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Student questions : foundations for inquiry

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STUDENT QUESTIONS: FOUNDATIONS FOR INQUIRY

A Thesis

Presented to

The Faculty of the College of Education

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Anthony Cody

August, 1998

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ABSTRACT

STUDENT QUESTIONS: FOUNDATIONS FOR INQUIRY

by Anthony Cody

This qualitative study explores how science instruction can develop student questions into centerpieces of ongoing classroom inquiry. By using student questions as a starting point, one builds student ownership and engagement, teaching the students to successfully ask and answer their own questions, a process that is a cornerstone of scientific inquiry. Further, students accustomed to being passive receptacles of knowledge are given the tools to understand their world, which leads to autonomy and empowerment. As this study began, the chief strategy employed open-ended inquiry instruction centering on student investigation kits. When this model proved ineffective, a more structured approach was used, continuing to focus on student questions, but providing a greater degree of teacher guidance and a more structured sequence of student interactions with materials. Active collegial dialogue, teacher research methodology and a reflective journal provide multiple perspectives for this exploration and establish the foundation for defining further questions.

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CHAPTER I

INTRODUCTION

Room 215 at Mark Twain Middle School is large -- formerly an art class, it is long, lined with cupboards and drawers. The walls are brightened by posters and student work. From the ceiling long swaths of sky-blue fabric with white clouds form gentle billows above students' heads. A large, inflated vinyl pterodactyl also hangs, frozen mid-swoop over the teacher's perennially messy desk. A large fish tank houses colorful African cichlids who chase each other constantly. There are eight tables for students to sit before, arranged in two rows.

Period one/two is a small seventh grade class, only twenty students. All are immigrants, the class designated as "LEP," Limited English Proficient. About ten are from Asia; Vietnamese, Mien, Cambodian. Another six are Latino, mainly Mexican. Three are from Tonga, an island republic in the South Pacific. Almost all, however, can speak, read and write English, having lived in the US for a long time. They are here for two periods each day, for both math and science. Period three/four is likewise math and science, but these are sixth graders, regular Oakland kids. The majority are African American, but there are several European American students, several Asian

Americans, Latinos and Filipinos.

I am in my eleventh year of teaching in an Oakland middle school. I chose teaching from dual impulses: first, to seek justice through the delivery of quality education to the largely minority students there; and second, a genuine love of young people. I received my credential in 1987, when the emphasis on "hands-on science" was ascendant. The school's curriculum, however, was a traditional textbook. I strove to integrate activities into my curriculum, and when the time came to choose a new text, I participated in the process. I helped select a text which was accompanied by kits of materials for actually doing the activities described. In practice, however, the kits were inadequate and the books were unpopular. I worked in my class to develop my own curriculum, centering on evolution and biology, and I worked with other teachers in the District to develop more lively and useful hands-on curriculum.

In 1995 I was asked to join a team of developers at the Lawrence Hall of Science, to help write a new middle school science curriculum. This curriculum will extend the Full Option Science System (FOSS) up through grade 8. For the past three years we have used one class at my school to try out our material as it was written. Once more the emphasis was on "hands-on activities," but we also strove to challenge students to make inferences based

on their experiences. Though we attempted to make our materials “developmentally appropriate,” I was not always satisfied with the level of engagement we achieved with my students.

As science educators, we face multiple challenges. We wish our students to develop an understanding of a number of specific science concepts, such as density, or states of matter. Beyond these content goals, we also wish them to be capable investigators of the natural world. My central objective this year has been to equip my students with this ability. As an urban educator, I have found that my students will not engage in active study of science if they do not feel ownership of the subject matter. Furthermore, I define active engagement in science as not merely the ability to follow directions in a science “cookbook,” but the ability to actually define questions for oneself, and answer them through investigation and experimentation.

I engaged in action research to see how I, as a teacher, could develop student questions into centerpieces of ongoing classroom inquiry. I chose as my initial tool a set of investigation kits, which students would use to develop their own investigations. In the course of my own investigation, however, my very definition of inquiry would be challenged, as well as the best way to achieve it with my students. Maintaining a focus on student questions, I revised my approach and found new insights from a more

structured model of student inquiry.

I present this description of an intense year of experimentation and investigation into my own practice as evidence of some valuable lessons about the structure needed to support effective student investigations. Lessons can also be drawn from the collaborative research process which helped guide my work. A wide circle of critical collaborators provided valuable guidance and critique as my work unfolded. Beginning with my trusted collaborative teacher research group, this circle extended to my students, to colleagues in my district and even in other countries, as publication of my journal on my web site attracted discussion and debate.

This thesis is a static record, an attempt to precipitate solid insights from a suspension of uncertainty and experimentation. The inquiry will continue beyond this document as an integral part of the process of teaching in a critical, collaborative environment. Please join me in exploring the unique circumstances of Room 215 at Mark Twain Middle School.

CHAPTER II

REVIEW OF THE LITERATURE

How Do We Acquire Knowledge?

To prepare for the use of a new pedagogical approach, inquiry based on student questions, I needed to review the literature on how students acquire knowledge. Here I will summarize the literature on constructivist learning; its history, its critique and its implications for the science classroom.

Inquiry is a tool scientists and others use to ask and answer questions of the world. Underlying the use of an inquiry approach in science instruction is a broader learning theory, known as constructivism. In definitions of inquiry, there exists a tension between the need to guide the learner and the role of a learner's agency in the learning process. This tension has been central in my work, as changes in the degree of teacher guidance have been a critical focus. The complex relationships of learner, teacher and subject matter are addressed by aspects of constructivist theory. Constructivism is a set of theories, held by a diverse set of authors. To understand what constructivism has to say regarding this, one must look at a range of adherents.

The movement for an improved course of study in science, coupled with Piaget's insights into child development and learning, led to the development of a constructivist approach to science education (NSRC, 1997).

Rosalind Driver (1983) advocates a constructivist pedagogy which begins at the level of the individual learner, with student preconceptions. Students are encouraged to develop their models, step by step, alongside their experiences. The role of the teacher is to intervene, to pose questions, challenge the students' models, and guide them to a better understanding. Teachers are encouraged to look at the models embedded within student observations or questions, and become skilled at drawing these out. The teacher is thus a diagnostician, whose job it is to understand the learner's misconceptions and guide them to a superior understanding. Though Driver focuses on the individual learner, in her view new ideas must go through a struggle to emerge, similar to the struggle Kuhn (1970) describes operating on a societal level. She writes:

Not only do children have to comprehend the new model or principle being presented to them, but they have to make the intellectual leap of possibly abandoning an alternative framework which until that time had worked well for them. To use the language of the philosophy of science, children sometimes need to undergo paradigm shifts in their thinking (p. 9).

Driver suggests that the "children's own ideas in fact can provide the necessary raw material to exemplify the plural nature of scientific theory, and act as a starting point for pupils to design critical tests to distinguish between different interpretations" (p. 77). In this way also then, Driver is placing the

student in the role of a scientist, functioning in an interactive community of scientists, where theories are placed in competition, with experiments designed to find the truth.

Driver (1994) is critical of a completely empirical approach that would minimize the role of the teacher. She writes,

Science ideas, which are constructed and transmitted through the culture and social institutions of science, will not be discovered by individual learners through empirical enquiry: learning science involves being initiated into the culture of science. If learners are to be given access to the knowledge systems of science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge for teachers lies in helping learners to construct these models for themselves, to appreciate their domains of applicability and, within such domains, to use them. If teaching is to lead pupils toward conventional science ideas, then the teacher's intervention is essential, both through providing appropriate experiential evidence and making the theoretical ideas and conventions of the science community available to pupils (p. 6).

She concludes that

Experience by itself is not enough. It is the sense that students make of it that matters. If students' understandings are to be changed towards those of accepted science, then negotiation with an authority, usually the teacher, is essential (p. 7-8).

Social Constructivists Target Social Relationships

O'Loughlin (1992) offers a cogent critique of traditional Piagetian constructivism. In his view, the pedagogy based on developmental

psychology is flawed, because it tends to view the learner in isolation from his/her social context. Thus it ignores the critical issues of culture, power and forms of discourse which create the learning environment in the classroom. The Piagetian constructivists are seen to be inquiring into student understandings of a subject for the purpose of “distancing” him or her from those understandings, through the introduction of discrepancies.

The ultimate goal, for the Piagetian constructivist, is a child’s ability to think autonomously, conducting cognitive processes internally. O’Loughlin and others fault this approach for effectively disempowering the learner, and making education a process of adapting to reality rather than transforming it.

The “student-centered, active learning” regime is likewise faulted by O’Loughlin. Drawing on work by African American researcher Lisa Delpit, O’Loughlin finds there are often power relationships effectively disguised or hidden within student centered pedagogies. Though students may be overtly invited to “construct their own meaning” from a given exercise, there is, in reality, a predetermined meaning, one which is privileged and drawn out by the teacher. The veiled agenda can disempower students of color, hiding the “codes of success,” and thus, fail to adequately prepare them.

O’Loughlin concludes that the “...universalist, rational, disembodied thought valued by Piagetian constructivists is ... ideologically bound, and

must be rejected in favor of a more suitable ideology that acknowledges the highly contextualized nature of the kind of learning that leads to genuine ownership of ideas and possibilities for transformation" (p. 809). Drawing on sociocultural theorists, O'Loughlin proposes that meaning is constructed by the learner through a process of linguistic mediation, where the influence of the cultural, social, historical and institutional setting all coalesce. Quoting Bakhtin, O'Loughlin develops the idea that our speech (and text) is dialogical; its purpose is to challenge others to produce counterimages and words. Bakhtin criticizes the authoritative voice for asserting the absolute veracity of its message. Rather, he proposes an open voice, "the internally persuasive word," which is "half-ours and half-someone else's."

