies and equipment budget and by placing orders on a bid basis which results in a savings of 30 to 40 percent of purchases. Thus, at times when many schools are unable to obtain adequate supplies and equipment for science instruction, Fairfield has been able to acquire excellent resources because of the dedication and sagacity of the department head.

The teachers in Fairfield have considerable experience. Because it is a pleasant community in which to live and work and because of good funding for schools, teacher turnover has been low. With the exception of one science teacher who was in her first year of teaching, the other seven science teachers all had more than ten years of experience with a mean of approximately 18 years.

Thus, the study focused on a well-ordered, middle- to upper middle-class community with schools that have been well funded with a stable teaching population. In short, this was a study of what most people would identify as a fine school system in a fine community.

DESCRIPTIVE EVIDENCE

This section, and the subsequent analysis and interpretation section, each contain three parts relating to the three research questions stated previously.

Formulation and Implementation of School Science Policies and Programs

The purpose of this part of the investigation was to determine how and by whom decisions are made about the nature and content of the school science programs. The roles of teachers and administrators in formulating and implementing policies relating to school science were also of interest. The questions of who decides what is to be taught, to whom, for how long, by what means, and what level of standards are to be employed in rating students' performance comprise the domain of interest in this section.

At the beginning of the inquiry, I examined the formal policies and procedures that existed in the district for formulating and implementing school programs in science. I also reviewed formal documents, such as the district's curriculum guide which is a large loose-leaf Curriculum Notebook designed to contain all of the formally approved statements about programs, descriptions of courses, and other written policies on all subjects including science. Later, I met with teachers and administrators both to observe them in their work and to interview them to gain insights regarding their understandings of the ways that programs and policies are formulated and implemented. At this phase, considerable attention was given to the work of teachers in implementing programs.

In my initial interviews with the Superintendent of Schools (January 28, 1982) and the Curriculum Director (February 9, 1982) I learned about the district-wide Curriculum Council and the Curriculum Notebook. The Curriculum Director provided me with a thorough explanation of the purposes, functions, and composition of the Curriculum Council. He stated that it is a 24-member group, composed of the Superintendent, the Curriculum Director, one principal and twelve teachers elected from various departments and buildings, four students from middle and high schools, and five parents. The Curriculum Council meets monthly and deliberates on any proposed changes in the curriculum such as new text selections, new courses, requirements for graduation, and time requirements in subject areas.

The Curriculum Director also pointed out that changes in the curriculum may arise with teachers, administrators, parents, or students. After a change is proposed, it is reviewed by the the department or other units concerned. If the affected or appropriate units approve of the proposal, it is forwarded to the Curriculum Council for review and approval. The Superintendent then has authority to approve or disapprove, as does the Board of Education. Thus, curricular changes are subject to multiple levels of approval by a wide range of persons with varied viewpoints and expertise.

On April 13, I observed a meeting of the Curriculum Council. No course- or text-approval requests were presented. The main agenda was the review of a report of a committee that had been studying ways of resolving a scheduling conflict that affected a small number of middle school students who had a particular course combination of band, physical education, and a special social studies course. One proposed solution was to waive the physical education requirement for these students. This proposal was rejected and an alternative one was accepted which allowed students to fulfil their requirement for physical education at another time.

It was interesting to note that the Curriculum Director was absent from this meeting, and his absence passed without comment. On the other hand, the Chairman of the Council, a chemistry teacher, was absent because of illness; quite naturally his absence was noted, and the Vice Chairperson conducted the meeting.

In my initial interview, the Superintendent stated that I could obtain accurate information on the science curriculum from the Curriculum Director. The Superintendent showed me his Curriculum Notebook and indicated the kinds of materials that it contained (philosophy, goals, course descriptions, etc.), but said he was reluctant to give me copies of the relevant pages because they might be obsolete. The Superintendent suggested that I could be assured of accurate information from the Curriculum Director. Therefore, when I arranged an appointment with the Curriculum Director, I requested these documents. When I arrived for our meeting, he gave me more than a dozen pages of descriptions which he had photocopied from his Curriculum Notebook. Later the Science Department Chairman told me that I had received outdated material. It is also important to note that the Curriculum Director served a dual role; he also is the Principal of one of the district's elementary schools.

Throughout my observations at Fairfield Middle School and Fairfield High School, I found very little evidence of interaction between teachers and administrators over instructional and curriculular matters. The middle school principal introduced me to the four science teachers in his building on February 19. He also provided background information on each of them. On May 13, after I had made several observations of each of the middle school teachers and as I was about to complete my study in his building, I interviewed him regarding evaluation procedures and discussed the wide variations in teaching style which I had observed. He indicted that the union contract called for evaluation of all teachers on a three-year cycle. He further stated that he was not able to fulfill this obligation (even though his staff of 29 teachers would require, roughly, one teacher evaluation per month). There is a clear lack of contact between the principal and teachers regarding issues of subject-matter teaching in the middle school, and there appears to be even less contact in the high school.

In my observations of middle school teachers, I observed a high degreee of variability among them regarding style, content emphasis, and time that students were required to attend to science content. The middle school principal defended these variations in approach among the three science teachers in grades 6-8 on the grounds of individual professional freedom and responsibility. He also seemed to be unaware of (or perhaps did not want to address) the poor teaching of one of the teachers, Teacher C. The following are some excerpts from Teachers C's classes:

> I observed Teacher C in six class periods on three different days. On February 13, my first visit, Teacher C had concluded the lesson for his 2nd-period class prior to my arrival, even though twenty minutes remained in the period. He was talking

with four girls who were seated at the front of this large, well-furnished, laboratory/classroom. The conversation was about his age and his hair loss. (Teacher C is greying at the temples and is losing his hair, somewhat prematurely; he is 31 years of age.) The repartee between them was cute and mindless. It continued for approximately 15 minutes, only punctuated by Teacher C's calling to five boys who moved slowly to the back door of the room in an atempt to leave class early. The "game" between Teacher C and the boys continued until the bell rang; that is, he would call the boys back when they would go into the hall, they would return inside the room and then slowly edge outside again.

On another visit (March 13), I observed three of Teacher C's classes. In one class, the major activity was to go over a work sheet on water pollution which he had prepared and had given out on a previous day. He called on students to answer specific questions. Students would give abbreviated answers of two or three words; Teacher C then would elaborate and explain answers. Sometimes he talked for two or three minutes to elaborate on a two- or three-word answer. His explanations tended to be abstract and some were nonsensical. For example, in reply to a question "Why are bacteria necessary in sewage treatment?", he replied "Bacteria kill the sludge." The answer does not make sense; it could only confuse students. He repeated it several times and no student questioned him about the statement. Moreover, students tended not to pay attention to Teacher C; many were talking, some were writing, and others were dozing.

Later in this same period, Teacher C returned to the discussion of his hair loss. Finally, one eighth-grade boy commented, "Don't worry, Teacher C, in a little while it will all fall out and then you'll look like Mr. Y (another teacher). He's totally bald and he looks really cool!"

On February 19, I also met briefly with Teacher C during his free period. He asked me for my opinion of a new book he was considering for eighth-grade science. He did not have a clear rationale for the use of this book as opposed to the one he was currently using. He said that he was "leaning toward" it. At some point, he will be required to present a written request for the change, utilizing the established chain of command. At the time of the conclusion of this study, he had not done so. However, I was surprised that he would be making the decision about the eighth-grade book independently, without consulting the other middle school teachers (he is the only eighth grade teacher) and without consulting with the Department Chairman.

Teacher C needs help with teaching and yet the principal is unaware of (or chooses to ignore) this fact. As a consequence, students are getting misinformation and poorly organized content. Moreover, they are not learning good work habits or appreciation of the subject matter of science, which will be important to them as future citizens.

Teacher C's classroom behavior is both ineffective and inappropriate. He has taught in the system for nearly a decade and yet he has received no assistance from the Principal, the Department Chairman, or other sources to help upgrade the quality of his work. This isolation of teachers and administrators from each other appeared to be characteristic.

The role of the Department Chairman is worth noting. Everyone whom I met in my early contacts in Fairfield spoke with highest regard for this man. He was described as dedicated, hard working, and competent by the Superintendent, other teachers, and principals. He is correctly credited with saving the district considerable money by requesting bids from suppliers for science equipment and supplies. His major role appears to be in this area. He told me that his staff of seven teachers at middle and high schools only hold "a couple of meetings a year." The science faculty does not meet regularly to coordinate teaching or provide mutual support of a philosophical, substantive, or pedagogical nature. The chairman, who is also a high school chemistry and physics teacher, has some released time for his extra duties; he may hire a substitute for 15 days. However, he chooses not to because of the detrimental effect he feels it would have on students' achievement. As a result, he is not able to aid teachers with instructional improvement or to enter into evaluations.

In addition to teaching a regular load and his duties as Chairman, he also is Varsity Baseball Coach. Therefore, during the Spring, he appeared to be over-extended. During all of my conversations with him he expressed repeated concern over details of baseball practice and demonstrated only moderate concern regarding the science program and its materials to which he gives attention at other times of the year.

Data presented above focus on one principal, one teacher, and the Chairman of the Science Department. Although there is a high degree of variability among the approaches which teachers use in their individual classrooms, these data serve to underscore two important points:

1. The chief areas of contact between administrators and science teachers concern general issues, such as allocation of budget for supplies, approval of course titles and general content areas, formal approval of texts, and establishment of minimum time requirements for science.

2. Beyond these general levels, individual teachers have a high degree of control over the content, methods, and standards employed in science classes, and there are few checks and balances in the system to assure quality performance by teachers.

Teacher C's independence in selecting text, his choices of content for his eighth-grade course, and his use of time (e.g., keeping students busy for approximately half of the period) are all examples of ways that he is autonomous and relatively free of checks and balances, even though he is quite ineffective in teaching students and in maintaining control.

By contrast, Teacher A is a first-year teacher who also teaches science in the middle school. Her classes were well organized and students' time was used fully. The following pattern seemed to prevail in Teacher A's classes:

> At the start of each class, she assembled children at their desks and gave about 10 minutes of instruction on the activities which they were to perform. Then students moved to lab stations around the perimeter of the room, formed groups of four or five, and began to make observations, measurements, or other activities which had been described earlier. Students recorded data on prepared laboratory sheets. Teacher A moved from group to group helping students, clarifying instructions, answering questions, and providing corrective feedback. After about 20 minutes, she signaled that the students should return materials to their proper places, and assemble again at their desks. The final ten minutes of each class consisted of discussion and review of the activity, placing it in the context of the larger instructional unit which continued for about a month.

Teacher A's conduct of her class was exemplary. It was well organized and the content was rich and exciting. In one class, the children were making observations of several coturnix (small Japanese quail) as part of a unit on anaimal behavior. The children had the opportunity to improve their skills in observing and measuring (scientific processes) while learning about the anatomy and behavior of this bird (scientific concepts).

However, it is important to note that the choice of content was hers. As a first-year teacher, she also was able to select the content of the curriculum and the nature of the students' experiences. Teacher A and I discussed her rationale for selecting certain content and for deviating from the approved text. Although her choices were good, her rationale was inexplicit.

Further, it was very clear that students in Teacher C's classes were learning something very different from those in Teacher A's classes. However, there appeared to be no checks in the system to correct what seemed to be an unfortunate set of circumstances for some students.

Four teachers teach nearly all of the required science courses in grades six through nine, with one teacher at each grade level. Those teachers differ greatly in their use of time and in the activities which students perform. Table 1 provides summary data based on observations made by the author in at least three classroom visits to each teacher.

Table 1

Use of Class Time by Science Teachers in Required Science Courses: Estimated Minutes per Class Period

Teacher	Lecture Discussion	Demonstrations or Lab	Housekeeping	Supervised Study	Disorder
A	15	20	7	0	3
B	10	25	5	0	15
C	15	0	5	15	30
D	0	0	5	35	5

The reader should note that the time reported for two teachers totals more than 45 minutes per period. This is because disorder persisted as the teachers were carrying "other activities." Further, supervised study included a variety of student activities with approximately equal numbers of students (a) studying individually, (b) studying in groups, (c) studying and talking, (d) talking with very little evidence of study, and (e) sleeping or sitting with no evidence of activity.

The data in Table 1 show quite different teaching styles. Teachers A and B (females) used the laboratory and demonstrations more. Teachers C and D (male) used more supervised study. All four teachers used work sheets and study guides which they had prepared. However, they used them differently. The source of data for students in classes taught by Teacher A and B was direct experience in a "lab setting," whereas, students in classes taught by Teachers C and D tended to get information from books in order to answer questions.

In the high school, four teachers taught elective subjects and their autonomy in choice of content, approach, and standards of quality was equally high. Further, although these four teachers and the ninth-grade general science teacher all shared common equipment storage and preparation rooms and were able to eat lunch together each day, each conducted his/her own classes independently. Each taught his/her own subject in his own style, selecting content from the wealth of information available in the text and other resources, and applying his/her own standards for student performance.

Another area where teachers have autonomy is in admission of students to elective or accelerated classes. In my initial interview with the Superintendent, I was told about a case where a boy was denied admission to an accelerated eighth-grade class. The teacher claimed tht the boy was immature and exhibited poor classroom behavior. The boy's parents objected because the boy had scored in the ninety-fifth percentile on a standardized science test, and they believed that he needed the added challenge which the accelerated class would provide. The case was reviewed by other teachers, and the initial decision by the teacher was upheld. Moreover, this case is not an isolated one, although it is the only one this year where parents obtained a review.

In short, Fairfield science teachers have an extremely high degree of control over content, methods, standards, and admission to advanced and elective courses.

Effects of Teachers' Knowledge, Values, and Belief Systems on Choices of Content, Methods, and Modes of Interaction with Students

Because teachers have a high degree of autonomy in their choices of content and methods, and because they have considerable freedom in their interactions with students, the effect of their knowledge, values, and beliefs on the choices they make is an issue of importance. The following incidents may serve to highlight a common phenomenon.

a. Teacher B has taught middle school science in Fairfield for fifteen years. Among her peers, she has a reputation as a firm disciplinarian and a competent teacher. In her second period class on February 23, 1982, fifteen seventh-grade students were in attendance. The topic was a laboratory activity on blood typing. At the start of the period with the students in the classroom section of her large lab/classroom, she tried to bring the students to order to review the procedures for the activity. After much calling out and inattention on the part of the students, she said, "Everyone take their places in groups at the lab tables." At this, the students became quite out of control as they moved to the rear of the room. One boy sat in a chair at one of the lab tables, put his feet on the table, slid his head through the chairback, and lay there with his head nearly touching the floor, his shoulders on the chairseat and his feet on the table. Other students chattered loudly about the imminent "blood letting" that would occur when students would puncture their fingers with lancets to obtain blood samples for typing. Teacher B ignored all of this behavior.

   After the students had completed the activity, Teacher B assembled the 15 students at the tables in the front of the room and then attempted to conduct a post-lab discussion to summarize the results of the previous work. Eight students participated with her in the discussion while seven sat in two groups and talked with each other in a normal voice about matters unrelated to the lesson. The students were blatant about their inattention, and Teacher B did not attempt to correct their behavior until more than 10 minutes had gone by, when less than one minute remained in the period.

b. On April 13, 1982, Teacher C began his second-period eighth-grade class, which is composed of about twenty students, by going to each student's seat and speaking with them individually and personally to determine (a) if the homework had been completed and (b) if students had encountered anv difficulties with it. The encounters took about 10 seconds each and were quite personal and humane.

c. On March 16, 1982, Teacher D's ninth-grade science class spent the entire period working on a set of questions which were written on the board. Teacher D spent his time walking around the room, looking over students' shoulders as they worked and making comments to them about their need to finish up their work. His comments were sarcastic and not helpful. Although some students worked diligently, over half of the students did little or nothing during the entire period. Four boys just sat, occasionally making comments as they stretched in apparent release of boredom. Five girls talked most of the period about The Guiding Light, an afternoon soap opera which is watched by many students, and about Phil Donahue's show on gay senior citizens. Teacher D made no effort to re-direct these students during the period. However, after class he did call aside one girl who had been at work during the period and complimented her on improved performance. This was the only positive interaction between Teacher D and the students which I observed during several class visits. Typically, he was aloof and his comments were neither corrective nor supportive.