In developing science investigations based on student questions, I have searched for an approach that embodies this dialogue. Students are not yet competent investigators of nature, yet their desire to investigate originates with their questions. If we can use these questions as a foundation for the development of ongoing inquiry, learning unfolds through an investigatory dialogue between teacher and students.

Constructivism and Social Change

As an advocate of social justice, I am interested not only in helping my students to learn the basics of physics and biology, I also want them to become confident, powerful people, capable of shaping their own destinies and reshaping our society. Shirley Grundy (1987) identifies in the work of Habermas a critical agenda for constructivism. The aim is not to correct misperceptions on the part of the learner. Rather, it is to empower the learner with critical faculties, so the learner perceives the social and political reality he or she is embedded in, and is capable of transforming that reality. Drawing on Freire as well, Grundy portrays education as a dialogical process. Grundy, using Habermas' characterization of three fundamental interests, technical, practical and emancipatory, finds that most educational reform efforts address only the first two.

In Freire (1992) we find a fundamental challenge to authoritarianism. Based, as it is, upon his lifetime of work developing literacy among the oppressed of the world, this message resonates. Freire actively rejects the authority of the left and the right. Transferred to the context of a science classroom, this rejection implies the absence of authority on the part of the teacher, and the "body of knowledge" the teacher would impart. This does not mean an egalitarian denial of difference in knowledge, however. Freire, in

Pedagogy of Hope, (1992) says,

Dialogue between teachers and students does not place them on the same footing professionally; but it does mark the democratic position between them. Teachers and students are not identical, and this for countless reasons. After all, it is a difference between them that makes them precisely students or teachers. Were they simply identical, each could be the other. Dialogue is meaningful precisely because the dialogical subjects, the agents in the dialogue, not only retain their identity, but actively defend it, and thus grow together. Precisely on this account, dialogue does not level them, does not “even them out,” reduce them to each other. Dialogue is not a favor done by one for the other, a kind of grace accorded. On the contrary, it implies a sincere, fundamental respect on the part of the subjects engaged in it, a respect that is violated, or prevented from materializing, by authoritarianism. Permissiveness does the same thing, in a different, but equally deleterious way (p. 116 – 117).

Thus Freire seeks a mutual respect between teacher and learners, based on the teacher acknowledging the legitimacy and authenticity of the learners’ experience and perspective, and their right to their own opinion, their own voice and their own conclusions.

Habermas, according to Grundy, proposes the development of critical theorems, the products of critical reflection. These theorems attempt to understand fundamental human capacities, unconstrained by the distortions of ideology. These theorems suggest undistorted forms of human society which represent a potential for enlightenment and emancipation. Both Habermas and Freire place in the hands of humans, the capacity and the need for action on their ideals, to reshape reality. Emancipation, from Habermas’

point of view, is reflective action. The emancipatory interest is defined as empowerment for people to engage in autonomous, purposeful social action.

Grundy draws Habermas and Freire together, to define an emancipatory curriculum as praxis. This praxis combines reflection with action in the social realm. Within praxis, meaning is viewed as a social construction, and the objective of the critique is social transformation. Curriculum is a matter of negotiation between teacher and learner. Grundy offers teacher action research as a form of praxis; embodying reflection, action and change. In my work, teacher research has laid the foundation for the transformation of my practice.

Building again on Habermas, Grundy describes critical pedagogy as one which confronts reality, actively incorporates Freire's conscientization, challenges ideological distortion and incorporates action as a fundamental part of knowing.

Inquiry as a Tool for Change

How can we reconcile the constructivist agenda with a liberatory one? For students to be truly engaged in active learning, they must have some agency. They need to control the variables. If we actually want them to learn to investigate, they need real experiences with that very process, from start to

finish. They must be able to apply their nascent skills to questions of importance to them, not be told in advance the questions to be answered. A partial answer to this challenge can be found by returning to one of the central tenets of the early science reform movement of the 1960's; to learn science, students should do science. The doing of science is then boiled down to a set of processes called "inquiry." Sund and Trowbridge (1967) offered a quite ambitious description of inquiry:

The inquiry approach requires the learner to be an active participant in the quest for knowledge. In so doing, the student discovers his ability how to learn by using his own mind to solve problems (p. 49).

They describe the teacher's role as a catalyst for creating a student's experience:

There is no way for a student to know the action a scientist experiences except by becoming actively involved in the methods of science. The teacher's role is one of organizing and contriving situations which will set the stage requiring a student to act out the role of a scientist in his activities (p. 53).

They present as an example a lesson:

An example of a laboratory experiment which can lead to training in inquiry and discovery is the monolayer experiment for determining the size of a single molecule. In this experiment the student is given a minimum of instruction and is encouraged to devise techniques to arrive at a satisfactory result (p. 56).

What follows are detailed directions for an elaborate lab experiment, accompanied by numerous questions to make certain the student understands the reason for each procedure. An example of the opportunity

given to the student to “devise techniques” can be seen here:

You will need to know the volume of one drop of the oleic acid-alcohol solution. How can you measure the volume of one drop? Remember greater accuracy can be found by getting the volume of many drops and taking an average (p. 58).

The problem here is not in the definition of inquiry, which is admirable, but rather in the execution. This form of inquiry was not empowering, since the student, far from being the author of the investigation, was merely using guesswork to fill in the blanks in the instructions.

The Indian author, Vaidya (1970) applied Piaget’s theories to children’s learning in science and was more successful in articulating a constructivism that could empower the learner.

He wrote,

...the goals of science education are effectively achieved if students base their work on their personal question and problematic situations encountered by them in their own immediate environment. The role of laboratory then, is to raise and define problems, to learn the meaning and use of controls and to test hypotheses and interpret data (p. 272).

Vaidya goes on to list several pages of children’s questions, as springboards to inquiry. Though these were rural children of India, their questions sound remarkably similar to those on the minds of my students in Oakland. “Why do we have day and night?; Why does water freeze only at the top?; Why does the moon not fall down?” Most recent curriculum, however, follows the

limited model of inquiry offered by Sund and Trowbridge, rather than the more student-centered approach of Vaidya.

What is “Inquiry” Today?

The concept of inquiry remains relevant today, as educators continue to struggle to bring to reality the definition offered by Sund and Trowbridge. Common to many approaches is the use of the learning cycle, pioneered by Karplus and Their in the 1960’s. According to Marek and Cavallo, (1997) the learning cycle breaks inquiry into three phases; “preliminary exploration,” “invention” and “discovery.” A number of curricula are based upon this cycle, including Full Option Science System (FOSS), the project I have worked on for the past three years. The National Science Education Standards (1996) take a strong stand advocating student involvement in an active process of inquiry. They describe the following process skills for grades 5 to 8:

IDENTIFY QUESTIONS THAT CAN BE ANSWERED THROUGH SCIENTIFIC INVESTIGATIONS. Students should develop the ability to refine and refocus broad and ill-defined questions. An important aspect of this ability consists of students’ ability to clarify questions and inquiries and direct them toward objects and phenomena that can be described, explained, or predicted by scientific investigations. Students should develop the ability to identify their questions with scientific ideas, concepts, and quantitative relationships that guide investigation.

DESIGN AND CONDUCT A SCIENTIFIC INVESTIGATION. Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables. They should also develop the ability to clarify their ideas that

are influencing and guiding the inquiry, and to understand how those ideas compare with current scientific knowledge. Students can learn to formulate questions, design investigations, execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures (p. 145).

The Standards are asking teachers to create in their classrooms the real working process of scientific investigation, from start to finish. If students are to achieve the skills described here, they will clearly need extensive experiences to do so. Though each and every curriculum published will claim to meet these standards, few will actually do so. It should be noted that though the National Standards quoted above set high expectations for students' ability to engage in scientific inquiry, the source of the questions being investigated is not explicitly addressed. Students are expected to be able to "refine and refocus broad and ill-defined questions," but these questions need not be their own.

The AAAS Benchmarks for Scientific Literacy (1993) are less ambitious regarding inquiry than the NSES. Nonetheless, they voice some criticism of the traditional classroom experiment:

The usual high school "experiment" is unlike the real thing: The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other experimenters for criticism; and, to top it off, the correct answer is known ahead of time (p. 9).

In spite of this accurate and scathing critique of secondary science lab instruction, the Benchmarks only recommend the following, characterized as an “ambitious step,”:

Before graduating high school, students working individually or in teams should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism (p. 9).

It is unclear how the high school student will have developed the skill to carry out this type of investigation. This approach might be likened to taking a child to the movies every week for a year, then asking him to write a movie script. The product being asked for looks superficially like the prior experience, but the process involved in actually creating an investigation is fundamentally different from following the recipes in science texts.

Whose Inquiry? Whose Questions?

How do we create a process of inquiry within the classroom that delivers students with solid experiences which they can build real understanding from, but places the student in a creative and active role? If the student is to have ownership of an investigation, perhaps she should help define the question being investigated. On this topic, Saul (1996) states,

I have worked with smart, scientifically skilled people designing curriculum for children. Invariably they begin with their own

excitement about a given problem, ask fascinating questions about the concept or material in question, and then create a series of activities that help answer their questions. The problem is, of course, that they are working with their questions. They don't trust children to have questions of their own, and they don't trust themselves to build on student questions in a creative way (p. 9).

Mestre and Lochhead (1990) likewise focus on students' questions in the following:

Students should be encouraged to ask, as well as answer, questions. Also, students should be helped to distinguish between those questions that can be meaningfully posed and answered within science, and those other nonscientific questions that are outside the purview of science. In addition, students should be taught the art of formulating scientific questions, breaking up "large" questions into more manageable "smaller" questions, and designing a procedure (whether involving experimental work, library research, or other means) for answering them (p. 62).

Children's ideas are windows on their existing knowledge, and are thus foundational to a constructivist teacher. Wynne Harlen (1996) points to the significance of children's questions as well. Harlen proposes that teachers categorize questions into those that are investigatable, and those that are not, and work to turn children's questions into the bases for investigations. She writes,

'Turning' questions into investigatable ones is an important skill since it enables teachers to treat difficult questions seriously but without providing answers beyond children's understanding. It also indicates to children that they can go a long way to finding answers through their own investigation, thus underlining the implicit messages about the nature of scientific activity and their ability to answer questions by 'asking the objects' (p. 112).

If students can indeed gain confidence in their ability to investigate, in their own ability to pose and answer their questions, they will have gained some very real power.

To summarize, constructivist theory places the experience of the learner at the center, with social relationships between learners and teachers playing a significant role. Critical theorists also focus on this relationship, calling for an active dialogue between teacher and learner. Science inquiry instruction based on student questions offers an avenue for the development of this dialogue, and allows students to build their skills in investigating the natural world with the critical support of their teacher. My research will explore and contrast two models of science inquiry instruction, both of which attempt to build inquiry on a foundation of students' questions.

CHAPTER III

METHODOLOGY

Overview

My methods draw together critical reflection, embodied in my journal, and critical dialogue, carried out within my collaborative research group and in the informal network of colleagues with whom I have established an extended dialogue over these issues. The collaborative teacher research group has developed what Hollingsworth (1994) calls “extended conversation” as a means of examining our practice. Using my web site and electronic mail I have established a similar community of critical colleagues who have also contributed to the development of my research. As difficult practical and theoretical questions arose, I used both of these communities as sources for insight. My students are a third set of collaborators. They have been active sources of information. I have observed their level of engagement and understanding as a result of the different instructional methods used, and asked them, in questionnaires and interviews, to give honest reflections on their experiences in the classroom.

Arriving at Inquiry

In my own practice, inquiry is a transcendent theme for all participants in the classroom. I wish student learning to be shaped by this process, and I wish my students to collaborate with me in my inquiry into how we can best learn. In the past, my instruction consisted of doing activities with the students, then leading students through a set of questions to make sure they got the point. Students lacked ownership in the activities. They lacked motivation, since they were not driven by any great curiosity about the subject of the activity. Neither were they learning any real process skills, since they were just following directions on a worksheet.

In the Spring of 1997, I attended a week-long professional development workshop sponsored by the Exploratorium's Institute for Inquiry. We went through a number of small-scale inquiries, and one in-depth inquiry. Emerging from this experience, I was at first critical of my work from the standpoint that it did not include enough inquiry. However, as I studied more, I learned that the issue was not the presence of inquiry, but rather, the origin of the questions being pursued in the inquiries. In my advocacy of student-designed investigations, I brought forth sections of the National Science Education Standards that stressed the need for inquiry. In my mind, for an inquiry to be fulfilling, it should be driven by real curiosity, and I felt

that this could only be accomplished by drawing from genuine student questions. In contrast to this view, a colleague related a personal communication with Rodger Bybee, whom he quoted as saying, "In inquiry the question could come from a student, from a teacher, from the curriculum, or from a classical scientific problem. To have inquiry one must have the accumulation of data, leading to the formulation of a model or an explanation that answers the question." Dissatisfied, I sought out further definitions of inquiry, and was led to define the central topic of this study, the role of student questions in inquiry.

The origin of a question is given significance in many definitions of inquiry. Marek and Cavallo (1997) write, "In an inquiry-oriented classroom, questions may be posed by the teacher or formulated by children. The critical element to inquiry is that the child seeks answers to questions and is not given answers" (p. 22). However, from my point of view as a middle school teacher in Oakland, the origin of the question has seemed very important. This seems so for two reasons. First of all, I must agree that the key to an effective classroom investigation is that students actively seek the answer to a question. In my experience, however, if students are not given an active role in defining the questions to be answered, they often lose interest in the investigation. If the questions are not theirs, neither are the answers.

Secondly, if we intend students to be able to “identify questions that can be answered through investigation,” and “design and conduct experiments,” they will need a great deal of practice in doing so, and this will best be done using their own thoughts and questions.

Structures for Inquiry

How can we create a framework for inquiry that provides the guidance students need, yet allows their questions to drive their investigations?

Charles Pearce (1993) describes a set of discovery kits he used with his 5th grade students. He provides each group of students with a rich set of materials, a list of possible questions to prompt investigation, and the expectation that they will experiment and document their results. My classroom experimentation this year began with this approach.

Mestre and Lochhead (1990) offer a description of what they term “structured inquiry,” which is very similar to the approach I took in the latter part of last year:

The idea is to provide a structure within which to carry out experimental work, but one that allows students the freedom to explore and learn on their own. Rather than providing all the details of an experiment, as in cookbook labs, the structured inquiry approach provides students with both a designated topic that will be the focus of the experiment and the equipment to conduct the experimental work. Within this framework, the teacher acts as a mediator (p. 30).

They go on to describe how a teacher orchestrates such inquiries:

Laboratory activities would begin with a classroom discussion of experimental design. The goal of this discussion is to help students pose questions or hypotheses about a topic that can be answered using the equipment available and to help students devise an experimental procedure by which the questions or hypotheses can be addressed. At first, posing meaningful questions and devising experimental techniques for answering them may be difficult for students, so the teacher must be ready to provide necessary assistance until students are capable of completing these two steps on their own. At the learning stage, wide-ranging class discussion is likely to generate several experimental questions and procedures, all of which cannot be investigated by an individual student. To ensure exploration of all relevant questions, the teacher can divide the class into collaborative groups, each of which can explore a particular question or related set of questions. Once this classroom discussion is completed, the students carry out the experimental work. After the students have analyzed the data and drawn preliminary conclusions, the class can reconvene for another discussion, this time about the findings and conclusions regarding the questions and hypotheses posed. This discussion provides the collaborative groups with an opportunity to pool their results and the teacher with an opportunity to serve as mediator in a discussion of the experimental findings. Unlike cookbook labs, this approach encourages students to be active participants in experimental design (p. 30 – 31).

To give genuine power to the students, an experience must develop within the student a sense of her agency, a critical consciousness of her relationship to others, and concrete skills which can be used to understand and transform the world. If the student is in the position to ask the questions that frame the inquiry, she has agency. If she actually develops the investigation to answer her question, she has not only agency, but access to the capacity to understand and therefore, reshape the world.

Looking ahead to the Fall of 1997, I outlined the instructional plan I would follow to develop inquiry abilities with my students. I posted this on my web site, Cody's Science Education Zone, as part of an open Inquiry Dialogue, inviting the comments and responses of my colleagues.

Inquiry Dialogue, June 15, 1997
Three Ways to Learn

A. Directed Instruction

I will be using a combination of three basic approaches to learning. The first approach is directed. This represents more traditional instruction. It may be hands-on activities in which the questions and procedure have basically been determined for the students. The activities might be cooperative, they might be a lecture, they might look student-centered, but the direction will be coming from me. I will expect to use this approach quite a bit at first, as I want to establish control in the class, and I also want students to go through a number of scientific investigations so they learn the vocabulary of an experiment.

B. Guided Inquiry

Overlapping a directed approach is guided inquiry. If the students can come up with the questions for our investigation, with some guidance from me, we are on the road to inquiry. To initiate this, I will do a demonstration of some sort, or give students some exploratory time with a set of new materials. Then, ask students to generate and record their questions. We will go through these to see which can be answered through our own actions, using the materials and equipment available. Then we will conduct the investigations. In some cases each group will get the materials to conduct the experiment. In other cases, I will ask one group of students to do the experiment at the front of the class.

The goals of guided inquiry are:

To develop students' ability to ask questions of nature.

For students to learn that some questions can be successfully investigated, while others are much harder to answer.

To center our experiments on actual student questions.

For students to develop skill and confidence in the process of

experimentation and investigation. This includes use of equipment, measurement, controlling variables, careful observation and making inferences.

C. Open-ended Inquiry

This could also be called "Discovery Time." I will have thirty-five separate boxes of materials for students to choose from, for their investigations. Each box will have a theme. Some will contain electricity kits, others Capsela materials, lego kits, seashells, fossils, optics, and anything else I can put together. Each box will have a number, an inventory sheet, and a signout, like a library book. Each student who uses the kit is responsible for checking the materials every time, and telling me if anything is missing. We will work with these kits for an hour each week.

Students will be asked to investigate the materials in the kit as they choose. If there are instructions, they can follow them or not, as they like. I will ask them to pose questions for themselves along the way, and keep a record of these, along with the answers. I will collect these each month.