Teachers B, C, and D teach nearly all of the required science for students in grades seven through nine. Each of them appeared to have adopted a "laid-back," nearly non-directive, approach with their classes. There was little evidence in any of their classes that teachers' were exerting pressure on students (a) to work on assigned tasks, (b) to conform to pre-established or customary norms of behavior, (c) to master important principles of science, (d) to acquire good study work skills, or (e) to apply the subject matter to contexts outside of class. Instead, students seemed free to make individual choices about behaviors toward the teacher, other students, and their work on the subject matter.

Because Teacher B's performance in class was at variance with the reputation portrayed by her peers as a firm disciplinarian and effective teacher, I interviewed her for nearly an hour regarding what was an apparent change in her behavior as a teacher. During the interview, she indicated that over the years, she had become more secure in herself, such that a student's inattention, back talk, or other poor behavior was not perceived as threatening to her own ego. She reiterated several times that her greater self-confidence allowed her to be more accepting of children's behavior than during her early years as a teacher. In more recent interviews, Teacher B indicated her acceptance of students' behavior as a normal part of teaching middle school students, even though that behavior is at times unpleasant to deal with.

Teacher B also stated that in addition to improvements in her own self-confidence, her more relaxed attitude toward students' behavior was in response to the needs of children. She noted that an ever greater percentage of the students come from "troubled homes." When she began teaching, she said that perhaps one or two students in a class would come from a home that had been disrupted by divorce, but today about half of the students are affected. Thus, she indicated that she tries to be supportive of junior high school age students who are having to cope with all of the normal stresses of the teen years and, in many cases, a family break-up, simultaneously.

In later interviews, Teacher C and D reiterated the same viewpoint. That is, students are troubled because of uncertainties and dissonance in their families in addition to the familiar difficulties of puberty and adolescence which affect 12-15 year olds, and as teachers, they do not want to "hassle" them. Thus, motivated at least partly by compassion, these three teachers have adopted a mode of interaction that is "low key" and, in their minds, supportive and helpful to students.

Another justification which all three teachers gave for their laissez-faire approach is that there is no benefit to be derived from putting pressure on students as it only increases frustration. This was based on the perception that parents and administrators would not be supportive of teachers who demanded high standards of performance.

Sources and Effects of New Information about Science and Pedagogy

As rapport was established with each of the nine science teachers in Fairfield Middle and High Schools, I began to inquire about their strategies for learning about new developments in science and pedagogy. The approach used in this phase of investigation was open-ended, informal questioning. Eight teachers were interviewed and the responses of teachers were varied. These are summarized in Table 2.

The teacher of chemistry and computer science was unusual in his professional development. He reported that he subscribes to and reads eleven journals in science, computer science, and related pedagogy. He also regularly attends professional meetings both in Michigan and in Canada, where he feels that more serious pedagogical work is going on. Further, he has completed a considerable amount of work toward a doctorate in science but was unable to obtain the degree because of lack of funds. His approach is serious and scholarly.

Table 2

Sources of Information Used by Teachers

Teachers	Journals Read Regularly: Scientific	Journals Read Regularly: Lay Science	Journals Read Regularly: Pedagogical	Professional Meetings	Inservice Programs	Television
Chemistry/Computer	V 5	V 5	I 1	V	N	I
Physics/Chemistry		I 2		I	N	I
Earth Science		I 2	I 1		N	I
Biology		I 2	I 1		N	I
D					N	
C					N	
B		I 3		I	N	
A		I 3		V	N	

Key:

V = Very Important Source
I = Important Source
N = Not Important
Blank = Not used as a source of new information

Arabic numerals refer to the number of journals read regularly

By contrast, most other teachers subscribed to no more than one or two journals which tended to report "lay persons' science." Some subscribed to none. One teacher indicated that she read Ranger Rick, which is a nature study magazine for children. Others read Discover, a Time-Life popular science magazine, and Science News, a magazine aimed at high school age students. No teachers mentioned that they were regular readers of Scientific American or Science 82 which are serious, yet popular, scientific journals which provide in-depth treatments of topics.

Reading of journals on methods and approaches for teaching science was reported by only two teachers. The biology teacher reported that he read the American Biology Teacher which combines both pedagogy and science content. None of the teachers reported reading The Science Teacher or The Journal of Research in Science Teaching.

Professional meetings ranked high, in teachers' reports, as sources of new information on both science and pedagogy. Five of the eight teachers had attended the Michigan Science Teachers Association meeting in February, and we discussed the kinds of sessions which they attended. Conferences such as the Michigan Science Teachers Association meeting have different kinds of sessions which may be categorized as:

1. How-I-do-it sessions in which one or more teachers describe activities they use to teach a particular topic or group of students (e.g., how to use computers in teaching physics, or activities to stimulate students with low motivation).

2. New techniques and materials sessions in which developers or researchers explain new ways of teaching science based on research and development (e.g., Smith and Anderson would describe the implications of their research for classroom practice).

3. New scientific or technological developments sessions in which a scientist or engineer would describe new knowledge (e.g., an astronomer would give a presentation on the results of the Jupiter probes).

4. Issues in science teaching sessions in which university, governmental, and/or school personnel examine issues such as declining enrollments in science, new goals and purposes for school science, and governmental policy changes.

5. Travelog sessions in which a person describes his/her safari in Kenya or canoe trip around Lake Superior. Usually these have a heavy conservationist orientation.

How-to-do-it sessions were mentioned most frequently by the six teachers interviewed. Over half of the sessions attended by the teachers were of this type. Travelogs and New Scientific and Technological Developments were next most frequently reported. Sessions on new techniques and materials and on issues in science teaching were not perceived favorably by the teachers. As the Department Chairman put it, "These are run by the University people and they have little meaning to us as teachers."

Similarly, inservice programs as a source of new knowledge for science teachers were held in low regard (see Table 2). There was one exception. Joint meetings between Fairfield and a very affluent neighboring community were positively perceived. This was because the two science department staffs met jointly and exchanged information on How-to-do-it!

Television was perceived as an impottant source of new information on scientific and technological developments by the specialist teachers in high school. Moveover, they used television in an unexpected manner to provide up-to-date science content in their classes: videotapes of television programs such as Nova were played in class for students. Because teachers tended to use their videotapes for more than one class, the content and logical organization of the program was observed by the teachers on several occasions. This redundancy in presentation, plus the additional processing of information which was necessitated by leading discussions of the program with the students, makes this an important source of new information for teachers who use it in this manner. However, not all teachers used videotapes this way; some merely played the program for students without watching it themselves and then did not provide follow-up discussions to integrate it with other subject matter.

Readers also may find the procedure used by teachers to obtain the videotapes interesting. The school's audio-visual director, at a teacher's request, would set up the school's videotape recorder to turn on automatically to a particular show at its scheduled time. For example, if a National Geographic Special on Dr. Leakey's work in Africa is to be aired at 8:00 p.m. on Thursday evening, the biology teacher would simply request that it be taped and Friday morning, at the beginning of school, the tape is available.

ANALYSIS AND INTERPRETATION

Formulation and Implementation of School Science Policies and Programs

The data presented in the previous section have led the author to state the following assertions:

1. Administrators and science teachers only contact each other regarding the more general aspects of the science program such as budget for equipment and supplies, approval of course titles and broad areas of content, formal approval of texts, and establishment of minimum time requirements in science.

2. Beyond these more general concerns, individual teachers have a high degree of autonomy regarding choice of content, classroom approaches, use of available class time, and standards of performance expected of students.

3. There are few checks and balances in the system to assure valid choices of content, quality teaching, or appropriate standards of performance.

The data obtained in Fairfield led the author to question if anyone has an adequate grasp on the overall science program in the school. Moreover, given the organizational structure and the nature of the involvements of key individuals, perhaps it is not possible for anyone to be in charge. The Curriculum Director served a dual role--he also is principal of an elementary school. Thus, he probably cannot devote a sufficient amount of time to the duties as curriculum director to know, in other than most general terms, what is being taught at various grade levels by different teachers. Moreover, since he gave the author obsolete program descriptions for science, perhaps he is unable to fulfill even the more general role of keeping accurate records on the formal curricular structure.

The principals of the middle and high schools clearly do not have the propensity to provide direct supervision of science teachers. They appear to give attention to areas other than instructional and curricular improvement. Moreover, because of the specialized nature of science, it is reasonably certain that they are not prepared to work with science teachers in planning the science program or in improving teaching either with individuals or with the entire department. In addition, it is clear that the teachers do not seek their help and would probably resent it if it were offered.

Finally, the Science Department Chairman does not have time available to observe classes of other teachers or to work with teachers on instructional or curricular improvement. Thus, it is reasonable to conclude that, in fact, no one is in charge. Within a very broad set of boundaries, each teacher is highly autonomous and few checks and balances exist to (1) help teachers improve their skills and effectiveness, (2) assist in implementation of a coordinated program from one grade level to the next, and (3) to correct deviant behavior in choice of content, approach, or standards imposed on students.

Since teachers have a high degree of autonomy in their classrooms and because policies, requirements, and standards on school science are very loosely implied and poorly communicated by colleges, testing programs, and administrators; teachers can, individually and unilaterally, make determinations on content, approach, and standards which should be made collectively. Moreover, these determinations are, quite likely, at variance with the actual intentions of parents and administrators but may result from misperceptions. That is, it is quite unlikely that the

Fairfield administrators would condone Teacher C's actions in mindless repartee with eighth-grade students about his receding hair line or his teaching students nonsense like "Bacteria in sewage treatment kills the sludge." Unfortunately, the system has no way of "checking up" on this kind of behavior. Moreover, in spite of the excellent work that Teacher A had done over her first year of teaching, her contract for the next year was not renewed because she lacks seniority. With injustices such as this in which a competent teacher is dismissed and an incompetent one is retained, one can only be disappointed and disheartened.

Beyond the inablity of the administrators to detect and remedy such unfortunate situations, there is a related problem. Since science teachers have such a high degree of autonomy in determining content, approach, and standards, what criteria can they use to make these choices and decisions? In the field of science education, this constitutes one of the most serious problems facing the profession at present. Gallagher and Yager (1981) reported on surveys of five populations of both regional and national scope which asked views of science teachers, supervisors, and university faculty members regarding problems facing science education. For all five populations surveyed, the most frequently cited problem was lack of clarity of goals and purposes of science teaching. Respondents also cited lack of leadership and agreement within this profession as a case of uncertainty. Thus, in view of the important responsiblity placed on teachers in making choices about content, approach, and standards, the uncertainty regarding goals and purposes which abounds in the profession should be a matter of grave concern. In short, our science teachers have a high degree of autonomy to make decisions but they are poorly equippped to make them. Moreover, the persons surveyed perceive leaders as giving mixed messages instead of clear direction.

If teachers are to benefit maximally from the professional growth activities which they now are using, some new vehicles are needed, especially to translate educational research findings into a form that is useful for practitioners; but it will be even more crucial to foster a different set of attitudes about knowledge and the need for continuing professional growth that will nurture reading and thoughtful investigation of new ideas.

Effects of Teachers' Knowledge, Values, and Belief Systems on Choices of Content, Methods, and Modes of Interacting with Students

The "low key" approach taken by three of the teachers studied with students in grades seven, eight, and nine, which was motivated by their desire to take pressure off students because of the confluence of internal family stresses and the usual stresses of the onset of adolescence, appears to be inappropriate. Instead of making it easier for students, the lack of structure and rules of good behavior required students to make choices that are difficult to make, given the strong peer influences that exist at this age. In essence, students had to choose between conformance to a set of norms established by their friends and a set of norms implied by the teacher. Moreover, the latter was relatively unatttractive, poorly articulated, and mildly enforced (except at report card time), while the former had a great appeal and provided immediate rewards and few sanctions.

However, it was clear that many students knew they were being short-changed by ineffective teaching and by the lack of standards of performance. In Teacher C's honors class, bright eighth-grade students conveyed disappointment at his inability to comprehend their questions and to help them learn the subject matter of their sophisticated, inquiry-based science program. As a result, like better students in ninth-grade classes, they worked together to solve problems and to compare answers and strategies for obtaining them.

It also was clear that required science classes were not places of mutual collaboration between students and teachers. Teachers did not require students to be attentive, to work on the subject matter, or to be courteous to one another or to them. Students did about as they pleased, within certain broad limits. No one left class. There was no fighting. There were numerous instances where students would call out comments that were disruptive to the teacher and to other students; some even bordered on disrespect. But teachers and students did not make contact with each other in an intellectual or emotional manner. Teachers did not help students learn subject matter, nor did they encourage quality in performance or work habits.

To reiterate a point made earlier, students and these three teachers were at a "stand-off" with each other. Students and teachers appeared to have formed an unarticulated truce that said "if teachers don't make too many demands on students, then students will behave reasonably well in class for teachers." Moreover, this "stand-off" has been reported to the author by peers who are knowledgeable about two other junior high schools in the area. Further, it may be inferred that it is an extension of the viewpoint which teachers perceive administrators promulgating that says "keep a smooth ship . . . don't let anything rock the boat!"

As a consequence of this "stand-off" between students and teachers, the interactions between them are benign. Teachers are not "touching" students. Little is happening between them. As with principals and teachers, teachers and students have their own agendas which are carried out with only modest "contact" with the other. But the consequence of this pattern of action is an ever-growing sense of apathy and alienation as teachers and students fail to make significant contact with one another. Each has fallen victim to one of the early stages of demoralization in which they are satisfied with an acceptable minimum performance (Shibutani, 1978). Apathy and alienation are fostered by the fact that each sees the other as uncaring. To students, the tasks assigned by teachers appear meaningless and students are powerless to change them. Teachers, who have been working for a decade or more at the same job, share students' feelings of meaninglessness in their work, and they also feel powerless to bring about change.

Mottaz found that powerlessness and meaninglessness are the most important determinants of estrangement between workers and their jobs. Further, Mottaz (1981) found that opportunities for promotion and supportive supervision were additional factors in preventing apathy and alienation of workers and their work place. Since both of these are lacking in the school environment as it is presently organized, one cannot be sanguine about the possibility of correcting teachers' sense of alienation. Further, since students share the same sense of alienation and since teachers are not providing the classroom equivalent of supportive supervision, the alienation between teachers and students may tend to increase.

On the positive side, many students do have opportunities for "promotion." More-able students recognize the bright possibilities which are available to them. This may be accounted for at least partly by the hope and exuberance of youth. Good students recognize that they will advance, go to college, and in all likelihood obtain a good job. Less-able students, on the other hand, perceive that school is not helping them advance toward successful adult roles. As a result their alienation increases, and they avoid academic subjects, including science.

Further, not only are many students presently being shortchanged in the amount of scientific knowledge which they will acquire during high school, but three other factors are important:

1. Students at Fairfield are not learning how to apply scientific knowledge in practical situations such as those which will confront them as adult decision-makers in a technological world. Neither were these students having opportunities in science classes to develop scientific attitudes such as belief in a rational approach to understanding, suspended judgment, weighing evidence, and using evidence to formulate conclusions. In our democratic society, where citizens have a strong role in decision-making, this is a serious omission.

2. Students were not being given the knowledge base in science and its technological applications that will serve future employment needs in a high technology world. In other industrialized nations and even in developing nations, nearly all students are given intensive scientific training so that they can be productive members of the workforce in an advancing technology (Hurd, 1982). However, the students observed in this study were not prepared for their future in a world of work which is growing in technical complexity.