The third marking period they will be asked to do an actual independent investigation. They can use their experiences with the kit as the basis for this investigation. They will need to define a question, conduct an investigation, and present their answer.

In the course of the fall and winter of 1997 and 1998, I used each of the three methods described here. My original intent was to begin with directed instruction, then guided inquiry, and culminate in the use of open-ended inquiry. I began with directed instruction as planned, and did some limited work in guided inquiry, but we began working with open-ended inquiry through investigation kits before the students had much experience with guided inquiry. We then returned to guided inquiry following several weeks of working with the kits.

Open-Ended Inquiry through Investigation Kits

Since the investigation kits formed the heart of my initial strategy, I devoted a great deal of time and resources to them. The Inquiry Dialogue described the process I was going through preparing for their use. This attracted the attention of teachers from around the country, and around the world. One teacher actually wanted to purchase copies of the kits for his district in Brazil. A teacher in Oakland incorporated the concept in a grant application for outdoor education that he was writing. I wrote the following in response to a teacher from South Carolina, who wanted a more detailed description of the kits.

Inquiry Dialogue, October 22, 1997

The kits are quite varied, and come from different sources. What I hope to do through this period of experimentation is to find out for myself what sorts of materials and structure work best in this situation. There are some Mr. Circuit electronics kits, that include solderless circuit boards. There is a box of Capsela pieces that can be put together to make devices. There are several optics kits, with lenses and an optics bench. There are several kits with seeds and materials for studying plants. All told, there are about fifty kits, about forty of which are in use. There are perhaps twenty-five different kits, since there are more than one of some of the kits.

I am planning to give them at least an hour a week with the kits. So far they are fairly motivated, but today was only the second day of their use. The first trouble occurred this morning when student after student came up to me asking to trade kits. I intentionally made more kits than would be needed because I knew not all the kits would be winners, and I wanted to be able to have some fallbacks, so kids would not be really disappointed.

The accountability I am using so far is in two forms. I have a sheet called a Scientific Investigation Log. It has space for the question they are investigating, their procedure, their results, and a box for a sketch. I have harped on them to keep a record of what they are doing, with only some success. There is also a little quarter sheet of paper that says "What I accomplished today." For more long-term accountability, I expect them to develop a significant investigation that they can actually write a report on during this marking period. This is the first one, so I am sure they will be uneven, but I think some of the students will do well. I hope these reports will become more elaborate and developed as the year goes on.

If I am to imbue my students with the knowledge that they can reshape themselves, and reshape the world around them, I must apply that truth to myself as well. bell hooks (1994) describes an "engaged pedagogy," in which the teacher recognizes that both teacher and student must be open to change for engagement to occur. There is a dialogical structure within the teacher-student relationship. She writes, "Engaged pedagogy does not seek simply to empower students. Any classroom that employs a wholistic model of learning will also be a place where teachers grow, and are empowered by the process" (p. 21). My quest, then, is for a classroom where exploration and investigation is the guiding theme, and each person's capacity to discover is nurtured and developed.

Educational Research as Critical Praxis

My work draws on a background of ten years of participation in a collaborative teacher research group. This group has developed a critical dialogue based on common commitment to social justice through education.

Hollingsworth and Sockett (1994) characterize the impulse toward critical praxis within the teacher research movement as being based on

...disenchantment with the view of control as a means of improving education, a concern with teacher autonomy, and a growing understanding of knowledge as a source of power in society created an ideological convergence which provides a clearer realization of the interconnected nature of knowledge, research and practice (p. 9).

Sirotnik (1991) defines critical inquiry as taking an ethical stance, committed to social justice. My work has as its goal that my students, primarily African American, Latino and Asian American, acquire the skills needed to effectively investigate the natural world. Once they have become effective at asking questions and getting answers from nature, they can move from understanding to transformation. Critical inquiry calls for an active investigation into the values and belief systems that underlie our knowledge, and conscious consideration of the "justice value" of a set of ideas before they are adopted.

Critical inquiry calls for an active dialogue. It acknowledges that our reality as educators is so complex that there are many sources of truth which

must be woven together to generate our understanding. Sirotnik says,

If we interpret dialectical methodology broadly as a knowledge-building process where what is presumably known is continually re-known through questioning, arguing, counter arguing, reflecting, challenging, contradicting, reconciling, modifying, revising, and so forth, then we can acknowledge and celebrate more formally what educators already do-and could do even better-as they use and generate knowledge in the context of practice (p. 247).

To establish insightful dialogue, Sirotnik calls for "competent communication," comparing this to Habermas' "ideal speech situation."

Sirotnik summarizes thusly:

In a nutshell, competent communication will only occur in an environment characterized by mutual trust-trust not only between people, but also trust in the ideas, facts, values, and interests that people share and upon which they act (p. 249).

Lytle and Cochran-Smith (1994) likewise recognize the importance of a community of communicators:

We have defined intellectual communities of teacher researchers as networks of individuals who enter with others into a search for meaningful work lives and who regard their research as part of larger efforts to transform teaching, learning and schooling (p. 32).

I have established this level of trust with my colleagues in my collaborative research group, and my fellow masters candidates at San Jose State University. I have experimented also with a more open form of dialogue, using email and the internet.

Sirotnik suggests that to be critical, an inquiry must begin with a

definition of current circumstances, followed by an exploration of the historical events leading to these circumstances. This is followed by delving into the values and beliefs involved, the interests being served by the situation. Knowledge from a variety of sources must then be brought to bear to create the last element; informed action.

The knowledge upon which we base our actions is central. To arrive at the competent communication described by Sirotnik, the collaborative research group to which I belong has engaged in extended conversation, generating what Hollingsworth terms "relational knowledge." Within our collaborative group we have used a model of sustained conversation to develop deep understanding of our classroom practice. Our 1994 book, *Teacher Research & Urban Literacy Education*, Hollingsworth, Cody, et al, showcases this process and defines conversation as a tool for growth.

Hollingsworth describes how she sees our conversation as praxis:

More than gaining specific guidance for immediate concerns, the conversations seemed to provide the intellectual stimulation and social interaction needed to create, act upon, and analyze our own broader knowledge about teaching (p. 47).

Hollingsworth goes on to say,

The ideal conversational situations for relational knowing, therefore, were those that provided opportunities for a renewed sense of questioning received wisdom through hermeneutic dialogue-conversation that contains a space for wonder, mystery, uncertainty,

and the barely knowable (p. 79).

The dialogue within our group has delved into our relationships with our students, and the role our ethnicity plays in these relationships. Our group is composed of three white women, one African American woman, and myself (I am also white.) Conversations with this collaborative group, as well as with my cohorts at San Jose State University, have provided the basis for renewed questioning that inspires my research. Here is how I described the work of the group three years ago;

The role of our collaborative group has changed over the years. In the beginning, as I struggled to become an effective teacher, it was useful to share some time with a group of supportive people experiencing similar troubles. As a beginning teacher, one is expected to be competent, so feeling less than competent can make one's existence isolating. I think this sets a pattern of defensiveness which many teachers never break out of, even as they become competent. Our collaborative group was a safe place to acknowledge each others strengths and failings. Our discussions in the early years frequently addressed specific problems in our classes, and strategies to use. We also developed a fairly thorough critique of the academic "educational establishment," and the process of teacher training we had all shared. This critique has served me well as I have tried to be an effective master teacher and mentor teacher over the past few years.

As we grew more experienced, our discussions became less focused on particular strategies to teach reading, and more on the issues we each were dealing with as professionals: how to respond when a school administration is ineffective and sabotages good teamwork among teachers? How can white teachers be effective with students of color? How can we develop our careers in a way consistent with our vision and ideals as educators? What does it mean to leave the classroom? What are different forms education can take, outside of a classroom context?

These discussions have allowed me to wrestle with issues of my

conscience. When I am not sure if what I am doing is right, I can bring it to light in the group, attempt to defend it, and see how the group responds. I know they will be honest with me, and challenge me if they think it is wrong. Often, the process of discussing such personal issues really clarifies my thoughts, and allows me to articulate them much more clearly.

My collaborative group has provided me with the most in-depth, long-lasting and consistent counsel. In addition to this, in the past year I have actively developed a small network of fellow science teachers to specifically discuss issues related to an inquiry approach. This network began with a young teacher, Jim Rogers, who approached me via email, looking for advice about difficulties he was having. He was struggling with many of the same issues, but not finding much success, hampered by a lack of experience and curriculum. After we shared a meal and heartfelt talk, I proposed that we conduct a dialogue over the internet:

How would you like to participate in a regular dialogue with me over the next year? Each week, we would exchange ideas, plans, dilemmas, and triumphs from our classes. I would tell you what I plan with my kids, you likewise, we would critique each others' ideas, point out possible trouble, then report to each other our results. This would provide each of us with a critical sounding board, and opportunity for extended reflection. As an extension, we could post the conversations on my web site, where others could read them. (Inquiry Dialogue, May, 1997)

Rogers agreed to participate in this dialogue, and in the summer and fall of 1997, we exchanged numerous letters. This was beneficial to both of us, and by

posting this dialogue on my web site, I attracted several more individuals, some of whom I have worked with in Oakland, and others from as far away as Brazil. As questions emerged in my work, I posted them on my web site, emailed them to colleagues, and actively sought their views. This forum actively informed and influenced my work.

Action Research

In this study, my classroom inquiry is focused through the lens of action research. According to Hopkins (1993), "Action research combines a substantive act with a research procedure; it is action disciplined by enquiry, a personal attempt at understanding while engaged in a process of improvement and reform" (p. 44). Hopkins attributes the origination of action research to Kurt Lewin, who felt that "through action research advances in theory and needed social changes might be simultaneously achieved." (p. 45) Stephen Kemmis refined the application of action research to teacher research, according to Hopkins. Kemmis developed an 'action research planner,' suggesting a sequence of steps for teacher researchers. His action research spiral is reproduced here, showing graphically the phases of action research. I have adapted this to show the phases my research has gone through. (See Figure 3.1, Action Research Spiral, page 35)

Figure 3.1: Action Research Spiral: Student Questions: Foundations for Inquiry

Hollingsworth and Sockett (1994) trace the origins of modern teacher research to the late 1960's and early 70's, giving credit to Laurence Stenhouse and John Elliott, who "...asked teachers to engage in a 'process model' of curriculum innovation where professional development and curricular development became the same enterprise (p. 5)." For them, "...the centrality of teacher-selves in research necessarily undermined the kind of objectivity espoused by traditional researchers working with a natural science model, and it also challenged hierarchical models in professional workplaces "(p. 6). This movement gained favor in the US in the 1970's and early '80's, spurred on by the publication in 1983 of Donald Schon's *The Reflective Practitioner*. According to Hollingsworth and Sockett, "To Schon, the alternative epistemology is knowing-in-action – as opposed to the 'trickle-down' view of the relationship of theory to practice. The professional is a reflective practitioner as opposed to a technician" (p. 6 - 7). Schon (1987), proposed a revision of the scientific mindset of researchers. He said,

When a teacher turns her attention to giving kids reason to listening what they say, then teaching itself becomes a form of reflection-in action, and I think this formulation helps to describe what it is that constitutes teaching artistry. It involves getting in touch with what kids are actually saying and doing; it involves allowing yourself to be surprised by that, and allowing yourself to be surprised, I think, is appropriate, because you must permit yourself to be surprised, being puzzled by what you get and responding to the puzzle through an on-the-spot experiment that you make, that responds to what the kid says or does. It involves meeting the kid in the sense of meeting his or her understanding of what's going on, and helping the kid co-ordinate the

everyday knowing-in-action that he brings to the school with the privileged knowledge that he finds in the school.

He went on to say:

These explanations give the teacher the knowledge of the greatest possible number of methods, the ability of inventing new methods and, above all, not a blind adherence to ONE method but the conviction that all methods are one-sided, and that the best method would be the one that would answer best to all the possible difficulties incurred by a pupil. That is, not a method, but an art and a talent. And this is teaching in the form of reflection-in-action. It involves a surprise, a response to surprise by thought turning back on itself, thinking what we're doing as we do it, setting the problem of the situation anew, conducting an action experiment on the spot by which we seek to solve the new problems we've set, an experiment in which we test both our new way of seeing the situation, and also try to change that situation for the better.

He called for research to take the form of reflection on reflection-in-action, which would mean to actually interrogate the process by which teachers conduct improvisational, artistic experiments in education. This is quite a contrast to the search for a "science" of education. As my inquiry developed last fall, I did not limit my approach to the initial model I wished to test. I elaborated, improvised, and ultimately tried a completely different approach half way through the semester. The rigor in my method derives not from rigidly adhering to a set of procedures or protocols, or effectively controlling variables, but from honestly reflecting on my experiences, and giving my students and colleagues opportunities to join me in that reflection.

Lytle and Cochran-Smith (1994) offer this to explain teacher research:

“Teacher research...we define as systematic and intentional inquiry carried out by teachers in their own schools and classrooms...” (p. 24). They go on to say that: “...teacher researchers see their classrooms as sites of inquiry into students' learning, and they often approach the planning of curriculum and instruction with central questions about the teacher's role” (p. 30 -31).

Regarding the actual methods used, Lytle and Cochran-Smith suggest:

Teacher researchers also study interventions that take place over time as groups of teachers and students construct and reconstruct the curriculum. They explore the dynamic relationships that evolve among talk, writing, choice and access, changing roles, and student achievement. Inquiries of this kind involve working with students to renegotiate the meaning of student ability, construct new routes to textual understanding, and alter views about knowers and knowing in schools and classrooms (p. 31).

My students have been my partners as we have used their ideas to provide the backbone of our science investigations. We have shifted roles, as I have tried to move from being the presenter of all challenges, to being an organizer of opportunities to investigate.

Hopkins describes a set of criteria for classroom research, distilled into a set of principles. These begin with a teacher's primary obligation to teach, which is an ethical imperative. Research efforts may legitimately test methods which may turn out to be less than optimal, but the aim is always improvement. Secondly, data collection must not be too time-consuming or

onerous for the teacher, for practical reasons. The methodology should, however, be rigorous enough that teacher researchers can write with confidence about their experiences, and draw genuine lessons from them. The research problem should be one to which the teacher is committed, and the problem must be within the scope of the teacher's power to effect. Teachers should adhere to ethical standards regarding work with research subjects. Lastly, teachers should seek to extend their vision and influence beyond the walls of their individual classroom, contributing to the professional development of everyone at the school site.

Woven into my research are stories, narratives that describe my classroom, my students and some of our times together. These narratives provide another avenue to the truth, another source for insight. Connelly and Clandinin (1991) describe an approach to research they call "narrative inquiry." They suggest, "The sense of the whole is built from a rich data source with a focus on the concrete particularities of life which create powerful narrative tellings."

My students themselves are naturally my most important source of information, and they are active collaborators in my work. My curriculum is based as much as possible on their ideas, and I base my understanding of the effectiveness of my approach on their response to it, as well as their

accomplishments and demonstrated learning. I have surveyed and interviewed my students to gain an understanding of their perceptions. I am working with two Math/Science core classes; the first is a group of 20 Limited English Proficient (LEP) students, immigrants from Asia, Latin America and Tonga. The second is a regular 6th grade class, with 32 students. The majority here is African American, with a few European American, Asian American, Latino and Pacific Islander students as well. The two groups are quite distinct, and provide me with a rich set of responses to the work we are attempting. I do not look for or expect my approach to always meet with student approval, but I am interested in their opinions, and why they like or dislike different methods. Nugent and Yerrick (1995) describe the resistance students offered to a non-traditional teaching method. Their students were unaccustomed to playing an active role in the search for answers in their classroom. They were much happier with a teacher who would just "give them the answer." If this were my students' point of view, I would be prepared to challenge them.

Data Collection

Any research is only as good as the data upon which it is based. To give a full picture of the results of this work, I will present my journal entries written at the time, as well as an analysis of student work. I will summarize

student performance on key indicators of successful inquiry, and provide excerpts from student work. Student voices will add a third dimension of understanding to the description, through student surveys and transcribed interviews. Hopkins recommends group interviews: "Far from inhibiting each other, the individuals 'spark' themselves into sensitive and perceptive discussion." (p. 124) I also will refer to my personal journal, where I have recorded reflections several times each month for the past several years. Much of this journal was published on my web site as an open-ended "Inquiry Dialogue," which attracted the participation of a number of interested teachers. Their reflections are also used as a source for insight. I invite you to join me in exploring the unique circumstances of Room 215 at Mark Twain Middle School during 1997 and 1998.

CHAPTER IV

ANALYSIS and FINDINGS

Inquiry in Practice

My quest began with a desire to equip my students with the ability to not only think for themselves, but for them to be able to apply the powerful tools of scientific investigation to their world. The model I initially placed the greatest hope in, open-ended inquiry, proved to be unworkable in the form in which it was attempted. Driver (1994) correctly notes that people do not “discover” how to work like scientists simply through unguided experience. She wrote,

Science ideas, which are constructed and transmitted through the culture and social institutions of science, will not be discovered by individual learners through empirical enquiry: learning science involves being initiated into the culture of science (p. 6).

Though my intention was to accomplish this initiation in the first six weeks of instruction, such a brief introduction proved inadequate. Students were unable to move beyond the exploratory phase of inquiry, using an open-ended model.

The guided inquiry model I used in the latter part of the semester proved much more productive. These findings support Mestre and Lochhead’s suggestion that this approach will yield students who are “active

participants in experimental design.” Likewise, Delpit’s call (1988) for more explicit communication of expectations was supported. Students were capable of designing and performing successful investigations, but only after extensive modeling and coaching. As a result, my students are much better equipped to engage in a scientific investigation than they were a year ago.