3. Stake and Easley (1977) reported that in eleven school districts in their study, students learned less science and mathematics content than they had expected, but instruction thoroughly reinforced the work ethic. In this study, many <u>students are learning neither scientific content nor the work ethic.</u>

Sources and Effects of New Information about Science and Pedagogy

Teachers did not appear to use systematic means of acquiring new information. As a result, they tended to get fragments of information or something other than a coherent picture of new developments. Moreover, the fragmented character of new information was reinforced because their readings tended to be sparse. Only one teacher read enough so that he could acquire coherent understanding of new information. Further, choice of sessions at professional meetings did not enrich their background appreciably as "how-to-do-it sessions" typically deal neither with subject matter nor pedagogy in a theoretical manner.

Further, teachers frequently equated the term "theoretical" with dysfunctional. The notion that ideas or theories can be useful guides to action did not appear to be part of most teachers' belief systems. Thus, there is a schism between university and governmental agency personnel, as leaders in science education, who tend to talk about a: : attempt to apply theories and other abstractions to practice, and teachers who appeared to comprehend teaching as a craft. This schism between "thinkers" and "doers" is serious because it influences (a) teachers' motivation to acquire new information about both science and pedagogy from reading and professio.al meetings and (b) the mind-set which teachers possess as they enter into inservice programs which, typically, are mandatory. Thus, practitioners in the schools and faculty in universities have different belief systems about knowledge and may attribute different meanings to key words and phrases.

Teachers appear to have invented a beneficial use of television programs which feature scientific and technological content. As they often appear to be used, videotapes of television programs provide an important vehicle for bringing relatively current scientific content into classrooms. Moreover, since the content of such programs usually has a logical organization that has been carefully thought out, this adds an important feature to the science program. Also, since many contemporary television programs give not only conclusions of science but also the processes by which conclusions were derived and the applications that have been made, teachers' and students' science instructi)n is enriched through the use of videotapes; however, there are some pitfalls. Often, television programs are very fast paced, and one viewing of a tape may not result in adequate comprehension of the subject even for teachers. Thus, teachers need to recognize the "density" of content in these tapes and plan instruction so that students can benefit from it.

In spite of the benefits which some teachers derive from reading, attendance at professional meetings and inservice workshops, and television, the overall effect of these activities on science teachers' professional growth is modest. For most teachers, the rate of acquisition of new scientific, technological, and pedagogical information is rather slow and it is unsystematic. Some vehicles like Scientific American and Science 82 provide more comprehensive systematic analyses of selected topics, but teachers tend to read Science News, Discover, and magazines about conservation and natural history which provide short, superficial coverage of topics. In pedagogy, few appropriate journals exist to translate the findings of research into a form that practitioners can utilize. Thus, it is not surprising that teachers' growth in this area is small.

At one time, teachers obtained new and up-to-date information from university graduate courses in science and education. Because teachers are now older and already possess continuing education certificates and advanced degrees, far fewer teachers are availing themselves of this approach to rapid acquisition of new knowledge.

If teachers are to benefit maximally from the professional growth activities which they now are using, some new vehicles are needed, especially to translate educational research findings into a form that is useful for practitioners; but it will be even more crucial to foster a different set of attitudes about knowledge and the need for continuing professional growth that will nurture reading and thoughtful investigation of new ideas.

SUMMARY

The preconditions for excellent science instruction existed in Fairfield, but, generally, it was not occurring. Although some teachers were providing good instruction, others were providing students with rather meaningless instructional content, presented in uninteresting ways. Lessons tended to be poorly organized and executed.

Teachers had almost total autonomy in decisions regarding what was taught, how it was taught, and the standards by which students were evaluated. Moreover, teachers had autonomy regarding entry of students in elective or honors courses.

Supervision by administrators was nearly absent in the district. Moreover, standardized tests were not keyed to instructional objectives and, therefore, were not used (nor were they useful for) appraising instructional effectiveness.

As a consequence, there were no checks and balances on teachers, who adopted a "laid-back" approach to interactions with students. It was as if teachers and students had called a truce not to seriously disrupt one another's peace. Thus, teachers "sorta taught" for a while each period and students "sorta attended" to learning. But the two agendas were quite independent of each other, and students who chose to be inattentive through the teacher's lesson were reprimanded only mildly, if at all.

Teachers and students did not have significant contact with each other in an intellectual or emotional sense. Little energy was invested by either, and few meaningful contacts were made. The learning environment was, for the most part, bland and unexciting.

Further, it appeared as though the consequence of this was estrangement of teachers from teaching and students from learning. Teachers conveyed the feeling that administrators and students did not care about quality performance in teaching; and similarly, it appeared that students felt that teachers had little interest in them and in teaching. Perhaps administrators also held the same views as students regarding teachers, but the author was unable to elicit much information from administrators on the matter of poor-quality teaching.

Related to the question of teachers' acquisition of new information, television programs, such as Nova, are important sources of new, well-organized scientific content that includes both the processes by which the knowledge was acquired and its applications. No counterpart relating to improved knowledge of instructional approaches was found. Moreover, teachers generally do not read professional literature of a scientific or pedagogical nature, although one of the nine teachers was an avid reader and subscribed to eleven scientific and educational journals. For most, however, their approach was unsystematic and the rate of acquisition of new knowledge was very slow. Further, teachers showed little interest in acquiring new information that would improve teaching other than narrowly conceived how-to-do-it techniques.

IMPLICATIONS

Why did the discrepancy exist between the potential which Fairfield Schools exhibited and the reality t[illegible] [illegible]ized, expecially in the required science courses? It has been prop[illegible] y this author that estrangement has set in between administrators and teachers on the one hand and between teachers and students on the other.

The term estrangement has been chosen to describe this phenomen[illegible] for two reasons. First, it has been used by Mottaz (1981) in [illegible]s sociological investigations to describe alienation between worker[illegible] and their work. Second, its [illegible]ning seems to fit the situation most closely. Estrangement means the [illegible]placement of a positive feeling with a negative one. In the elementary school, students generally like school, teachers, and science. During this [illegible]thor's observations, many students' feelings toward Fairfield's required science classes exemplified estrangement. For some students, attitudes approached hostility and demoralization. Teachers also generally begin their careers with positive attitudes toward administrators, students, and their subject matter; Teacher A's enthusiasm for her work and for her students is not atypical of new teachers. However, the other three teachers of required science courses demonstrated varying degrees of estrangement toward their work, students, and the subject matter. Moreover, one high school teacher told me of his desire to find a new job if only one were available.

Possible reasons for estrangement between teachers and their work were suggested by Mottaz. He stated that feelings of meaninglessness and powerlessness are the two most significant determinants of estrangement between workers and work. Further, he pointed out that supportive supervision and opportunity for advancement are the important deterrants to estrangement between workers and their work. Clearly, then, one implication for reduction of estrangement would be to increase the level of support and supervision which principals or the department chairman would provide for teachers.

Opportunities for advancement require more careful thought. In our present educational climate, only a small percentage of classroom teachers are able to move into administrative or university positions. Also, few are willing or able to give up the security and moderately good salaries which teaching provides to find advancement elsewhere. A few science teachers, who are well trained and somewhat specialized, are able to work in industrial laboratories during the summer as a temporary form of advancement. The effects of these arrangements are beneficial, and further opportunities need to be provided.

Perhaps opportunities for advancement need to be internalized and tied to advancement of the teachers' knowledge of science and pedagogy. In this regard, Part 3 of the study on teachers' information sources takes on added meaning, especially in its relationship with values and commitments studied in Part 2. Is it possible that individuals who advance their own knowledge of science and improve their effectiveness as teachers are able to internalize their own professional growth as advancement?

If this is possible, then perhaps there is a way of providing teachers with opportunities for advancement within the context of the present school organizational structures. At present, we do not have sufficient data to make a judgment. Therefore, investigation of this question is needed. If this is not possible, then alternative solutions need to be sought regarding the "professional ceiling" which teaching places on people. Regardless of the outcome of such investigations, the effects of lack of opportunities for advancement for teachers are serious and need attention.

In addition, there is a parallel between the estrangment of teachers and their work and the estrangement observed between students and their work in required science courses. The parallel also is two-fold: first, teachers and students need to make contact with each other regarding the subject matter of science and the values inherent in it. The responsibility for this lies with teachers and administrators. Second, science needs to be be made meaningful, since many students appear to feel that science, as it is presently being presented in required courses (and in some elective courses, too), is meaningless in helping students fill adult roles. Many students presently seem unable to comprehend how it contributes to their future advancement. Responsiblity for correcting this problem lies with the teachers, but it is not solely their domain. The goals of school science need to be clearly defined by leaders in the field and by appropriate professional organizations (Gallagher and Yager, 1981). Moreover, instructional materials and tests should be refined so that they reflect these goals. Administrators, teachers, and teacher educators need to subscribe to these goals, putting an end to the attitude that "whatever one wishes to teach in science is acceptable!"

Returning again to the question of teachers' acquisition of new knowledge about science and pedagogy, the desire to be a continuing learner did not appear strong among most teachers studied. Profes. onal growth, improved competence, and deeper understanding of sub t matter, teaching, or students did not appear to be prized. Superficial knowledge seemed adequate for most teachers. It is most impo tant to know why teachers tended to emulate their students' attitudes regarding search for, acquisition of, and use of new knowledge ather than exemplifying intellectual curiousity and a desire for depth of understanding of both the subject they teach and the processes of teaching and learning. Further, why are science teachers neither interested in nor able to utilize their own classes as objects of inquiry in learning more about learning and teaching?

Administrators and teachers in Fairfield felt that their work was effective. The Community Survey, cited earlier, shows that adults in the community are satisfied with the way that schools are functioning. Millage votes have been successtul, and no teacher strikes have occurred. Each teacher was unequivocal in showing how his/her actions were consonant with the best interests of students. Each administrator was also unequivocal in stating that he was doing his best, given the myriad of demands placed upon him.

With teachers and administrators believing that current practice is at least satisfactory, change will be difficult. Shibutani (1978) has shown that effor.s to "shape up" organizations that are functioning poorly may make matters worse, instead of better. Thus, as we enter a new period of reform in science teaching, governmental and educational leaders, who are formulating and implementing policies for change, must comprehend current school practices and the values and beliefs which underlie them. Mandating that more science be taught to more students at a higher level or standard may not bring desired outcomes unless school personnel believe it is both desirable and practical. In short, we cannot change practice unless we also change the values and beliefs which lie behind it.

This was a pilot study of one district. It is clear, even in this ideal setting, that science instruction is in deep trouble. But, before one can generalize about school science, other districts need study. Therefore, the author requests assistance from other ethnographers and science educators in continuing this work on a much larger scale. The ideas included here are extremely important if we are to make sensible judgments about the improvement of school science. Moreover, other questions regarding science instruction need to be explored using these techniques. Therefore, more work is needed!

References

Agar, M. H. The Professional Stranger: An Informal Introduction to Ethnography. New York: Academic Press, 1980.

Goodlad, J. School Curriculum Reform. New York: Fund for the Advancement of Education, 1974.

Gallagher, J. J. and R. E. Yager. "Science Educators' Perceptions of Problems Facing Science Education: A Report of Five Surveys." Journal of Research in Science Teaching, 18: 505-514, 1981.

Helgeson, S. L., P. E. Blosser, and R. E. Howe. The Status of Precollege Science, Mathematics, and Social Science Education: 1955-1975. Volume I, Science Education. Columbus: Ohio State University, 1978.

Hurd, P. D. The State of Precollege Education in Mathematics and Science. Paper delivered at convocation of National Academies of Science and Engineering, May 12, 1982.

Kaufman, H. Administative Feedback: Monitoring Subordination Behavior. Washington: Brookings Institution, 1973.

Korth, W. and C. Cornbleth. Classrooms as Settings for Cognitive Learning Opportunity and Instruction. Unpublished paper. Pittsburgh: University of Pittsburgh. (Undated)

Melman, S. Decision Making and Productivity. New York: Wiley, 1958.

Mottaz, C. "Some Determinants of Work Alienation." The Sociological Quarterly, 22: 515-520, (1981).

National Commission on Excellence in Education. A Nation at Risk: The Imperative for Educational Reform. Washington: U. S. Government Printing Office, 1983.

National Science Board. Educating Americans for the 21st Century. Washington, National Science Foundation, 1983.

National Science Foundation. What Are the Needs in Precollege Science, Mathematics and Social Science Education? Views from the Field. Washington: National Science Foundation. Publication 80-9, 1980a.

National Science Foundation. Science and Engineering Education for the 1980's and Beyond. Washington: National Science Foundation, 1980b.

Shibutani, Tamotsu. The Derelicts of Company K: A Sociological Study of Demoralization. Berkeley: University of California Press, 1978.

Simon, H. A. Administrative Behavior: A Study of Decision-Making Processes in Administration of Organizations. New York: Macmillan, 1981.

Stake, R. E. and J. A. Easley. Case Studies in Science Education. Urbana: University of Illinois, 1978.

Weiss, I. R. Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education. Durham, N.C.: Research Triangle Institute, 1978.

Wirszup, I. "Science Education and Economic Development." Keynote address, Conference on Science Education and Economic Development, Michigan State University, May 19, 1981.

INTRODUCTION TO CHAPTER EIGHT

This is the first chapter in this yearbook to present a study that would qualify as "research" under the paradigm that prevailed at the time of the first AETS yearbook in 1974. The studies recorded in this chapter involved relatively large numbers of teachers and careful attention to such issues as experimental design and reliablity of data collection. Even this study, however, was primarily qualitative rarher than quantitative in nature: the studies reported here focused on the collection and analysis of narrative data.

In this chapter, Julie Sanford writes about management of science classrooms, an issue that anyone who has spent much time in science classrooms will recognize as important. She describes a series of studies in which she and her co-workers have established that good managers have a number of common characteristics, describes those characteristics, and demonstrates that the skills of good management can be taught to beginning teachers.

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SCIENCE CLASSROOM MANAGEMENT AND ORGANIZATION

Julie P. Sanford*

Introduction

This chapter examines science classrooms from the perspective of research on classroom organization and management, with the purpose of providing teachers and teacher educators with a framework for thinking about this aspect of effective teaching. There is, of course, no simple answer to the question of how to manage a science class. A wide range of management approaches exists; and specific strategies must be selected in light of different instructional objectives and student, school, community, and teacher characteristics. However, research has demonstrated the importance of a number of general principles and management skills. Information about these general principles and illustrations of how these principles operate in different classes can help teachers plan for effective learning environments, assess their own management practices, and decide what changes might be worthwhile.

First, what is meant by the term classroom management? Before we settle on an operational definition, let us consider the hypothetical case of Jim Brown, a third-year teacher of eighth-grade science. Jim has an excellent background of university coursework, and he shows a real flair for communicating information and enthusiasm about his subject. Jim says that he likes his students, but that they do not listen, and the misbehavior of a few causes difficulties for all. He is getting discouraged with teaching, and lately he has attempted fewer interesting activities with his classes. If we were to visit Jim's class, this is what we might observe:

> When the bell for class rings, Jim Brown is at his desk, conferring with a student who has been absent. Several students are out in the hall, three stand at the aquarium, and two wait by the teacher's desk for attention. The other students are seated at their desks, visiting. After several minutes, Jim manages to get everyone seated and begins checking roll, but a girl calls out asking what they are doing today. Jim announces the topic and says that they will use their textbook. Four students say they did not bring their book and request passes to their lockers. The teacher turns down the request and tells them they will have to share. As he finishes roll call and begins an announcement, a tardy student enters. The teacher stops to question the boy and

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notices that he has come with no book or supplies.

Jim announces the topic for the day's lesson again and begins a discussion, but while he is talking many students are getting out their supplies. The boy who was tardy borrows paper and pencil. Two students get up to use the pencil sharpener. The teacher stops his presentation to remind the students that they are not supposed to sharpen pencils when he is talking. The students say they need their pencils to take notes, however, and Jim relents and waits for them to finish. He begins again. The 15-minute lesson is well prepared and well organized, and the teacher uses a model, transparencies, and the chalkboard to help students understand and take notes. The examples and illustrations he uses are appropriate and engaging. Many students seem interested and involved, but students in the center front section of the room answer most of the questions or volunteer comments. Others on the periphery are less involved. Two pairs of students whisper persistently about social affairs. One girl is writing a letter. At least four students take very few or no notes. In fact, three have nothing out on their desks.

At the end of the presentation, Jim assigns three pages of the text for students to read. Then they are to use the text information and the notes from the lesson to answer some questions. The teacher tells students the page numbers and begins to give directions for the written assignment. Two students call out, asking for a repetition of the page numbers. Meanwhile, students are passing back the handout of questions, and several are moving their seats to share textbooks. Some talk persists while the teacher gives directions. When Jim finishes talking, several students ask their neighbors what to do, and one boy loudly calls out to the teacher, who is seated at his desk, with questions that had just been answered: When is this due? Do we have to write the questions? The teacher answers these questions again and announces that he will be calling students individually to his desk to help them with their term projects. He reminds students to keep the noise down.

In the ensuing 30 minutes, the teacher's conferences with individual students are constantly interrupted by students walking up for assistance or calling out questions. The teacher several times asks the class to get quieter, as first the students sharing books and then much of the class begin to talk too loudly. Several students appear to do nothing. Others begin writing without reading the assigned text. Everyone's work is interrupted once, as a boy wanders over to the aquarium and announces that a fish has died. When someone accidentally knocks a glass beaker onto the floor, the teacher has trouble getting students to return to work.

When the bell for the end of class rings, Jim has managed to confer with only four students about their projects. He tells students not to leave until they have returned the handout, which he needs for the next class. Several students complain, saying they have not copied the questions and will no be able to finish. Others are finished but have put the handout in their notebooks. One student is upset because she has written her answers on the handout. The class ends on a harried note.

Although Jim Brown is fictional, many classes like the one described above have been observed during studies of classroom managment conducted at the Research and Development Center for Teacher Education at The University of Texas. Teachers like Jim Brown are often dissatisfied with their classes, but they may not think of themselves as having managment problems, for they equate management with discipline problems, specifically with handling disruptive, disrespectful, or uncooperative students. Many such teachers can think of few ways to improve their students' involvement with instructional activities or to make their classes run more smoothly.

Yet, classroom research on effective teaching in the past 10 years suggests that teachers like Jim Brown could be more effective if they had a broader conception of classroom management. A teacher's role as manager encompasses many tasks--pacing activities, monitoring work, designing efficient routines and teaching students to use them, providing and organizing materials, among others--that are essential for maintaining good classroom learning environments.

Failure to perform these management tasks well had both immediate and long-term results. Classroom management studies have found that poor management is associated with low levels of student engagement or involvement with learning activites (or low time-on-task), large numbers of students unable to complete tasks successfully, or a high incidence of inappropriate, disruptive, or off-task, unsanctioned behavior. Studies have also called attention to large portions of class time wasted in slow starts, long transitions, and periods of confusion, delay, or waiting for many students. Many of these indicators are clearly present in Jim Brown's class.

Short-term measures such as engagement are not in themselves indicators of effective teaching or learning. However, research has established links among measures of student engagement, class-time use, disruptive student behavior, and student learning gains. These links have been most clearly demonstrated in basic skill learning in elementary grades (Good, 1979), but a relation between student behavior and achievement has also been suggested by studies in secondary reading, English, mathematics, and science (Evertson and Emmer, 1982; McGarity and Butts, 1982; Newton and Capie, 1982; Stallings, Needels, and Stayrook, 1979). Other long-term effects of management are related to the impact of managment concerns on teach · ' curriculum decisions and thus on the content students experience in the classroom (Anderson and Barufaldi, 1980; Doyle, 1979). This line of research suggests that teachers who experience difficulties getting students to cooperate and activities to flow smoothly may be more likely to limit their classes to a narrow range of routine seatwork tasks. Finally, orderly learning environments seem to be preferred by students (Fisher and Fraser, 1983). In sum, there is ample evidence that good classroom management and organization are necessary though not sufficient condition for effective instruction.

IDENTIFYING EFFECTIVE PRACTICES

A series of studies of classroom management at The University of Texas included a descriptive study of 102 junior high school English and mathematics classes (Emmer, 1981; Evertson and Emmer, 1982). In that study, classroom observations began on the first day of school, continuing through most of the school year. Each observation extended throughout the entire class meeting, and each teacher was observed regularly by at least two different observers, who made narrative records of classroom events and sequences of activities and completed student engagement ratings (periodic counts of students involved in academic or procedural activites, off task, or in dead time). They also assessed student and teacher behavior on a number of variables relating to instructional management, rules and procedures, meeting student concerns, managing pupil behavior, disruptive and inappropriate student behavior, and classroom climate. In addition, student achievement test scores were obtained.

Data analysis consisted of a two-step process. First, data on student achievement gains and student behavior were examined to identify groups of more and less effective managers. Effective managers were defined as those whose classrooms were characterized by:

1. High mean proportions of students engaged or involved in instructional activities and relatively few students off task;

2. Low occurrence of disruptive or inappropriate student behavior; and

3. High class mean achievement test scores, adjusted for entering achievement levels.

The second step in data analysis was to examine classroom management behavior, which we will describe and illustrate later in this chapter. An interesting aspect of results of the study was lack of findings for some factors many assume to be important for management. For example, no significant findings resulted for teacher characteristics such as warmth or listening skills, for provision of a <u>variety</u> of activities or differentiated assignments and materials, or for most specific stategies for dealing with disruptive student behavior. Analysis of the effects of differences in class ability level, class size, ethnic composition of classes, and subject areas (mathematics or English) showed that, while some of these context variables have effects on classroom processes, the teacher's management skills and behaviors are much more important influences on students' classroom behavior and achievement. Good classroom managers are likely to be effective with different kinds of classes, and general patterns of effective management behaviors hold across different subject areas and different groups of students.

Results of this large descriptive study indicated that effective managers establish and consistently use workable, comprehensive classroom procedures and rules, monitor student work and behavior closely, deal with inappropriate behavior quickly and consistently, communicate directions and instructions clearly, and organize and pace instruction so that events flow smoothly at a pace appropriate for students' ability levels and attention spans. The narrative data collected during classroom observation provided many specific examples and illustrations of how different teachers in the study established and maintained good learning environments.

To learn more about management in different subject areas and contexts and to test the principles and generalizations that had resulted from the study, we developed a manual for teachers Organizing and Managing the Junior High Classroom (Emmer, Evertson, Sanford, Clements, and Worsham, 1982) and field-tested it in the Junior High Mangement Improvement Study (Emmer, Sanford, Clements, and Martin, 1982). The manual contains guidelines, checklists, case studies, and examples to help teachers organize and plan for the beginning of the school year, maintain good student behavior, and organize instruction. To assess how well the manual could help relatively inexperienced teachers establish and maintain well-managed classes, two teacher groups, balanced for years of experience, grade level, and subject area were formed before the school year began. One group received the manual and attended two workshops at the beginning of the year. Teachers in the comparison group received the management materials later in the school year at the end of the study. Two classes taught by each teacher in the study were observed frequently from the first day of school to monitor the extent to which teachers used the management practices recommended in the manual and to assess the effects of management practices on students' behavior. Each teacher was seen by several different observers who did not know the group assignment of teachers. Observation procedures were similar to those used in the earlier descriptive study.

Results of the JMIS indicated that teachers who received the manual and attended the workshops at the beginning of the school year used the recommended management strategies and behaviors more than teachers in the comparison group and that using the recommended strategies helped teachers establish classes with higher levels of student task engagement and cooperation. These results were similar to those obtained in a parallel study at elementary grade levels (Emmer, Sanford, Evertson, Clements, and Martin, 1981).

Describing Management in Science Classrooms

Part of the sample for the JMIS included 26 science classrooms (grades 6-8) taught by 13 teachers. A separate, correlational analysis of data from these classes was carried out to identify teacher management behaviors related to student on-task, off-task, and disruptive behavior in science classes. In addition, to investigate in more detail how effective teachers manage typical science classroom activites, three groups of teachers in the science sample were identified: three very effective managers, seven moderately effective managers, and three less effective managers. Narratives of classes taught by teachers in the three groups were read, compared, and summarized to describe and illustrate more and less effective management and organization practices.

The fictional Jim Brown's class meeting, described at the beginning of this chapter, was fairly typical of science lessons conducted by less effective managers in the study. They were characterized by low levels of student engagement, frequent confusion over lesson requirements or directions, unnecessary delays and disruptions, and little work accomplished. In contrast, lessons taught by the most effective managers in the sample were more like those of James Smith. One of his class meetings is described below.

(The class had been introduced to the topic of chemical elements and the periodic chart of elements on the previous day.) During roll check the teacher has students clear their desks, except for pencils. Then he begins class with six minutes of review presentation and questioning about the elements. He distributes a worksheet and gives directions for completing it. Students listen and ask questions, which the teacher answers. Then he gives the class directions for a second task: After students complete the elements worksheet on their own, they are to copy a list of elements and symbols from a transparency on the overhead projector. He explains that he will be calling students up in groups to check their understanding of the periodic chart and to help them with the last part of the worksheet. If students have a question about the worksheet before they are called up, they are to wait, working on their second assignment if they cannot continue on the first. He writes these two numbered assignments on the board.

As soon as all students start work, the teacher calls eight students for instruction at the periodic chart. He spends about five minutes questioning and instructing students in this small group. When some students working at their desks begin to talk, he reminds the class to work alone on the worksheet, then he finishes his discussion with the small group and sends these students back to their desks. A second group is called for instruction at the periodic chart. Students move quickly to the teacher, who watches the transition while standing near the chart at the front of the room. When the teacher finishes instructing this group (in about six minutes), he calls the remaining students in class for small group instruction at the periodic chart. The rest of the class continues work at their seats. When some talk begins the teacher quickly stops it with eye contact or a word or two.

As soon as the periodic chart instruction is finished, the teacher circulates around the room, helping students with their worksheet. He finds a boy who has stopped working and helps him get started again. As some students begin to copy the list of elements and their symbols from the overhead screen, the teacher announces that there will be a quiz over these elements, their spelling, and symbols tomorrow. He tells students that after copying the list they should begin studying it, and that they may work quietly together.

Ten minutes before the end of class, the teacher asks for a show of hands of anyone not finished with the worksheet, and tells these five students to finish it at home and to begin work now on their list of elements. He also announces that he will now begin to check the papers of students who have finished the worksheet, and he circulates around the room to check work. Near the end of the period, many students are studying quietly in pairs, quizzing each other over the elements and symbols. The teacher stops students' work one minute before the bell, reminds them what to bring to class the next day and about the quiz, and tells them to get ready to leave.

The differences in terms of management success in the above description contrasted with Jim Brown are obvious. In thinking about these two cases (and about real science classrooms), results of our science classroom study suggest the following management considerations, organized around three major dimensions: classrom procedures and activities, managing student behavior, and managing student work.

Classroom Procedures and Activities

In the 26 science classrooms that were studied, high student on-task rates and cooperative behavior were strongly associated with observer ratings of appropriate general procedures, efficient administrative routines, efficient opening and closing classroom routines, low incidence of students calling out for teacher's assistance, and structured group work procedures. Managing interruptions efficiently, having procedures that enable students to get help without interrupting the teacher, and effective teaching of procedures and rules to students were also significantly related to one or more of the student behavior criteria.

General routines. Of the three teachers in the best manager group, two (B 1 and B 2) used similar approaches to classroom management and procedures while one (B 3) used a less structured but equally effective system. In classes taught by Teacher B 1 and B 2, classes began with a routine that required students to take their seats immediatley on entering the room and begin copying the objectives and assignments for the day from the chalkboard. While students complete these routine tasks, the teachers handled administrative chores. In Teacher B 3's classes, students took their seats immediately and waited quietly until the teacher completed roll check and began to give directions for the day. During class the three best teachers generally had procedures that effectively governed student talk, participation in oral lessons and discussion, getting out of seat, checking or turning in work, what to do when work was finished early, and ending the class.

At the beginning of the school year, all three teachers clearly explained their expectations for student behavior during class, and then followed their presentations with review and reminders of policy as needed in subsequent weeks. In all three classes teachers gave clear, simple directions and provided structure for transitions. They kept students apprised of time left for an activity; they forewarned the class of upcoming transitions; and they brought one activity to an end before beginning another. They also told students what materials would be needed for an activity and had students get materials ready before beginning. Like the fictional lesson taught by James Smith, their classes usually proceeded smoothly, with minimum time and energy lost to procedural and non-instructional matters.

Compare the practices above with those evidenced in the description of Jim Brown's class (which resembled in many ways the less effective managers in our study). In Jim's class no efficient routines were in place for beginning and ending the period, handling administrative matters such as student absences and tardies, student talk during seatwork, or getting help from the teacher. Transitions from one activity to the other as well as at the beginning and end of the period were a source of confusion and delay, because Jim did not signal changes clearly or bring one activity to an end before giving directions for another. He gave directions without getting students' attention, and did not forewarn students of the end of class or of other events and requirements.

Laboratory activities. In the junior high study, narratives of class meetings with hands-on activities provided many illustations of the difficulties that some teachers encounter in trying to conduct such activities. Laboratory activities conducted by poor managers were often characterized as chaotic, with very little work accomplished by students. Students often did not appear to listen to or follow teachers' instructions. Classes were very noisy and many students were rowdy. Teachers ignored most off-task and inappropriate behavior while trying to help individuals.

In contrast, laboratory activities in classes taught by the three best managers usually ran smoothly and efficiently. These teachers defined the task clearly for students, prepared materials and established procedures that allowed students to work with a minimum of confusion and delay, and monitored students' work closely. Students appeared to be involved in the laboratory activities and able to complete their assignments successfully. They were orderly and talk was mostly task related. Management practices associated with such good laboratory work environments showed evidence of teachers' careful decisions about pacing students in their work, student use of materials and supply stations, assignment of students to work groups, communication of directions and objectives, monitoring student work and behavior, procedures for students getting assistance when needed, and expectations for what students should do when finished with work.

Time use and instruction. These findings for science classes suggest a number of considerations for classroom procedures and the conduct of activities. However, the research offers few clear guidelines about how science teachers should allocate time in different types of classroom activities. In our study, relative amounts of class time spent in whole class presentation or discussion, individual seatwork, group work, and testing varied greatly from class to class, and there were no patterns of differences between more and less effectively-managed classrooms. Even with regard to transition time, despite their poor control of student behavior, the low manager group did not have a higher mean proportion of class time spent in transition. (Time per transition may have been longer in those classes, but the teachers attempted fewer activites per class and so had fewer transitions.) Thus, analyzing the proportion of class time spent in different activities does not appear to be a productive way to look at management in junior high classrooms. Instructional time categories are less important variables than are appropriateness, pacing, student accountability, and student engagement rates.

The three best managers in this sample of science teachers were characterized as having a lot of work for students to do in class. Often, several activity segments were planned for each class meeting, and well chosen procedures and routines enabled teachers and students to accomplish instructional activities smoothly. The vignette of the lesson taught by James Smith illustrates many features of skillfully managed classroom activities, such as attention to pacing, student accountability, and provision of adequate instruction related to student tasks. Later we will return to it for further discussion of the management of student work.

Managing Student Behavior

In our study of 26 science classrooms, behavior management practices identified by earlier research and in other content areas were supported by strong correlations with student behavior variables in science classes. Successful management seems to depend on teachers' consistency in responding to student behavior, effective monitoring, stopping inappropriate behavior quickly and with minimal interruption to lessons, and avoidance of students wandering in the classroom. Few significant findings were obtained for various teacher responses to inappropriate or disruptive behavior or for the use of specific reward or punishment systems; for the most part, the more successful managers were successful because they prevented misbehavior rather than because they responded to it differently.

In the three best managers' classes, students were generally expected to work quietly when doing individual assignments and only brief, whispered exchanges between students were permitted. During lab assignments and when students were assigned to work in pairs or groups, talk was allowed. The three best managers monitored student behavior closely, circulating around the room to look at students' work. Even when these teachers worked at their own desks, they were accurate in spotting off-task students. As in the fictional description of James Smith's class, minor inappropriate behavior was usually stopped quickly by all three teachers by reminding students of what they were supposed to be doing, saying the student's name, or asking for silence.