Decision-making in Inquiry

Since my objective is for students to take responsibility for key decisions along the path of ongoing science investigations, I have developed a comparative framework that allows us to see the locus of key decisions as this process unfolds. (See Figure 4.1, Models of Inquiry: Locus of Decisions, page 44) For each model of inquiry, I present a list indicating the necessary decisions, and who makes them, the student or the teacher. In the open-ended inquiry model, almost all of the decisions are made by students. However, as will be seen, most students failed to move past the exploration phase, and thus did not actually make the question definition and experiment design decisions sought after. The guided inquiry model places similar responsibilities for question definition and investigation design upon the students. However there are several key differences. First of all, in the guided inquiry model students are addressing a topic as a class, rather than

Figure 4.1: Models of Inquiry; Locus of Decisions

Open-ended Inquiry Model		Guided Inquiry Model	
Student Decisions	Teacher Decisions	Student Decisions	Teacher Decisions
Choice of kit/topic (Working solo or in pairs)	Topics and materials in numerous different kits	Initial Exploration	Topic Choice Selection of materials (Same topic for whole class)
Exploration		Question generation	
<div>Most students did not move beyond this stage.</div>		Question refinement	Critique
Question definition	Critique	Investigation design	Critique
Experiment design	Critique	Student group critique	
			Choice of investigations for students to perform.
			Lab instruction sheets created based on students' design
			Lecture, discussion and vocabulary definition to formalize student learning
			Assessment of student knowledge

individually or in pairs. This allows for greater teacher and peer guidance. Second, the teacher plays an active role in filtering and choosing the investigations the students will perform, and making sure they are done scientifically. Lastly, the teacher engages in whole class instruction to ensure there is a common understanding of the scientific principles at work in the investigation. In both models, students are asked to make decisions at comparable levels of difficulty. However, these decisions are given greater teacher guidance in the guided inquiry model, and are followed by more involvement on the part of the teacher, to ensure that the investigations are sound, and the appropriate conclusions are arrived at.

Investigation Kits Implemented

As I began teaching in the fall, my goal was to build up the students' scientific vocabulary, to equip them with conceptual tools they would need in doing their own investigations. I used several activities from the FOSS Variables module, including an investigation into pendulums. Students were taught how to collect, record and organize data, and how to write a conclusion summarizing their results. As we proceeded, we defined terms like "variable," "control," "data," "average," "range." We also did some more open-ended sequences building on the concept of density and completed a

guided inquiry sequence in which the students suggested experiments to discover why an ice cube sank rather than floated. I hoped they would be able to apply this experience to the experiments they would need to design themselves using their investigation kits. The day the students first dug into the kits was a momentous one for me, representing the culmination of months of preparation. I wrote this description that evening:

Inquiry Dialogue, October 17, 1997
Investigation Kits Launched

Today was the big initiation of inquiry in my class; the launching of the investigation kits I have spent the past five weeks building for. We have taken a patient approach, trying to lay down some basic investigation process skills. We used the FOSS Variables kit to explore pendulums and paper cup boats, emphasizing careful record keeping and the importance of accurate measurement. In the last week, we did a class investigation into the density of liquids, trying to discover why some objects float in water, but sink in alcohol. This last investigation focused more on the ongoing process of generating questions, testing them, and moving on to new questions.

On Tuesday of this week, I gave students in each of my two classes a list of about 25 kits to choose from. Each class had a distinct list, so no kit will be used by more than one group. Students chose based only on the name of the kit, without looking at the contents.

I distributed the Investigator's License, which is a list of responsibilities they agree to as a condition of working with these kits. The list includes having a question in mind when investigating, keeping accurate records, preparing a report following major investigations, and keeping track of equipment in their kit. Then I allowed students to find their kits in the cupboards. It looked like Christmas, with each child discovering a new set of toys. Some of the students wanted to start right away. Before long, Lakisha was planting seeds in a large egg carton. She needed a bit of direction to label the different spots with the type of seeds she had planted, and draw their

location on a separate sheet of paper. Malou and Leilani were soon blowing bubbles onto their table top, and Jimmy and Pete had attracted a clump of students anxious to see them demonstrate a magic trick from their kit. Cathy had constructed a Lego lever system, John and Caleb a hydraulic device. About five different groups were busy working with electricity or electronics.

The groups with very simple kits seemed a bit at a loss. The girls who had chosen mapping and found maps, tracing paper, compasses and aerial photographs were allowed to switch. Another pair who had chosen the stethoscope kit were likewise unhappy, and switched. I am hoping that as the students get more comfortable working on their own, these kits will be chosen and explored more vigorously. Thinking about the kits, there are some that are more technological, such as the electronics kits. The students using these kits may have a hard time coming up with "experiments" in the way an inquiry approach would suggest. I expect them to produce reports more along the lines of "this is how a burglar alarm works." They will know as a result of building one. Once they have created something like a burglar alarm, we can open it into more of an investigation, by posing some questions: Does it matter how long the wires are? What the wires are made of?

Others, such as the Crystal kit, seem natural for inquiry. Since it involves a recipe, the students can vary ingredients or conditions and record their results, looking for patterns. Some, like the plant kit, are pretty wide open. With seeds, soil, fertilizer and small microscopes, it offers many avenues for a student to pursue.

Next Wednesday, they will have another chance to use the kits. I hope to move them from exploration to the beginning of investigation. They will still be primarily exploring, but I will ask them to begin thinking about questions they might pose, variables they might change, experiments they might do. I will look for students doing this to hold up as examples. If students are to this point, I will supply them with Investigation Logs to use to record their experiment design upon. By the end of the period, I expect to have several of these completed so that I can share them with the class, so they know what I am looking for in this phase. I will also stress the importance of keeping careful records of what they are doing as they proceed, so that they can learn from their experience.

Critical Reflection: Confounded by Reality

My expectations for what the students should be able to do as a result of their work with investigation kits were high. I believed that students could define their own questions and investigate them, if they were given the right kind of preparation. As I struggled to maintain these expectations, I tried to analyze the aspects of the kits that worked, and those that did not.

Inquiry Dialogue, Nov. 5, 1997

Trials and Tribulations with Kits

We are at a critical stage in the work with the kits. The students have been exploring for about two weeks. Very few have thus far settled on a real question to investigate. So today we spent a half hour writing about what their questions are. I had them fold a paper twice, to make four sections. In the first, I had them write: I have done.... The second; I have learned.... The third; I wonder.... The fourth; I plan to.... I had them discuss in groups their results, but I am afraid these eleven and twelve-year-olds were not really capable of helping each other much. So I basically did a roll call, and asked each student their topic and their question, and how they planned to answer it.

A few of the students had workable questions, but most of them needed some modification. For example, one student said she wanted to find out "how plants drink and eat." I suggested she choose something to focus on, such as, how much fertilizer do plants need? Or how much light or water, rather than looking at everything at once. By the end of the period she had gone from having four plants, and a very vague question, to a setup with 18 seeds planted, with three different amounts of fertilizer on them. Another group working with a Lego gears kit said their question was "how do gears work?" "Unacceptable," I said. I told them they had to find something to compare -- some way to change the setup. For example, they could look at what difference the gear size makes in how the gear works. This

approach seemed most successful with a couple of students working with a Capsela kit. This is a modular toy, consisting of motors, gears and wheels encased in plastic capsules that snap together. I suggested the students investigate how different things affected the speed. By the end of the period, the students working on this told me they thought weight was a critical factor, and they were going to make different models, weigh them, and see how fast they went. This was their idea. A number of the students working with electronics are rather at sea, so I augmented their kits with some light bulbs and resistors, and made electric meters available to them. Some of them seemed to be making some discoveries with this material, but they will need some monitoring, and some assistance in developing their record-keeping practices.

I have not fully reviewed all of the investigation plans. I feel we are under way, however, and we are quite a bit farther along than we were a week ago. There are several students, especially in the first period class, that I am concerned about. Some of their investigations do not seem to provide them with very much work to do during investigation time. For example, one student wants to compare infant heartbeat rates to those of teenagers. This is fine, but she does then not have much to do during our time with the kits, since she does not have an immediate opportunity to collect the data she needs. Some of the kits are problematic in this way. I will be reviewing the investigation plans and deciding if the students should proceed. In some cases I may redirect them within their topic to a new question, or even to a completely different topic.

I reviewed the plans the students had written. Most were lacking in a defined question that could be answered clearly. One student wrote for her question: "I wonder if the crystals grow faster if they have a crystal seed." I had suggested this question to her, but in spite of having an investigatable question, her plan shows she does not know how to follow through and actually answer it. Her plan said: "My plan is to get a crystal or crystals growing. I also plan to read books about crystals or gems." I responded, suggesting that she "compare different formulae (recipes), measure growth and keep records." Ultimately, this student did little more than grow some crystals. I was looking for

her to define a variable that might affect the rate of growth, or the size of the crystals, but she was mainly just interested in seeing if she could get the crystals to grow. Other students ended up with similar reports, describing how they had created electrical circuits, or projected images using lenses.

My goal was for the students to complete four steps. First, I wished for them to engage in exploration with the materials. Second, I asked them to define questions to answer through investigation. Third, I wished them to conduct an experiment using a control, and obtain measurable results. Lastly, to complete their investigation, I expected a conclusion or report summarizing their results.

A few teams succeeded in completing these four steps. Two boys in my LEP class working with crystals completed this report, reproduced here verbatim:

In the first day, Miguel and me made cristal. We put salt, bluein, namonia and water. The second day we put wan in the warm place and another wan in the cold place. The cold place was in a refrigerator, the warm close to the heater. The day the wan in the warm place had a lot of snow flakes, but in the cold place had a little snowflakes.

warm: 4 cm

cold: 1 cm

The four day the wan in the warm was groin a lot but the cold place wasen groin.

warm: 8 cm

cold 4 cm

I found that crystals grow better in a warm place, that why they grow in mines, under groun.

These students came up with the idea for this experiment, and prepared the two treatments themselves. They observed regularly, recorded measurements, and reached a sound conclusion. Their

experiment lacks sophistication, and they fail to report key features of their experiment, such as the quantity of the various materials, and the temperatures at their two locations. These are clearly beginners, but they have the central elements of a successful experiment. Few of their classmates achieved even this measure of success. Typical was a student investigating magnets. His conclusion states:

The iron filling is atrat to the magnets. The magnets were sticking to the iron filling. When you put the iron filling in a plastic bag and move a magnet out side of the bag the iron filling moves. When you put two peaces of metal 2 ich apart in the springholder it lighter. What I lerend about this project is that magnets can be atacket to a lot of thangs like metal.