Consequence systems (e.g., demerits, detention after class, and rewards for good behavior or work) were much more visible in classes of effective Teachers B 1 and B 2 than in classes taught by Teacher B 3. Teacher B 3 seldom used (or appeared to need) any kind of penalty with the exception of one mention of "points off," and he used no rewards other than grades. Teachers B 1 and B 2 used a system of demerits and detention after school consistently and fairly to enforce their classroom behavior rules. All three teachers were task oriented, business-like, and congenial. What they said and what they did communicated very clear behavioral expectations to the students.

In contrast, expectations were ambiguous or inconsistently applied in the six science classes taught by three ineffective managers. One of these teachers announced at the beginning of the year very strict classroom behavior rules, but ignored these standards thereafter and often appeared to be comfortable with a very permissive atmosphere in class. All three teachers made fairly clear (although not comprehensive) presentations of classroom procedures and rules at the beginning of the year, but they provided little or no review or reminders afterward. All three presented elaborate consequence systems which were seldom or never used. Compared to student behavior in the other 20 classes of the science sample, students in these classes were often disruptive, uncooperative, inattentive, and they got very little work done.

A problem that consistently characterized poorly managed classrooms was lack of active monitoring. Teachers who were poor monitors were often unaware of whether their students were doing their work successfully or misbehaving. Poor monitors often focused their attention on a group of students (usually those nearest the front of the room c the teacher's desk) and lost contact with the rest of the class. Thus, they were not aware of students who were inattentive, did not have the right materials out, or were not following directions. Some frequently let students congregate around their desk or work station, blocking their view of the rest of the class. Often incidents of minor inappropriate behavior escalated to disruptive events before these teachers noticed and intervened.

In the science sample, the importance of being aware of all student behaviors was especially evident during laboratory or hands-on activities. In these situations there were so many demands on a teacher's attention--replenishing supplies, answering questions, helping and directing groups of students in their work, adjusting equipment, responding to emergencies and minor accidents, demonstrating procedures--that some teachers were unable to maintain surveillance of the class as a whole. Effective managers minimized problems by careful planning and efficient procedures, then gave top priority to monitoring, even if it limited their involvement in student activities and opportunities for individual or group instruction. Episodes of instruction or assistance during the laboratory lesson were usually brief.

Managing Student Work

A consistent characteristic of well-managed science classes as well as other junior high classrooms is that students are held accountable for completing their work and that teachers regularly gather information about student work. Procedures governing student assignments are designed to help students meet work requirements and develop good work habits. In junior high classrooms there is a close relationship between effective work management and appropriate student behavior and task engagement. For example, in the science classroom study, strong relationships were found between good student behavior and such teacher behaviors as consistently enforcing work standards, having efficient routines for assigning, checking and collecting work, and effectively monitoring students' progress and completion of assignments.

Differences in the amount of information some teachers routinely gather about student work on a day-to-day basis are illustrated by contrasting the description of Jim Brown's class with that of James Smith's physical science class (the chemical elements lesson). At the end of the class period, Jim Brown did not know which students had finished the assignment or whether some had misunderstood the directions or failed to start the work at all. The only time he actively solicited information about student understanding was during the content presentation, and then he got little information from students around the periphery of the class. In contrast, the second teacher, James Smith, collected much information about students' progress and understanding: in review questions at the beginning of class, in interaction during small group instruction at the periodic chart, by circulating to help students and look at their work, by surveying to see who had not finished, and by checking the papers of students who had finished.

Frequent monitoring of student progress on assignments was also seen in classes taught by more effective teachers in the science classroom study. They had very clear work requirements and effective routines for assigning, collecting, and checking work. The beginning class routine used by two of the best managers helped students and teachers keep track of assignments. Students were held accountable for copying each day's assignment and schedule of activities into their notebooks. A permanent record of these "plan of the day" descriptions for each six weeks was also maintained on display in the room, so that students who were absent from class could assume responsibility for their own make-up work. In all three of the best managers' classrooms due dates for assignments were not routinely extended or ignored. Students were held responsible for knowing when work was due and for getting it done. They were usually penalized in some way for late work. The work-related procedures and policies in these classes contributed to a sense that the work was important and purposeful.

Both from the teachers' and the students' points of view, one problematic aspect of work procedures in the junior high or middle school grades is managment of long-term assignments such as research papers or projects. Typically at least one such assignment is included in the eighth-grade curriculum, and it may have a large impact on students' grades for one grading period. The procedures used by one of the effective managers in the study provide an example of how science teachers working with junior high and middle school age students can structure long-term assignments to help students succeed:

> For her eighth-grade students' first research paper, Mary Jones assigned topics, rather than allowing students to choose their own. An assigned topic made it easier for students to begin quickly and allowed the teacher to make some adjustments in the difficulty of assignments for different ability levels of students. When she introduced the research paper assignments, the teacher gave each student two handouts describing the requirements. On one page was a description of the topic for the paper and a list of specific questions that the paper should address. The other handout outlined general requirements for the research paper, a calendar of check points, a due date for the assignment, and information about how the research paper would be graded. When she distributed the handout, Mary went over all of the directions and requirements with the students. Standards described in detail included the final appearance of the paper, procedures for corrections, number of references, number of written or typed pages, and a form for compiling the biliography. The check points for the project included an initial approval of the student's list of references and an examination of the student's notes and outline. At each check point students received credit toward daily assignments, the teacher gave them comments or suggestions, and they were required to make up work if they had fallen behind. Mary also provided students with examples of research papers from prior years for examination during class, and she scheduled several days of class work in the library. Before the written report was due, students received a check-off sheet that they used to determine whether they had met all of the requirements before they turned in their reports. (Most requirements had to do with form, not content.) Before oral presentations of the projects were given, Mary distributed copies of and discussed the criteria she used for evaluating presentations.

DISCUSSION AND IMPLICATIONS: INTEGRATING MANAGEMENT AND INSTRUCTIONAL CONCERNS

The work procedures for Mary Jones' long-term assignment illustrates several points. First, it is clear that managing a long-term assignment at the junior high or middle school grade levels requires as much careful planning and sustained effort from the teacher as from the students. More to the point, the description of her procedures touches on an important issue for applying results of management research: management decisions should be made with awareness of curriculum goals and student characteristics. Mary's very structured procedures had costs: students were denied opportunity to choose topics that interested them, the content of the paper was identified (and perhaps organized) by the questions the teacher gave students, and the procedures and grading criteria emphasized form and completeness over content. Students also assumed a minimum of responsibility for organizing and managing their own work. Certainly, different procedures would be appropriate for an older, more-experienced group of students. The procedures Mary chose resulted in all students engaging at some level in the project, and most produced a product with some measure of "success." Students learned something about the process of producing a term paper.

We can point to many other instances of the balance that needs to be maintained between management goals (getting student engagement and compliance) and curriculum goals. For example, research suggests that, especially when working with younger-secondary or lower-ablity students, assignments that are very structured, short term (i.e., students are able to complete a product in a single class period or part of the period), and not too difficult are more easily managed than assignments that are longer term, less structured, and more challenging. Yet all students sooner or later need opportunities to engage in problem identification, decision making, exploration, problem solving, and organizing their own time and efforts. Similar tensions between management concerns and curriculum concerns occur when teachers' desire for quiet and order or the need for individual students to do their own work conflicts with the good that can come from student interaction during hands-on or challenging problem-solving activities. One of the issues at stake is the quality of engaged time. Several researchers (e.g., Newton and Capie, 1982) have demonstrated that student engagement in tasks directly related to particular learning goals may be as important a consideration as simply maintaining student engagement in general. For example, development of science process skills is best promoted by student engagement in planning and data collecting, although obtaining high levels of student engagement in these activities may be more difficult than in simple seatwork activities.

Certainly, science teachers are faced daily with the need to make many management decisions. These decisions are made best by teachers who have awareness and understanding of important dimensions of classroom management. An experienced teacher may decide to tolerate a certain amount of student off-task behavior during laboratory activities in order to assist and provide instruction to individuals. The teacher should be aware of the cost, however, and of alternative strategies available. Similarly, when teachers make decisions about whether to let interested students call out responses and comments during class discussion or whether to call methodically on different students to respond, they may have to balance their desire for an enthusiastic, comfortably-paced discussion against the need to keep all students actively engaged and to monitor all students' understanding. Certainly, the topic and purpose of the discussion need to be taken into account, but many teachers fall into the trap of frequently allowing a small number of students to dominate class discussions and lessons, without being aware of the effects of or alternatives to this teaching practice.

This chapter has highlighted some of the principles that have emerged from research on classroom management and organization, with the assumption that classroom management skills are necessary though not sufficient for effective science teaching and that a detailed awareness of management considerations would help many teachers improve their instruction. In preservice teacher educaton, providing students with information about management variables can help structure observations during field experiences. Our experience with beginning teachers suggests that many do not get enough information about classroom procedures and practices, nor adequate help in planning and preparing for their first teaching assignment and for the first weeks of school. Yet, research provides good evidence that many important management skills can be taught. Providing teacher candidates and teachers with research-based information about management can make a difference in their success as teachers.

In inservice education and supervision, classroom management research is a good resource for providing teachers (and supervisors) with a framework for observing and analyzing their own or others' classrooms. The teacher's manual Organizing and Managing the Junior High Classroom developed as part of our research is being used in many inservice education programs throughout the United States. While quick solutions for teachers experiencing management difficulties are unlikely, providing teachers with information and suggestions from management research can help many improve learning environments in their classes.

References

Anderson, C. W. and J. P. Barufaldi. Research on Elementary School Science Teaching: A Study Using Short-term Outcome Measures (O.P. No. 37). East Lansing, Michigan: Institute for Research on Teaching, Michigan State University, 1980.

Doyle, W. "Making Managerial Decisions in Classrooms." In D. L. Duke (Ed.), Classroom Management. 78th Yearbook of the National Society for the Study of Education (Part 2). Chicago: The University of Chicago Press, 1979.

Emmer, E. T. Effective Classroom Management in Junior High School Mathematics Classrooms (R & D Rep. No. 6111). Austin: Research and Development Center for Teacher Education, The University of Texas at Austin, 1981.

Emmer, E., C. Evertson, J. Sanford, B. Clements, and M. Worsham. Organizing and Managing the Junior High School Classroom (R & D Rep. No. 6151). Austin: Research and Development Center for Teacher Education, The University of Texas at Austin, 1982.

Emmer, E., J. Sanford, B. Clements, and J. Martin. Improving Classroom Management and Organization in Junior High Schools: An Experiemental Investigation (R & D Rep. No. 6153). Austin: Research and Development Center for Teacher Education, The University of Texas at Austin, 1982.

Emmer, E., J. Sanford, C. Everston, B. Clements, and J. Martin. The Classroom Management Improvement Study: An Experiment in Elementary School Classrooms (R & D Rep. No. 6050). Austin: Research and Development Center for Teacher Education, The University of Texas at Austin, 1981.

Evertson, C. M. and E. T. Emmer. "Effective Management at the Beginning of the Year in Junior High Classes." Journal of Educational Psychology, 74 (4): 485-498, 1982.

Fisher, D. L. and B. J. Fraser. "A Comparison of Actual and Preferred Classroom Environments as Perceived by Science Teachers and Students." Journal of Research in Science Teaching, 20(1): 55-61, 1983.

Good, T. "Teacher Effectiveness in the Elementary School." Journal of Teacher Education, 30(2): 52-64, 1979.

McGarity, J. R. and D. P. Butts. "The Relationship Among Teacher Classroom Management Behavior, Student Engagement, and Student Achievement of Middle and High School Science Students of Varying Aptitude." Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, Wisconsin, 1982.

Newton, R. E. and W. Capie. Effects of Engagement Quality on Integrated Process Skill Achievement in Grade 7-8 Science Students of Varying Ability Levels. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, Wisconsin, 1982.

Stallings, J., M. Needels, and N. St ook. The Teaching of Basic Re ng Skills in Secondary Schools, F. : Final Report. Menlo Park: Stanford Research Institute International, 1979.

INTRODUCTION TO CHAPTER NINE

If students are to learn science successfully, then they must remain engaged in learning tasks, but what teacher behavior is most likely to promote student engagement? What can teachers do that promotes quality engaged times as well as quantity? These are among the questions considered by Kenneth Tobin and William Capie in the final chapter of this yearbook.

Drs. Tobin and Capie also consider a number of methodological issues that they have dealt with in the series of four studies described in this chapter. What, for example, are the best techniques for recording and analyzing various types of classroom variables? How can we make sure that there is enough variance on a given variable to make the data worth analyzing? Finally, Drs. Tobin and Capie consider the cognitive mechanisms by which demonstrably effective teaching practices, such as the use of wait time, may have their effects.

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RELATIONSHIPS BETWEEN CLASSROOM PROCESSES AND SCIENCE LEARNING

Kenneth Tobin
William Capie

INTRODUCTION

In the last decade concern for increasing the quality of teaching and learning has had many focuses. In science education, one area of considerable interest has been improving students' ability to use the process skills. These skills are a collection of behaviors which are often grouped under the umbrella of planning and conducting an experiment and interpreting the results. Various process skill components have been named and popularized by a number of elementary and secondary curriculum programs.

The emergence of the process-product research model in the classroom research community has coincided with the concern for improving students' process skill achievement. Process-product research involves studying classroom activities (e.g., pupil achievement). The model can be elaborated somewhat if pupil engagement in activities is included. In this sense the pupil activity may be considered a product associated with the teaching processes. Then, pupil activities would also be processes associated with products such as achievement. The relationships between teacher behaviors, pupil engagement, and outcomes have been depicted with inferred causal links in Figure 1.

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teacher                   pupil engagement              pupil
behaviors       --->       in activities        --->    outcomes



Process ------------------> Product
                            Process -----------------> Product
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Figure 1.

Process-product researchers are also interested in context variables which might influence the effect of processes on product outcomes. Among the context variables likely to influence learning is the time allocated to learning tasks. This fact is generally recognized by teachers at all levels and often manifests itself in competing requests for allocation of a greater proportion of school time, which is usually a fixed resource. Carroll (1963) distinguished between opportunity to learn and engagement. Opportunity to learn may be viewed in terms of the amount of time budgeted by the system or teacher for learning activities. However, engagement, or time on task, cannot be viewed in this way since it is related to the amount of time that a learner is intellectually involved in an activity. Several studies have indicated that the proportion of time in which students engage has a positive and predictable relationship with student achievement (e.g., Hecht, 1978; Ladaherne, 1968; Samuels and Turnure, 1974) while others have confirmed a link between student engagement and teacher performance (e.g., Cornbleth and Korth, 1979; Goldstein and Weber, 1979).

Theoretically, time on task appears to be a necessary yet insufficient condition for learning in classrooms. Slavin (1982) suggested that other variables need to be considered in time-on-task research. For example, variables related to the nature and quality of the tasks in which students engage are also likely to be related to achievement. Recently, researchers commenced investigations of cognitive processes as mediators of teacher behavior and student achievement. The stimulus for this research emanated from Doyle (1975) who argued that a major weakness of the process-product paradigm was that it focused only on student behavior and ignored covert responses during classroom instruction. Doyle presented a paradigm for classroom research that focused directly on the processes that mediate between instructional stimuli and learning outcomes. Winne and Marx (1983) stated that classroom researchers should consider internal processes of students in classrooms and should focus on the student as an information processing learner. They contended that if learning is to occur the student must: perceive the instructional stimuli; note their occurrrence; understand the cognitive processes that are required; use the processes to create or manipulate information to be stored as learned material; and encode the information for later retrieval. If these criteria are accepted as valid, teaching roles can be defined in terms of maintaining appropriate student task involvement and utilizing cues to stimulate the cognitive processes deemed necessary for learning.

Teaching Behaviors Related to Engagement

In order to influence student engagement and achievement, teachers need to maintain a classroom environment that is conducive to learning and ensure that students remain productively engaged in relevant learning tasks. Because of the complexity of classroom learning, there are several types of variables likely to influence the quality of student engagement and level of achievement. Weber (1977) distinguished between instructional behaviors intended to facilitate student achievement on specific objectives and managerial behaviors that create and maintain conditions in which instruction can occur effectively and efficiently (Weber, 1977, p. 287). Several studies have found that instructional behaviors are not effective in promoting achievement unless effective teacher managerial behaviors are also used (e.g., Anderson, Evertson, and Emmer, 1980). An effective learning environment should allow students to practice tasks without distraction from others. If interruptions do occur, student involvement might transfer from productive tasks to off-task behaviors. In such instances the opportunity to learn is less than optimal. Thus, identification of teaching behaviors that establish and maintain high rates of student engagement and minimize the incidence of disruptive events is of considerable importance. Significant relationships between management variables and student engagement have been obtained in numerous studies conducted over a wide range of subjects and grade levels (e.g., Arlin, 1979; Breuning, 1978; Capie and Ellett, 1982; Emmer, 1982).

Another set of teacher variables that is logically related to student engagement and achievement is questioning quality. Teachers can use questions to provide a cognitive focus to promote student engagement on specific tasks. Thus, variation in questioning quality could lead to changes in student engagement and achievement. By providing challenging problems and posing questions at an appropriate cognitive level, teachers might promote the types of thinking required for students to productively engage in tasks during science activities. Other questioning variables are also potentially important. For example, questions that lack precision can lead to confusion or to misunderstanding among learners. Similarly, questions that are not related to the lesson objectives or questions asked at inappropriate times are not expected to contribute to relevant student engagement or to higher achievement.

Teacher discourse is the stimulus most frequently used to focus student engagement and learning. However, if teacher discourse is to influence student learning, information contained in the discourse must be cognitively processed by the learner. As a consequence, the rate at which information is presented should be matched with the cognitive processing capabilities of students. Cognitive processing of data is likely to be dependent on characteristics of the discourse as well as learner attributes such as cognitive aptitude and motivation state. For example, processing time for cognitively complex discourse is expected to be greater than the time required to process less complex verbal information. Thus, as teachers supply information or establish a cognitive focus through soliciting, sufficient time should be allowed for all students to engage in the intended manner. To ensure that adequate time is provided, teachers should consciously manage the duration of pauses after solicitations and provide regular intervala of silence during explanations.

Pauses following student discourse are also of potential importance. As Rowe (1974a) noted, speech is interspersed with pauses that range from quite short time intervals separating individual words to much longer intervals that occur as a speaker completes a segment of speech and pauses to consider what next to say These time intervals often exceed three to five seconds. Siegman and Pope (1965) reported that the length of pauses in discourse increased in proportion to the difficulty of the task, while Rochester (1973) stated that pauses were related to cognitive processing and that their frequency increased as the emphasis on interaction increased. Consequently, as a student attempts a complex explanation, greater cognitive activity is called for and longer pauses separate bursts of speech. Longer pauses provide ample opportunity for a teacher to interrupt student discourse and subsequent task involvement by completing the answer, reacting to the answer, or by asking another question. The student is therefore deprived of the opportunity to completely develop an answer to a question or to correct errors that may have been made. Interruptions of this type, having disrupted cognitive activity, could impair learning. If a teacher can refrain from speaking until three to five seconds have elapsed, the teacher and students will have time to consider what has been said, the respondent may elaborate on the response, or another student might commence to speak.

Pupil Engagement

Two categories of engagement have been defined. Bloom (1980) described overt engagement in terms of doing assigned work or in some way responding in a relevant manner to instruction and the instructional material. If student task involvement is overt, participation can be directly observed. For example, overt engagement might involve discussion, manipulation of materials, writing, drawing, or graphing. Students can use process skills overtly to formulate responses to questions, to justify points of view, to explain events or procedures and to interpret or decribe results. Engagement is best assessed for individual students rather than an entire class. To measure engagement an observer must infer whether or not a learner is intellectually engaged. Two kinds of inferences relative to each observed student are required. The first inference concerns teacher expectations of the focus of student attention, and the second requires a judgment of whether a student is attending to the desired focus. The on-task rate for a class is the percentage of positive responses for all students. Overt engagement is estimated reliably when students are speaking, manipulating materials, or even asleep; but inferences become more difficult when learners appear to be attending but may actually be daydreaming or otherwise engaged.

Covert engagement was described by Bloom as th ing in relevant ways about what is going on in the classroom. If student involvement is covert, participation must be inferred by an observer. nce process skills may be use covertly as students attend to the teacher during instruction, contemplate the plan of an investigation, or consi er how a graph is to be interpreted. Covert engagement has been addressed by a number of researchers who have attempted to determine student thought processes during an activity. Making such measurements can be disruptive. Hecht (1978) used a process called stimulated recall to attempt to measure covert engagement. He replayed a videotape of a lesson and periodically asked learners to recall what their thoughts were at specific points in the lesson. The procedure also enabled the quality of student engagement to be measured by investigating the cognitive processes used by students while they are engaged in various tasks.

The type of task allocated by the teacher and the way in which the classroom is organized can often determine whether student involvement is overt or covert. For example, most of the data collecting tasks prescribed for middle school classes are concrete in nature. Accordingly, students are able to engage in an overt manner as data are collected. However, in comparison to engagement in data collecting tasks, engagement in investigation planning and data processing tasks is often covert. Engagement in such tasks can be overt if students discuss plans with others, write procedures to be followed, calculate a scale for a graph, represent data in a graph or diagram, and write generalizations from the results of an investigation.

In most classroom research student engagement has been measured dichotomously in terms of on-task behaviors and off-task behaviors. Although significant positive relatinships with achievement has been obtained for the time-on-task variables, there is intuitive appeal in the notion that certain types of student engagement represent appropriate practice for the intended outcomes while other types of engagement do not. Capie and Tob' (1980) suggested that logical analysis of intended outcomes can lead to the identification of student engagement categories that constitute appropriate practice for specific outcomes. Stallings (1980) reported a study of basic reading skills in which student engagement was categorized in terms of nine on-task categories and three off-task categories. She reported significant positive relationships for certain on-task categories, zero correlations for others, and in some cases significant negative correlations with the Comprehensive Test of Basic Skills. The identification of achievement related engagement modes and concomitant teaching strategies can directly benefit classroom practice if teachers can be encouraged to adopt strategies to enhance rates of student engagement in specific learning tasks

Methodological Concerns

The general goal of process-product studies is to develop statistical and logical models for classroom activity. While variables might be initially identified in case studies or larger naturalistic studies, more useful interpretations of results can be drawn from experimental studies. Frequently, the preliminary phase of the research can help to identify the logical relationships between variables to be investigated in a later experimental study. Then measures of context variables and treatment variables can be used in regression analyses or with similar techniques to construct the most useful model for predicting the outcomes of interest. This process will be illustrated in the studies summarized later in this chapter.

In classroom research the experimental treatments are defined by what occurs in the classroom. Although treatments are named by the intended teacher behavior, memberships in groups to which teachers or students have been randomly assigned does not constitute the experimental treatment. Indeed, unless measures of classroom processes are obtained, there can be no guarantee that teachers or students do behave in the prescribed manner. It cannot be assumed that teachers and students change behavior to conform to suggestions advocated by a research team. Manipulated variables should be measured, and the values obtained should be used as a basis for hypothesis testing.

In order to measure classroom process variables, a number of methodologies often need to be incorporated into a single study. For example, many instructional and managerial variables are best measured by direct observation utilizing a checklist or rating scale. Similarly, student engagement can be measured by direct observation using a time sampling procedure whereby selected students are observed periodically throughout an activity. Other variables, such as those related to teacher and student discourse are best measured from audiotapes of an activity. In all cases valid and reliable data are a crucial concern. Capie (1980) has abstracted a number of principles for sampling data to ensure reliability of classroom studies described here in the measures.

An overriding concern in the design of a study is to minimize the probability of committing type II errors. Researchers typically incorporate a sufficiently large sample size into the experimental design and ensure that instrumentation and data collection procedures enable reliable data to be collected to test research hypotheses. However, a problem that sometimes occurs in classrooom research is that the magnitude of a variable in naturalistic settings may be below a threshold value that must be exceeded if desirable outcomes are to be attained. The average duration of pauses separating speakers, known as wait time, is an example of such a variable. Rowe (1974b) observed desirable changes in teacher and student verbal behavior only when teachers maintained an average wait time above 3 seconds. Because average wait time in naturalistic settings was approximately one second, validation of wait time as a teaching strategy was most unlikely unless manipulation occurred. Results reported by Tobin (1980a) highlight this potential difficulty.

Tobin's study consisted of a naturalistic phase in which teachers were sensitized to wait time and an experimental phase in which wait time was manipulated. In the naturalistic phase of the study, all teachers used a normal wait time during instruction. The average teacher wait time was 0.5 seconds. In the experimental phase, teachers from one group endeavored to extend mean wait time beyond 3 seconds, while another group maintained a wait time between 0.5 and 1.0 seconds. The average teacher wait time in this phase was 2.1 seconds. On the basis of the results of the naturalistic study alone, Tobin would have concluded that teacher wait time and student achievement were not related. In the experimental phase of the study, however, many teachers exceeded the 3 second criterion wait time, and a significant relationship was obtained between teacher wait time and student achievement.

An effective procedure for manipulating teacher variables involves model analysis combined with performance feedback. During model analysis teachers are provided with precise definitions of the variables to be enhanced. Providing operational definitions to teachers enables them to become sensitized to variables, and in cases such as questioning quality and wait time, specific statements of high and low performance are contained in the definitions. Although sensitization alone is unlikely to result in meaningful chage, sensitization plus systematic performance feedback appears to result in desirable changes in behavior. Through modifications of teacher and student behavior, performance levels can be changed in a predictable manner. Because precise performance levels cannot be easily specified in advance, often the best that a researcher can hope to achieve is to enhance performance through manipulation such that the levels that occur in naturalistic settings are clearly exceeded.

Although the variables that need to be manipulated in a particular study will be related to research questions, some variables for manipulation in a classroom study are those that are characterized by a low mean and a comparatively high standard deviation in naturalistic settings. In such cases, procedures can be used to enhance performance for one set of teachers and/or students while another set continues in a naturalistic mode. For example, wait time appeals as an ideal variable to be manipulated since the mean in naturalistic settings is usually less than one second while the range often exceeds three seconds. Thus, teachers continuing in a naturalistic mode are likely to use a mean wait time of less than one second while others can be encouraged to average more than three seconds. In contrast, variables such as questioning clarity are potentially more difficult to manipulate since most teachers ask clear questions in a naturalistic mode of instruction.

Variables that cannot be controlled in the experimental design of a study can often be measured and incorporated into the statistical model used for hypothesis testing. For example, variation in classroom management variables might account for a considerable amount of the variance in student engagement. As a consequence, significant relationships between instructional variables and student engagement might be masked unless variation in the management variables is controlled in the experimental design or in the statistical analysis. For similar reasons, instructional variables that are likely to account for a significant proportion of the variance in a dependent variable should be statistically controlled.

Student variables are also likely to have direct and indirect effects on student achievement. For example, formal reasoning ability is likely to determine whether a student can engage in the intended manner when higher cognitive level outcomes are a concern. Similarly, a variable such as the locus of control (the tendency of a learner to accept responsibility for academic success or failure), might affect the extent to which a student engaged in the higher cognitive-level learning tasks. Unless such variables are controlled in the experimental design there is merit in obtaining measures to allow for statistical control. Decisions on what to control and what to measure are inevitably guided by the research questions that prompted the study. However, logistical concerns and a need for parsimony act to counterbalance a need to minimize type II errors. Although measuring all variables is not possible, care should be taken to obtain measures for variable likely to have a significant effect on the dependent variables.

FOUR PROCESSES - PRODUCT STUDIES

This section of the chapter describes four studies examining the relationships among teacher behavior, student engagement, and student learning of process skills. Each of the studies was conducted in middle school grade levels: two with samples of student from Georgia, U.S.A., and two with samples of students from Western Australia. A feature common to three of the four studies was an attempt to manipulate teacher or student behavior in classrooms through the use of systematic feedback to teachers on variables to which they had been sensitized and had a clear understanding.

Study One

The first study was conducted by Tobin (1980b) under the supervision of Capie. This process-product study investigated the effects of two manipulated variables, teacher wait time and questioning quality, on student engagement and process skill achievement in middle school science classes. Teacher wait time was defined as the duration of the pause preceding teacher talk, and questioning quality consisted of three variables: clarity, relevance, and cognitive level of questioning. Additional instructional and managerial variables were measured to allow for statistical control of potentially important variables. Two student attributes, formal reasoning ability and locus of control, were also measured in the study because of their potential importance to learning in materials-centered environments.

Thirteen classes from four middle schools in Georgia participated in the study. Five classes were from grade eight, four were from grade seven, and four were from grade six. Within each grade level, classes were assigned to one of four feedback groups defined on the basis of manipulation of questioning quality and/or teacher wait time. The groups were:

1. extended teacher wait time, high questioning quality;
2. extended teacher wait time, normal questioning quality;
3. normal teacher wait time, high questioning quality; and
4. normal teacher wait time, normal questioning quality.

A sequence of eight science lessons was presented in each class over a two-week period of time. Teachers in the extended wait-time groups were asked to maintain a mean wait time between three and five seconds. Teacher wait time and questioning quality were measured from audio-tapes of each lesson. Teacher wait time was measured with an accuracy of one-tenth of a second using a servo-chart plotter. After each lesson, teachers in the extended wait-time groups received feedback on performance and advice on maintaining an extended wait time. Teachers in the high questioning quality groups were also provided with feedback, and they were asked to maintain a high cognitive level of questioning and to ask clear and relevant questions. So that all teachers in the study received feedback and consultation, teachers in group four received suggestions on lesson organization or use of materials.

A four-point scale was used to assess the cognitive level of each of 30 questions randomly sampled from audio-tapes of each of eight lessons. A rating of one was assigned if the questions required students to recall facts or definitions; a rating of two was assigned if the question required data to be quantified or required student comprehension; a rating of three was assigned if the questions required students to use operations related to planning a controlled experiment (e.g., identifying variables that may affect the dependent variable in an investigation) or interpreting data (e.g., using data to construct a hypothesis); and a zero rating was assigned if the question was intened to elicit non-cognitive behaviors, such as assembling equipment, or off-task behaviors. The cognitive level of questioning for each teacher was defined as the mean of the ratings assigned to the eight lessons.

A clear question communicates precisely what is required of the learner. The presence of one or more of the following indicators in a question suggested a lack of clarity: words that are difficult to understand were used; excessive vocabulary was used; multiple questions were posed; complex sentence structure was evident; tangles of words were present; qualifiers were used (e.g., almost, pretty much, quite a bit, possible, etc.); one or more false starts occurred; halts in speech disrupted the flow; and redundant information was presented in the question.

A rating of two was assigned to a clearly-stated question. A rating of one was assigned when the presence of one or more of the above indicators contributed to slight imprecision. In this case there was no evidence of misunderstanding attributable to lack of clarity of the questions. A rating of zero was assigned when the presence of one or more indicators resulted in unclear presentation of the question. Questioning clarity was defined as the mean of the ratings assigned in the eight lessons.

To obtain measures of performance on managerial and instructional variables, all teachers were assessed on 25 teacher performance variables from the Teacher Performance Assessment Instruments (TPAI) (Capie, Johnson, Anderson, Ellett, and Okey, 1979). Rating criteria for each variable were precisely defined by a five-point scale.

Three pencil-and-paper measures were used in the study. Formal reasoning ability and locus of control were assessed as premeasures. Formal reasoning ability was measured with the test of Logical Thinking (TOLT) (Tobin and Capie, 1981), locus of control was measured with the Intellectual Achievement Responsibility (KAR) scale (Crandall, Katkovsky, and Crandall, 1965). The dependent variable, process skill achievement, was measured with the Test of Integrated Science Processes (Tobin and Capie, 1982).