This student clearly has done a lot of exploration, and reports a number of observations. However, he never defined a question to investigate, and therefore disparate observations are all he has.

When I surveyed the students to find out their feelings while they were working on the kits, almost all of them said they liked the experience. One girl wrote, "What's great about it is seeing my partner and I being successful at making our project work." Another student wrote, "It's fun to put the wires together and when it works you get so happy. When it doesn't you go to investigate more so it's fun." The students indeed felt ownership of their materials, and the joy they

experienced from their successes was genuine. However, the majority of students had been largely unsuccessful in defining investigatable questions. Very few were producing anything that could be characterized as an experiment. As we continued working with the kits I exhorted them to define the question they were trying to answer, but they were vague on what I meant, and were unable to do so. At this point, I was still focused on the kits, and felt that if I could redesign the kits, they could still work. I thought the kits needed an avenue for initial exploration, and materials that allowed for experimentation. I clung to the kit model because I felt it was the only sure way to put the responsibility for thinking and designing experiments where it belongs, in the head of the student. But as time went on, I began to question whether this model could work, at least in the time frame I had. A fellow Oakland teacher, Norman Brooks, sent me this response to my description of my work.

Inquiry Dialogue, Nov. 6, 1997

Anthony, thanks for the update. I really appreciate this. I think this is one of the important bases for our district program. I'll read your update more closely this evening but from the first part about the difficulties forming good questions it appears you're on the right track. It sounds like a perfect example of constructivism. You can tell the students a lot. You can show them a lot. They won't get it until they do it a lot. I would not tell them what is a good one or bad one. Let them do some bad ones and try to explain them. Let them watch other students and let them figure out on their own what works and what

doesn't. I see the teacher's role as one who keeps them trying and excited. I would be afraid to criticize too much for fear they will get frustrated and give up. I see this as a long, maybe slow, process. It would be great if teachers could take their time and give the students time to "construct".

Norman's comments reflect a discovery approach to science pedagogy.

However, I was not prepared to wait for students to discover how to do experiments. I wrote him in response:

Regarding the issue of how much to direct them, I am also concerned that if they only "mess around," and never really nail down an investigation, they won't learn what one is. I feel the need to set clear expectations, otherwise they are content to muck around for an indefinite period of time, never actually conducting what a scientist would recognize as an investigation. (Nov. 6, 1997)

Changing Strategies: Moving to Guided Inquiry

It became apparent that though we had spent about six weeks doing experiments and teacher-led investigations at the beginning of the semester, this was woefully inadequate preparation for students to work on their own to come up with similar investigations using the kits. Since my goal was not to get students to use kits, but to actually teach them to investigate, I decided to change my strategy, and return to an approach I saw as intermediate between directed instruction and

open-ended inquiry. I called this guided inquiry, and it is very similar to the “structured inquiry” of Mestre and Lochhead (1990). We began with an investigation into helium, followed by an exploration of dry ice. Here is the description I posted as I began this inquiry.

Inquiry Dialogue, November 26, 1997

Guided Inquiry: Helium

This week we returned to the central focus of the course: the investigation process. We are planning to do an investigation into dry ice, and I am hoping students will be able to make some clear observations of CO₂ gas. However, they have had little experience with gases, and I don't think they are even aware that density is a property held by gases as well as liquids and solids. So I thought we might begin with an investigation into helium, a gas they are somewhat familiar with, and one in which low density is an obvious property. We began with a story I have posted on my web site, “Lawn chair Larry Flies!,” about a fellow who launched himself into the air using 45 helium weather balloons. The story is rather funny, and set the stage for a thinking exercise. Students were asked to record all they know about helium, and what they wonder about it. In a discussion after this writing was done, they were asked to report back. They came up with nine questions. They were: Why does helium make your voice high? Will helium burn? What will happen if you put a helium balloon in the freezer? Can you breathe helium? How is a helium balloon like a hot air balloon? How long will a balloon last? Do different types of balloons take different lengths of time to lose their helium? Why is a helium tank cold? How many balloons would it take to really fly? The next day, I gave students at each table a sheet with three of these questions on it, with space for them to write what they thought the answer was, and to propose an experiment. I gave the groups about ten or fifteen minutes to confer and come up with experiments, and then, using the overhead, I went through the questions one by one, discussing the proposed experiments. At least two groups had each set of questions, since there were only

three sets, so all the students could suggest ideas. But I made the students at the tables with those particular questions the “experts” on those investigations, responsible for recording what the class decided to do.

The students were good at coming up with the skeleton of the experiment. They understood that to find out what happens to a balloon when you put in a freezer, well, you can put one in the freezer. But what to do next, I asked. “You monitor it,” a student suggested. “How do you monitor it?” I asked. We agreed, with guidance from me, that measurement would be important. I also introduced the idea of a control. In this case, I will suggest we have helium balloons inside and outside the freezer, and air balloons in and out as well. Then we can observe the behavior of both helium and air, and begin to learn about our atmospheric gases as well.

Next week I will place before them yet another form for them to use in planning their investigation. It asks them to state their question; hypothesis; experiment design, including materials, procedure and measurement technique; then gives a bit of space for the recording of results and new questions. Before we begin to experiment, they will need to have a clear plan agreed upon by everyone on their team. We will only have helium for about 25 balloons, so they must be careful with their use of materials.

I see this as guided inquiry. When I read them the story, and prepared to bring helium to class, I had in mind a rough outline of the investigation we would do. The question of how many balloons it would take to lift a person was a clear one I expected to explore. But I wanted the students to take responsibility for framing the investigation, for two reasons. First of all, I think that if the students are given the role of determining the questions to be explored, their participation becomes much more meaningful, and they get more engaged and excited. Second of all, and even more critically, the students need to learn how to ask good questions. Not all the questions thought of by the students will prove fruitful for our investigations. For example, “Why does helium make your voice change” is not something we can directly investigate. It is valuable for students to begin to distinguish productive investigation questions from ones that are not likely to be

productive. Beyond asking the questions, students then are being asked to design the experiments. This is not being done without guidance. I tried that with the kits and found frustration. The design process is a collaborative one, involving first teams of students, then the entire class, with the teacher as facilitator, coach, and Principal Investigator, if you will.

Guided Inquiry into Properties of Dry Ice

We continued this process with a new material, dry ice. The students had seen dry ice before, but very few had ever really worked with it before. It is a marvelous basis for investigation because it behaves like nothing the students have ever seen, turning directly from a solid to a gas. The gas also is denser than air, creating a sharp contrast to the helium we had just finished investigating.

Inquiry Dialogue: January 7, 1998

Dry Ice Investigation: In Progress

Student Questions as the Starting Point; Student-Designed Investigations as the Path

Our next focus has been on dry ice. In December we worked with vinegar and baking soda to generate carbon dioxide. I thought students should have some experience with this gas before we began working with dry ice, so they might have some concrete knowledge of the gas before experiencing the solid. Just before Christmas break I gave students a chance to mess about with dry ice for a class period. A number of them attempted impromptu experiments; adding alcohol, salt or vinegar to the dry ice, recalling our earlier experiments exploring density. Several even requested thermometers and measured temperatures. One group trapped the gas using the technique from the vinegar and baking soda experiment, a balloon over an Erlenmeyer flask.

Our goal now is to reiterate the process used in the

helium investigation, building on the students' skills in refining questions, designing investigations, collecting and representing data and summarizing their results. I began once more with the I Know/I Wonder lists. Then students were asked to design experiments to answer two of the questions they had identified. Students will be given a sheet that asks them to break these plans into six parts: question, hypothesis, materials, procedure, measurements and data collection. They will be asked to review and critique their team mates' plans, and we will polish them further. The clearest and sharpest experiment designs will be reproduced for the class to follow next week.

The students were prolific in their questions about dry ice. "How long could it last? What gas is it making? How is dry ice made? Would dry ice make liquids other than water bubble? Can you burn it? What is its temperature? Why does it burn you? What will happen if you put dry ice in boiling water?" I gave them a form I had developed for designing investigations. It asked students to state the question, their hypothesis, the materials needed, the procedure, and the form in which data would be collected. They chose a question from those the class had come up with and designed an investigation to answer it. Some questions were going to be hard to answer with an experiment, such as "how is dry ice made?" I put a sort of rudimentary yes/no rubric on the side of the investigation plan worksheet. For each element, they were asked to evaluate their own proposal. "Can the question be clearly answered by an experiment?" "Does the hypothesis clearly answer the question?" "Could you follow these directions easily?" I began by working with the class to critique the following student investigation plan, which I presented on an overhead:

Question: Can a dry ice gas make a balloon float?

Hypothesis: I think the balloon will not float because the gas I think is heavy.

Materials: Erlenmeyer flask, balloon, water, dry ice and table.

Procedure: Put the water in the flask then set it on the table.

Then put the dry ice in. Then put the balloon over the top of the flask. When full take the balloon off and tie it up. See if it floats.

We went through this plan step by step to see if we could improve it. Through class discussion, we figured out how to

measure the weight of the balloon and how to make a valid control, so we could compare the dry ice gas to air. Here is the revised version the student presented:

Question: Will dry ice gas make a balloon float or sink? If it sinks, how much heavier than air is it?