A trained observer measured student engagement by direct observation of classroom processes. A quasi-random sampling procedure was used to select twelve students from each class as data sources for the investigation. To assure a broad range of formal reasoning ability in the sample, four students were randomly selected from those scoring greater than three on the TOLT, four students from those scoring two or three, and four students from those scoring less than two. In classes where less than four students were represented in a reasoning ability category, additional students were randomly selected from the highest category which had extra students.

The behavior of each student was observed for one lesson of every two using a time-sampling procedure in which each student was observed for four seconds during each 30-second interval. Student engagement was rated using eight on-task and one off-task categories on the basis of the predominant behavior to occur in the second interval. The categories are defined in Figure 2. The lesson and the order in which students were observed were randomly determined to minimize dependency of engagement measures within classes. An engagement measure for each student was calculated as the percentage of time on task in the four lessons observed.

The results of study one indicated that teaching behaviors had direct and indirect effects on student achievement. Clear teacher questioning was associated with higher student engagement rates and use of an extended teacher wait time enhanced summative achievement and retention. Accordingly, teachers can be encouraged to ask clear questions and to utilize an average wait time greater than three seconds in middle school science lessons.

Several non-manipulated teacher variables were also significantly related to the amount of the time students engaged in learning tasks. Seven managerial variables and four instructional variables were significantly correlated with student engagement rates. Student engagement rates tended to be higher in classes where: teaching methods were appropriate for objectives, learners, and environment; directions and explanations related to lesson content were given; teachers demonstrated ability to work with individuals, small groups, and large groups; learners were provided with opportunities to participate; learners were reinforced and encouraged to maintain involvement; teachers attended to routine tasks; instructional time was used efficiently; appropriate classroom behavior was maintained; instructional materials were used to provide learners with appropriate practice on objectives; learners were provided with feedback throughout the lesson; and teachers demonstrated ability to conduct lessons using a variety of teaching methods.

When teachers allocated time for planning and data-processing related tasks, three trends were evident: more than 50 percent of the time students were covertly engaged; students were off-task for approximately 30 percent of the time; students engaged in recalling behaviors for 5 percent of the time; and students engaged in over-planning and generalizing tasks for only 2 percent and 5 percent of the allocated time, respectively.

Category	Definition
1. Attending	Looking at the teacher, book worksheet, paper, chalkboard, etc. Physically attending to a task.
2. Recalling	Responding to questions with recalled facts. Stating definitions. Stating names and/or terms without explaining their meaning. Stating matters of fact.
3. Collecting	Collecting data in an investigation. Copying material from books or the chalkboard, etc. Recording data in an investigation.
4. Comprehending	Explaining the meaning of a term. Naming data points on a graph. Describing graphic or tabular data. Reporting techniques. Reporting data. Representing data in a different mode.
5. Quantifying	Calculating relations between data. Reducing many bits of data to a representative value. Determining a scale for graphic representation of data. Reducing many bits of data to sub-groups.
6. Planning	Identifying variables that are relevant to a given problem. Identifying the dependent variable in an investigation. Identifying the variables that may affect the dependent variable in an investigation. Identifying the independent variable to be manipulated in an investigation. Identifying procedures for manipulating the independent variable in an investigation. Identifying the variable to be controlled in an investigation. Identifying methods of measuring the dependent variable in an investigation. Identifying variables to label the axes of a graph or to be the headings on a table.
7. Generalizing	Comparing data from an investigation. Identifying data that support a hypothesis. Interpolating between or extrapolating beyond data points in tables or graphs. Using data to construct an inference. Using data to construct an hypothesis. Justifying an explanation or a decision.
8. Non-cognitive	Non-cognitive behaviors that are goal-directed (e.g., collecting items of equipment, assembling apparatus).
9. Off-task	Behaviors that are not goal-directed (e.g., reading a book while the teacher is explaining how to solve a problem).

Figure 2. Definitions for Transactions in Science

Process skill achievement was significantly related to formal reasoning ability, student engagement, and teacher wait time. Locus of control was directly related to the time student engaged in learning tasks and was indirectly related to science achievemnt. However, the results indicated that formal reasoning ability was the most important variable in determining whether students learn science process skills. Students with higher formal reasoning ability tended to achieve at a higher level. The results also indicated that students demonstrating higher engagement rates achieved at a higher level than students who were not engaged in learning tasks to the same extent. As a consequence, students may be able to increase process skill achievement by increasing their engagement rates. However, the results indicated that engagement in certain tasks may be more fruitful than others.

The proportion of attending and generalizing were each significantly related to process skill achievement. Students who attended to instruction tended to achieve at a higher level than those who did not. Similarly, those pupils who exhibited higher rates of generalizing behavior also tended to attain higher achievement scores. The statistical significance of attending raises a question on the relative importance of overt and covert student engagement. Since the frequency of occurrence of several of the engagement modes (e.g., planning) was close to zero, the principal means of engaging in those categories was covert through the attending mode. By noting the predominant teacher behavior during the same time interval in which pupils were rated, the allocated task to which students were attending was deduced. Thus, for each engagement mode a covert and an overt measure was available for each student. When total engagement was considered (overt plus covert), comprehending, planning, and generalizing were each significantly related to summative achievement and retention. These results supported the view point that appropriate practice on the instructional objectives results in higher student achievement.

Study Two

The study conducted by Tobin (1983a) with students from fifteen Australian middle school classes was concerned with relationships between types of student engagement, process skill achievement, and student perceptions of the learning environment. Formal reasoning ability was measured for all students participating in the study. Task allocation and student engagement were measured by direct observation of twelve students in each class for four of the eight lessons. The coding system and procedures for collecting student engagement data were obtained for all students during the same four lessons.

Student perceptions of the learning environment were measured with a short form of the Individualized Classroom Environment Questionnaire (Fraser and Fisher, 1983). The instruments used to measure reasoning ability and process skill achievement were the same as those used in study one.

As was the case in study one, a strong relationship was found between formal reasoning ability and process skill achievement. However, somewhat different results were obtained as far as student engagement was concerned. Student engagement was not related to process skill achievement. This may have been due to a ceiling effect for engagement in study two. An average time on task of 90 percent was high compared to the 63 percent reported in study one. A relatively small standard deviation in conjunction with the high mean value for student time-on-task are possible explanations for the null relationship between student time-on-task and achievement. A linear relationship between student engagement and achievement was not apparent for the range of time-on-task that occurred in this study (88 to 100 percent), whereas a significant relationship was reported in study one when engagement varied over a wider range (5 percent to 98 percent). The results also indicated that students who participated in over-planning and data-collecting tasks tended to obtain higher achievement scores than students who did not engage in this manner. The proportion of student attending was not significantly related to achievement in the study. Unlike study one, wait time was not manipulated in the investigation. As a consequence, classroom discourse was likely to be characterized by rapid teacher questioning and short student responses. In such circumstances, attending to the teacher was unlikely to be as beneficial as attending to a teacher in long wait-time classes.

The proportion of time in which students demonstrated overt generalizing behaviors was low and the standard deviation was also low. In the range represented in the data, a linear relationship between achievement and generalizing was not found. Possibly, none of the students in the study had sufficient practice on generalizing tasks in order to enhance achievement. For example, generalizing may have been linearly related to achievement in the range fro 0 to 0.20. However, with a maximum value of 0.09, there is a possiblity that too many students obtained values for student generalizing below a threshold above which achievement is enhanced.

Although teachers appropriately distributed the total time for investigation planning, data collecting, and data processing tasks. students were predominantly engaged in an overt manner only when data were collected. Students were engaged in a passive attending mode for 37 percent of the allocated time. This result reflects the way in which classes were organized. Typically, teachers utilized large group instruction for investigation-planning and data-processing tasks.

Covert engagement decreased significantly and overt student engagement in learning tasks increased significantly during the sequence of eight lessons. The results also indicated that student perceptions of participation were significantly related to process skill achievement. This result raises the possiblity that student perceptions of engagement may provide a valid maeans of assessing engagement in future research.

Study Three

The purpose of the study conducted by Newton and Capie (1982) was to further investigate relationships between student engagement in a range of tasks and process skill achievement. The study attempted to overcome certain difficulties encountered in study one. Many of the tasks investigated in studies one and two occurred infrequently. As a consequence, reliabiity coefficients for the measures were unacceptably low for hypothesis testing. Without intervention to effect an increase in the incidence of the tasks being investigated, type II errors were inevitable. By increasing variability through manipulation of the levels of engagement, the reliability of the engagement measures can be increased, thereby reducing the probability of committing type II errors. In order to overcome infrequent occurrences of overt engagement in planning and generalizing tasks, levels of student planning and generalizing were manipulated in the study.

Twelve students in each of eight intact middle school science classes were selected to ensure variation in reasoning ability. Reasoning ability was measured with the TOLT. The research design employed in the study was a posttest-only control-group design involving three treatments that varied in levels of student planning and generalizing. A sequence of six science lessons based on process skill objectives was presented over a two-week period. While all eight teachers received the same set of objectives, the lesson plans contained activitiea and procedures designed to promote the engagement mode corresponding to the assigned treatment group. The procedure used to manipulate student engagement on planning and generalizing tasks consisted of three parts. Teachers in the appropriate treatment groups received lesson plans that placed differential emphases on planning and generalizing tasks. Teachers were also provided with explanations and precise definitions of the variables to be enhanced and reasons for enhancement. Daily feedback was provided to teachera to maintain the desired levels of student engagement.

The system used to measure student engagement studies one and two was modified and extended for study three. Additional categories were created in order to differentiate types of non-cognitive behaviors, to differentiate types of off-task behavior, and to distinguish engagement that was teacher focused from overt student engagement on learning tasks. Measures of student engagement were obtained using a time sampling procedure in which each of the twelve subjects was observed for five seconds during sixty- second cycles throughout the instructional period. The order in which students were observed was randomly determined. Students were observed during each of the six lessons comprising the study.

Process skill achievement was measured with the Test of Integrated Process Skills (Dillashaw and Okey, 1981).

Student planning, data collecting, and generalizing were significantly correlated with process skill achievement. These results suggest that there should be greater emphasis on student-focused engagement modes, such as planning and generalizing which are significantly related to achievement but occur for less than three percent of the instructional time. Conversely, continued use of frequently occurring engagement modes that yield low correlations with achievement should be reviewed. The results indicated that student planning, data collection, and generalizing are important and should provide a focus for science lessons.

Study Four

The fourth study (Tobin, 1983b) was concerned with establishing links between teacher wait time, teacher and student discourse, and student achievement. The study involved students from twenty intact classes at sixth- and seventh-grade levels in Western Australia. Teacher wait time was manipulated in the study. Ten teachers were randomly assigned to a wait time feedback group, and ten teachers were assigned to a control group that received placebo feedback. All teachers in the study were provided with seven lesson plans and class sets of the required materials. The lesons were designed to develop concepts related to probability. Each lesson commenced with a materials-centered problem to be solved by students. Through direct involvement in planning how to solve the problem, collecting data, and interpreting the results, probabilistic concepts were introduced and applied. The time taken for each lesson was approximately one hour. At the conclusion of each lesson teachers in the wait time feedback group received advice on the magnitude of the wait time used in the previous lesson. Teachers in this group were encouraged to maintain an average wait time of three to five seconds. Organizational aspects of the lessons were discussed with teachers in the placebo feedback group. The study was necessary becsuse the results from study one suggested that, although variation in teacher wait time was significantly related to variation in process skill achievement, there was no observed relationship between teacher wait time and overt student engagement on specified learning tasks.

Teacher wait time and discourse variables were measured from audiotapes of each of seven lessons. A ten-item summative achievement measure was administered as a posttest at the conclusion of the lesson sequence.

The results indicated that achievement was higher for wait time feedback group classes than achievement for control group classes. The results suggested that teachers in the wait time feedback groups used the additional time to formulate discourse that required students to respond at greater length and to react to responses of others. Such student discourse appears to be beneficial becsuse the results indicated that the average length of student discourse and the proportion of students reacting were significantly related to achievement. Differences between wait time feedback group teachers and control group teachers included: the average length of student discourse was greater in wait time feedback group classes; the average length of teacher discourse was less in wait time feedback group classes; the number of teacher utterances was less in wait-time feedback group classes; the proportion of teacher soliciting was greater in wait time feedback classes; the number of solicitations per unit time was less in wait time feedback group classes; the proportion of teacher reacting was less in wait time feedback classes; the proportion of teacher structuring was greater in wait time feedback classes; the proportion of teacher mimicry was less in wait time feedback classes; and the proportion of teacher probing following student responses was greater in wait time feedback classes.

IMPLICATIONS FOR TEACHING AND RESEARCH

This section contains a synthesis of the findings of the four studies and a discussion of the implications for research.

Synthesis of Findings

The four studies indicated that teaching behaviors have direct and indirect effects on student achievement. Clear teacher questioning was associated with higher student engagement rates, and use of an extended teacher wait time enhanced student achievement. Accordingly, teachers can be encouraged to ask clear questions and to utilize an average wait time greater than three seconds in middle school science lessons.

The fourth study provided insights into the effective use of an extended wait time in whole class settings. If an average wait time of three to five seconds can be maintained, the quality of teacher and student discourse can be improved and student achievement can be enhanced. Teacher and student discourse characteristics suggested that longer duration pauses between speakers were used for cognitive processing. Teachers tended to probe for additional student discussion rather than mimicking or evaluating student responses. As a consequence, the average length of student utterances and the proportion of student reactions increases in extended wait time classes. The use of an average teacher wait time of three to five seconds appears to create an environment in which covert engagement in whole class settings is beneficial. In contrast, covert engagement in classes utilizing a normal wait time style of teaching does not appear to facilitate learning. The results highlight the importance of the way that students engage in learning tasks. An extended wait time can contribute to a learning environment in which productive covert engagement in learning tasks can occur. On the basis of the results of the study, teachers can be encouraged to utilize an extended wait time in whole class settings to improve the quality of the learning environment and increase achievement in middle school subjects where verbal interaction assumes an important role in promoting the learning of higher cognitive level outcomes. The findings highlighted the influence of teacher discourse on student discourse and emphasized that the provision of added silence is of no importance in its own right, but that concomitant improvements in the quality of teacher discourse lead to improved student discourse and higher achievement.

On the basis of study four, the following suggestions are advocated for improving the qualit, of engagement in whole class settings.

1. A question is clearly presented at a relevant time during the lesson.

2. All students are given three to five seconds of silence in which to consider a response.

3. One student is called on to respond to the question.

4. The student is provided three to five seconds to commence a response. If the student does not respond, the question is repeated, rephrased, or redirected to another student.

5. After a response to a question, three to five seconds are provided for the student to commence to elaborate or evaluate the response and for others in the class to consider the appropriateness of the response.

6. The question or the response is redirected to another student in the class. The redirecting strategy may be utilized for a maximum of three to four occasions.

The purpose of the above strategy is to ensure that the quality of covert engagement is maximized for the majority of the students in the class. By asking a question before calling on a student to respond, the payoff is high for students to listen to the question and formulate a response. The purpose of the pause between the question and the teacher calling for a response is to allow time for cognitive processing by students and to enable the teacher to consider an alternative course of action if the question is not answered. After calling for a response, time needs to be provided for the student to commence an answer.

Once an answer is commenced, however, cognitive processing continues. As a consequence, elaborated responses are often delivered as bursts of speech, with each burst separated by a pause that often exceeds three seconds. Pauses of this duration provide ample opportunity for an unwary teacher, or another student, to interject and assume control of the discourse. This course of events may deprive the initial respondent of the opportunity to fully develop an answer or to self evaluate the adequacy of a response. If there was value in asking a question in the first place, then the student should be provided with reasonable time to respond in an appropriate manner.

When a student response is completed, there is often value in directing the response to another student for evaluation or elaboration. Similarly, questions that are initially unanswered can be redirected to others in the class for a response. Knowledge that a question or a response will be redirected for additional discussion increases the payoff for students to listen to one another.

Eleven non-manipulated teacher variables were found to be significantly related to student engagement. Engagement rates tended to be higher in classes where teachers quickly intervened to minimize disruption and thereby maintained a classroom conducive to learning. Since the objectives for the science activities were related to investigation planning, data collection, and data processing tasks, teachers needed to vary both the tasks in which students were to engage and the group structure to ensure that students were able to actively participate. For example, data collecting tasks were usually conducted in small groups while investigation planning tasks tended to be carried out in whole-class settings and to a lesser extent in individualized seatwork activities. As a consequence, teachers were required to successfully manage individuals, small groups, and whole-class settings. High rates of student engagement tended to occur in classes where a variety of teaching methods were used to ensure that students engaged in tasks that were relevant to the objectives. Conversely, a higher incidence of off-task behavior was associated with classes in which the type of student task involvement was less varied. For example, the incidence of off-task behavior was high when students were required to attend to a teacher in a whole-class setting for an extended period of time. In order to increase opportunities for overt student engagement, teachers may need to utilize individualized seatwork or small group activities to a greater extent when investigations are planned and data are processed.

There are usually opportunities for off-task behavior during transitions between activities in science lessons. For example, following a discussion in a whole-class setting students may have to move into work groups. As well as movement of students, rearrangement of furniture and distribution of equipment and materials frequently occur during the same transition. High levels of off-task behavior can occur unless teachers take action to ensure that students have a clear understanding of what is required of them and that students are not without assigned tasks for too long during a transition. The use of clear explanations and directions during lessons ensured that students knew what to do during transitions and during activities. Engagement rates tended to be higher when lessons were well coordinated with short duration transitions between activities and when students were involved in the management of routine tasks such as furniture arrangement and distribution of equipment.

Student engagement rates were also found to be higher in classes where teacher questions were used to determine whether individual students received sufficient practice on the objectives, where teachers reinforced students participating in learning tasks, and where teachers responded to students who were off-task. Teacher questioning was often followed by a discussion with students in which feedback was provided on response adequacy and probing or redirecting strategies were used to encourage students to evaluate their own understandings. Further evidence of the value of involving students in evaluating their own understandings and responses of others was obtained in Study Four where the proportion of students reacting was significantly related to achievement.

Those concerned with curriculum design and implementation can plan and implement science activities so as to increase the time allocated for overt engagment in investigation planning, data collecting, and data processing tasks. Three of the studies indicated that teachers allocate sufficient time for planning and processing tasks; however, student engagement tends to be covert while attending to the teacher in whole-class settings. Teacher education courses and curriculum guides should provide precise suggestions of activities to enable students to engage in an overt manner in planning and processing tasks. The results of the studies suggest that teachers should provide a learning environment in which students can overtly plan investigations, collect data, and interpret the findings. Another important outcome was that overt student planning and generalizing levels were enhanced with the use of lesson plans, model analysis, and performance feedback. This outcome raises the possibility of substantially increasing overt engagement in these modes in order to enhance achievement. Although the results of the studies indicated ample opportunity to accomplish such an increase by decreasing the incidence of off-task behavior, teachers might find this difficult to accomplish. Changes may be required in the way teachers seek to engage students. For example, rather than having one student extrapolate from a graph while others in the class attend, a preferable procedure might require all students to provide a written extrapolation from the graph. In this way all students are able to engage in an overt way rather than a covert manner. Supervised seatwork or small-group activities might be encouraged to enable a higher proportion of students to actively engage in investigation-planning and data-processing tasks.

Implications for Research

The engagement category system that is most sppropriate for a study is dependent on the research questions that prompted the study. The procedure for identifying appropriate categories, however, is generalizable. For example, in study one an observation instrument was developed to measure student engagement on a set of categories related to process skill achievement. Although process skills are usually taught in science programs, they are generic intellectual skills that are applicable to a wide range of problem-solving contexts. Thus, student behaviors were identified that were logically involved in planning and conducting an investigation. Additional behaviors that frequently occurred in science classrooms were also identified and defined so that every behavior to occur in the classroom could be rated. Engagement was categorized in terms of seven overt on-task categories, one covert on-task category, and one off-task category. An alternative procedure was formulated by Newton and Capie in study three for use in lessons with a process-skill orientation. THe IPOG and DPOG (Yeany and Capie, 1979; Capie and Tobin, 1980) could also be used in process-product research for measuring engagement in investigation planning, data collecting, and data processing tasks.

Teacher wait time, questioning clarity, and the cognitive level of questioning were manipulated in the first study. The results indicated that wait time was an easier variable to manipulate than were the questioning variables. Since questioning clarity was characterized by a relatively high mean in naturalistic settings, it was difficult to enhance performance levels to exceed those in non-feedback groups. Although clarity and other verbal behaviors were successfully manipulated in study one, the benefits of manipulating such variables may not compensate for the time involved and the inconvenience attributable to intervention into normal classroom activity.

A universal concern of educational research is to use dependable measures when hypotheses are tested. If unreliable data are used, relationships between variables are more difficult to discern. The problem of low reliability is particularly evident with infrequently occurring behaviors. For example, research on the relationship between the amount of student planning be'avior in science classes and process-skill achievement encounters a difficu. y in that students are rarely involved in investigation-planning tasks in most classrooms. As a consequence, reliability coefficients for variables such as student planning are usually unacceptably low for hypothesis testing in naturalistic settings. However, by increasing variablity through manipulation, the magnitude of the reliability coefficient can be increased, thereby reducing the probability of committing type II errors.

Compelling reasons for measuring student engagement relate to the potential influence of the variable on learning. Despite the intuitive appeal of the argument that students can learn when they are direclty involved in what is to be learned, additional research is needed to improve the quality of science teaching. The studies reviewed in this paper have indicated that engagement in certain tasks tends to enhance achievement while engagement in other tasks does not. Additional research based on global conceptualizations of student engagement is unlikely to assist practitioners. The research that is needed should incorporate distinctions between categories of tasks in which students engage, the group structure in which the tasks are embedded. and specific details on the nature of the engagement. For example, a distinction needs to be made between a student who recalls information during a whole-class structure in the planning stage of an investigation and a student who evaluates the adequacy of a peer response in a work group during the planning stage of an investigation.

Research has indicated that managerial and instructional behaviors of teachers can influence the quantity and quality of student engagement in learning tasks and process-skill achievement. The findings suggest that overt engagement in specific learning tasks can enhance achievement. Yet the covert engagement that precedes overt student engagement and occurs concurrently with it influences the quality of engagement and learning. Research should be directed toward identifying the types of student cognitive processing that occur in process-oriented science activities. In order to investigate hypotheses related to student cognitive processing, different methodologies will need to be used to measure engagement.

Three procedures appeal as being most suitable. A thinking-aloud technique whereby students are asked to report on their cognitive processes as lessons are implemented is a technique that is likely to provide suitable data. Although the technique is obtrusive, the close proximity of the classroom event to the stimulus to recall should enable high quality data to be obtained. An alternative is a replay of a recent lesson, and then students are asked to recall what they were thinking at selected locations during the lesson. A third technique is to ask students to report on their engagement on a questionnaire administered immediately after a lesson or at selected locations during a lesson. There are obvious advantages and disadvantages associated with the use of each of the above procedures. However, each appeals as potentially suitable for answering types of research questions on cognitive processing science classes.

Cognitive processing of teachers is also an area that needs to be researched. During process oriented science lessons teachers are required to make a large number of managerial and instructional decisions. Presumably, teacher behavior in science lessons is closely related to the quality of student cognitive processing that occurs. If cognitive processing is directed toward formulation of appropriate instructional strategies, teachers can influence student congitive processing and thereby enhance the quality of overt engagement and increase achievement. Within this framework the use of an extended wait time appeals as an important instructional variable. For example, research is needed to provide insights into the manner in which the use of an extended wait time is able to influence the quality of classroom environments and student learning. From a theoretical perspective the provision of longer pauses between speakers should enable teachers and students to process information pertinent to instruction. When higher cognitive level outcomes are concerned, teachers and students should utilize pauses of up to five seconds duration for relevant cognitive processing. However, in classes where a regular wait time is utilized, necessary cognitive processing might not occur and the quality of teacher and student discourse could suffer accordingly.

At this stage teachers' and students' use of wait time for cognitive processing is only postulated. If this can be verified through reseach, wait time can be used in conjunction with other variables to stimulate cognitive processing in order to promote learning. For example, the duration of waittime pauses could be matched to the amount of time required for cognitive processing. The time could be quite long in contexts such as synthesizing the results of investigations or quite short where recall of information is required. By relating the use of an extended teacher wait time to cognitive processing; educational researchers, teacher educators, and teachers could be confident in advocating the use of an extended teacher wait time whenever additional time is required for teacher or student thinking.

CONCLUSION

The studies discussed in this paper indicate that teacher behaviors, student attributes, and types of student engagement are positively related to process-skill achievement. Teachers can influence science learning by using questions and silence to focus student engagement and to stimulate thinking. Importantly, the studies also indicated that achievement can be enhanced by increasing the proportion of student engagement in planning, collecting, and processing tasks. As a consequence, teachers are provided with a means of providing a learning environment in which all middle school students can learn to use science process skills.

The methodologies utilized in the studies discussed in this paper provide researchers with suggestions for improving classroom research. Dependable measures of classroom processes were obtained for a number of different data collecting procedures, including direct observation using rating scales and time sampling procedures involving classroom observers and observations from audio tapes. Manipulation of teacher and student behaviors also provided promising results. Variation in specified teacher and student behaviors was increased and dependable measures were generally obtained and used in hypothesis testing.

REFERENCES

Anderson, L. M., C. M. Evertson, and E. T. Emmer. "Dimensions in Classroom Management Derived from Recent Research." Journal of Curriculum Studies, 12(4): 343-362, 1980.

Arlin, M. "Teacher Transitions Can Disrupt Time Flow in Classrooms." American Educational Research Journal, 16: 42-56, 1979.

Bloom, B. S. "The New Direction in Educational Research: Alterable Variables." Phi Delta Kappan, 382-385, 1980.

Breuning, S. "Precision Teacher in the High School Classroom: A Necessary Step Towards Maximizing Teacher Effectiveness and Student Performance." American Educational Research Journal, 15: 125-140, 1978.

Capie, W. "Sampling Considerations in Classroom Research." A paper presented at the annual meeting of the American Educational Research Association, Los Angeles, 1980.

Capie, W. and C. D. Ellett. "Teacher Performance Dimensions and Pupil Engagement Rates in Elementary Classrooms." Paper presented at the annual meeting of the American Educational Research Association, New York, March 1982.

Capie, W., C. E. Johnson, S. J. Anderson, C. D. Ellett, and J. R. Okey. Teacher Performance Assessment Instruments. Athens, GA: Teacher Assessment Project, University of Georgia, 1979.

Capie W. and K. G. Tobin. "A System for Analyzing Lessons Where Investigations are Planned." Paper presented at the annual meeting of the Association for the Education of Teachers in Science, Anaheim, CA, March 1980.

Capie, W. and K. Tobin. "Pupil Engagement in Learning Tasks: A Fertile Area for Research in Science Teaching." Journal of Research in Science Teaching, 18: 409-18, 1981.

Carroll, J. B. "A Model for School Learning." Teachers College Record, 63: 723-732, 1963.

Crandall, V. C., W. Katkovsky, and V. J. Crandall. "Children's Beliefs in Their Own Control of Reinforcements in Intellectual-Academic Situations." Child Development, 36: 91-109, 1964.

Dillashaw, F. G. and J. R. Okey. "Test of the Integrated Science Process Skills for Secondary Science Students." Science Education, 64(5): 601-608, 1980.

Doyle, W. "Paradigms for Research on Teacher Effectiveness." A paper presented at the annual meeting of the American Educational Research Association, Washington, D.C., April 1975.

Emmer, E. T. Management Strategies in Elementary School Classrooms (R&D Rep. No. 6052) Austin, TX: The University of Texas of Austin, July 1982.

Fraser, B. J. and D. L. Fisher. "Development and Validation of Short Forms of Some Instruments Measuring Student Perceptions of Actual and Preferred Classroom Learning Environment." Science Education, 67(1): 115-131, 1983.

Hecht, L. W. "Measuring Student Behavior During Group Interaction." Journal of Educational Research, 71: 283-290, 1978.

Ladaherne, H. M. "Attitudinal and Intellectual Correlates of Attention: A Study of Four Sixth-Grade Classrooms." Journal of Educational Psychology, 59: 320-324, 1968.

Linn, M. G. "Free-Chioce Experiences: How Do They Help Children Learn?" Science Education, 64: 237-248, 1980.

Newton, R. E. and W. Capie. "Effects of Engagement Quality on Integrated Process Skill Achievement in Grades 7 and 8 Science Students of Varying Ability Levels." Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, Wisconsin, April 1982.

Rochester, S. R. "The Significance of Pauses in Spontaneous Speech." Journal of Psycholinguistic Research, 2: 51-81, 1973.

Rowe, M. B. "Wait Time and Rewards as Instructional Variables, Their Influence on Language, Logic, and Fate Control: Part One - Wait Time." Journal of Research in Science Teaching, 11, 263-279, 1974a.

Rowe, M. B. "Pausing Phenomena: Influence on the Quality of Instruction." Journal of Psycholinguistic Research, 3: 203-223, 1974b.

Samuels, S. J. and J. E. Turnure. "Attention and Reading Achievement in First-Grade Boys and Girls." Journal of Educational Psychology, 66: 29-32, 1974.

Siegman, A. and B. Pope. "Effects of Question Specificity and Anxiety Producing Messages on Verbal Fluence in the Initial Interview." Journal of Personality and Social Psychology, 2: 522-530, 1965.

Slavin, R. E. "Cooperative Learning and the Alterable Elements of Classroom Organization." Paper presented at the annual meeting of the American Educational Research Association, New York, March 1982.

Stallings, J. "Allocated Academic Learning Time Revisited, or Beyond Time on Task." Educational Researcher, 9(11): 11-16, 1980.

Tobin, K. G. "Relationships Between Reasoning Ability, Engagement, and Middle School Science Achievement." Paper presented at the annual meeting of the American Educational Research Association, Montreal, April 1983a.

Tobin, K. G. "Relationships Between Wait Time, Classroom Discourse Characteristics, and Mathematics Achievement." Paper presented at the annual meeting of the American Educational Research Association, Montreal, April 1983b.

Tobin, K. G. "The Effect of an Extended Teacher Wait Time on Science Achievement." Journal of Research in Science Teaching, 17: 469-475, 1980a.

Tobin, K. G. "The Effects of Variations in Teacher Wait Time and Questioning Quality on Integrated Science Process Achievement for Middle School Students of Differing Formal Reasoning Ability and Locus of Control." Dissertation Abstracts International, 41(4): 1520-a, October 1980b.

Tobin, K. G. and W. Capie. "Development and Validation of a Group Test of Integrated Science Processes." Journal of Research in Science Teaching, 19: 133-142, 1982.

Tobin, K. G. and W. Capie. "The Development and Validation of a Group Test of Logical Thinking." Educational and Psychological Measurement, 41: 413-424, 1981.

Winne, P. H. and R. W. Marx. "Students' Cognitive Processes While Learning from Teaching: Summary of Findings." Burnaby, B. C.: Instructional Psychology Research Group, Simon Fraser University, Occasional Paper No. 83-03, 1983.

Weber, W. A. "Classroom Management." In J. C. Cooper (Ed.), Classroom Teaching Skills: A Handbook. Boston, Mass.: D. C. Heath and Co., 1977.

Yeany, R. H. and W. Capie. "An Analysis System for Describing and Measuring Strategies of Teaching Data Manipulation and Interpretation." Science Education, 63: 355-361, 1979.

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An Analysis of the Secondary School Science Curriculum and Directions for Action in the 1980's. John R. Staver.

Teaching Children Science: Changing Adversity into Advocacy. Bernard W. Venson.

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