Hypothesis: (to be filled in by individuals)

Materials: Template, two balloons, scale, one 200 ml Erlenmeyer flask, 8 gram piece of dry ice, meter tape, water and air.

Procedure: First take the Erlenmeyer flask and put some water in it. Then put the dry ice in the flask. Quickly put the balloon over the top of the flask. Use the template to measure when the balloon is full. Then use the centimeter tape to measure the circumference of the balloon. Then blow up an air balloon just as you did the dry ice balloon. Then weigh the balloons on the scale. Then poke a hole in the balloons and weigh them again empty. Then subtract the weight of the empty balloons from the weight of the full balloons to get the weight of the gases inside.

Other students made similar revisions and improvements. I took the perhaps thirty proposals I got from my two classes home and sorted them that night. Some were impractical or unworkable, but the majority were reasonable. A number were very similar, so I combined them into one. I used a worksheet format to present the students' investigation plans as if they were a regular lab activity. I created space for them to record their data in an organized way, made it clear what they should measure, and in some cases, gave them a question or two to guide them to a conclusion. At the top, after the title, I gave credit to the authors of the plan. If more than one person had written basically

similar plans, I combined their instructions to make a single plan, crediting all of them. In this way, I presented the students with their choice of nine different investigations to choose from, with 16 different authors. We spent two separate days performing these experiments. I chose several for everyone to do, and then allowed students to choose from the others, so each student could do the experiment he or she was most interested in. The students worked with discipline and enthusiasm. My colleague, Norman Brooks, came to observe, and wrote, "They were so focused. Every single student was recording data. Every single student was interested. I've never seen anything like it before."

To wrap up the investigation, I used several more traditional tools. I placed a large glass aquarium at the front of the class, and put three lit candles in it at different heights. Then I placed a piece of dry ice in some water in the aquarium. Gradually the aquarium filled with CO_2 , and the candles went out, one by one. I asked the students what this showed. They recognized this as evidence that the gas was indeed CO_2 , since we had put out fire with CO_2 in the past. They also noted that it was denser than air, since the lowest candle went out first. I then brought out a chart we had been creating recording the characteristics of

different gases, and we compared CO₂ to air, natural gas and helium. This demonstration and discussion was designed to reinforce the scientific concepts I wanted to emerge from our exploration. Because they had a wealth of personal experience with the dry ice, they were extremely interested in my explanation of how this material worked.

I wanted the students to see all these separate experiments as threads to be woven together to complete a whole investigation sequence, so at the end of the month, I gave them a final test, which asked them to create an investigation portfolio. This would start with their initial question notes, and include their investigation plans, actual investigations, and notes from our discussion and demonstration. I also asked them how they would go about actually testing an unknown gas, and how they could demonstrate the density of a given gas. (see Science Final Test, Appendix C)

This guided inquiry approach proved to be far better suited to the students' abilities than open-ended inquiry with the investigation kits. Since we worked through the questions as a class initially, we eliminated those that could not be successfully answered through an experiment. Likewise, we worked together to make sure the procedures and measurement techniques were clear. However, the students

retained ownership of the investigations. They were on the spot to think of the questions to start with. They had to come up with the methods to answer them. To return to the Locus of Decisions framework, the students had indeed succeeded in refining their questions and designing investigations, while they had largely failed to make these decisions in their work with investigation kits.

Comparing Results

My goals with the two models of inquiry were similar. In each case, I wanted students to succeed at four phases of an inquiry cycle. I wished them to explore, then define investigatable questions, conduct experiments, and write a conclusion reporting what they had learned. To compare the two approaches, I analyzed student work samples to see how many students successfully completed these steps with each model of inquiry. The results are presented in Figure 4.2, Models of Inquiry Compared, (see page 62.) Both forms of inquiry gave students ample time for exploration, and students were successful at this phase in both models. To summarize the key differences, with the guided inquiry model 52% of the students succeeded in defining investigatable questions, while only 28% succeeded when using an open-ended

Figure 4.2: Models of Inquiry Compared

1. Question Definition

No question defined

Poorly defined question

Investigatable Question

2. Experimentation

None

Some

3. Conclusion/Synthesis

None

Key

Investigation Kits Model

Guided Inquiry Model

inquiry approach. For a students' question to be investigatable, it needed to be answerable through experimentation. Almost all (92%) of the students performed at least two complete experiments through guided inquiry, while 52% of the students using open-ended inquiry did no experimentation at all. In guided inquiry, 40% of the students wrote a good conclusion summarizing their experiments, while only 16% of the students did this associated with the open-ended inquiry model.

In analyzing the results of the open-ended inquiry work, it would be fair to say that most students never actually moved past the exploration phase with their materials. Each pair of students had a unique set of materials, so each group had to come up with their own questions. Though I prodded and tried to model investigatable questions, most students simply could not apply this approach to the materials in their kit. Since they lacked investigatable questions, they were unable to conduct experiments, and therefore had little material for their conclusions.

In contrast, the guided inquiry model focused the attention of the entire class on a single topic. First with helium, then with dry ice, students explored together and generated observations and questions as

a class. They were challenged to transform their “I Wonder” questions into investigation plans individually, but this process was made collaborative through whole-class discussion and small group review of plans. This allowed for much-needed guidance, and also allowed students who were unsure how to design an investigation to get help from their peers. Since I took their investigation plans and turned them into lab activities, complete with space for recording results, all the students were able to conduct experiments, even those who had not come up with investigatable questions. This acted as a filter, making sure all the students had workable experiments to perform. Since the investigations were authored by the students themselves, however, they retained ownership of the process. The guided investigation model thus provided a scaffold from which understanding of the scientific process was built. In addition, since one topic was addressed by the whole class simultaneously, I was able to provide key vocabulary concepts, as well as some demonstrations to highlight key concepts. This gave the students a stronger understanding of the topic, allowing for a greater proportion to achieve understanding and complete conclusions.

In reviewing the portfolio of work I had students pull together

to complete this investigation, I think they would have benefited if I had set before them the task of writing a comprehensive report on dry ice and phase change. I attempted to find out what they had learned from their experiences, but this process could have been used as a chance to really deepen their understanding of what they had learned. Their portfolios, though superior to the results of the investigation kits work, still do not show a complete consolidation of their experiences and insights.

Following the dry ice investigation, I surveyed the students to discover which approach they felt was most effective. I asked them first what they felt they had learned the most about, then what they felt the best way to teach science was. Here are the results:

Table 4.1: Survey Results

Number of responses: 39

1. What is one thing you are glad you learned about this year?

a. Dry ice:	23
b. Gases:	9
c. Investigation kits:	7

2. What do you think is the best way to learn science?

a. Do experiments from a book.	4
b. Write research reports.	3
c. Do experiments we designed ourselves.	27
d. Watch educational videos	3
e. Teacher lecture	2

The overwhelming majority felt the best way to learn science was through designing their own experiments. However, they identified the guided inquiry sequence around the subject of dry ice as the most productive, rather than the investigation kits.

I used interviews with students done several weeks after these experiences to try to reveal their perceptions of the different models. All of the students interviewed said they felt they now knew how to do investigations, which they attributed to their experiences in this class. When asked to compare the different models of inquiry, the students recalled difficult times with the kits. "Some things you couldn't find the answer for, or you couldn't think of a certain kind of question." One boy said, "We needed more ideas. Like we should have had the whole class give you ideas. It was kind of hard making the question." Working independently on his investigation kit, this student felt at sea

without adequate direction. He felt much happier when able to draw on the resources of the class for the definition of questions. This same student commented on the guided inquiry, "(I liked)...that we got to make our own questions, and if you make your own questions, you will remember it, what you had did. We wasn't in the book, we was like touching it. We were doing experiments. That was good."

When asked to compare guided inquiry to teacher-directed instruction, the students were favorable to both. "It's equal, because we used to make up our own science experiments and they make up some for us too. It used to be [in elementary school] that some teachers used to make up experiments that you really didn't want to do, and they (the teachers now) have experiments that you do want to do." To them, the critical variable was the quality of the experiment, not the source. The other students interviewed actually saw teacher-led instruction as more efficient. One said, "I like how we do it now, with the plants, how she tells us what to do. I like that better, because I kind of learn more, I learn more about the plants, faster." Her friend agreed, saying, "I like the plants here because it's sort of easier, and just that you don't have to really worry. They give you questions and all you gotta do is find the answers. You don't have to think of the questions and find the

answers.” This satisfaction with being told what to do echoes Nugent and Yerrick’s findings, (1995) where a teacher using a non-traditional approach found students resistant to the process. Most of my students were willing to stretch themselves to tackle the investigation process, but they clearly take comfort in a more straightforward approach, with the teacher providing more direction.

As a teacher, if the object of my instruction is to cover course content efficiently, I am ill-advised to spend time having students design their own investigations. The students are correct in their estimation that it is faster if a teacher directs them through a crafted sequence of activities. However, if my aim is to actually teach them to investigate, this will not suffice. While my student is happier not having to “worry about thinking of both the questions and the answers,” I see that responsibility as a powerful learning tool. All of the students felt that, as a result of their experiences in this class, they had learned to conduct an investigation. As I reviewed with them the elements of a good experiment, I was surprised by what one student suggested would be an example of a poor question. She said, “A bad question is when you really don’t... like, say you had to think of an experiment to do for a science project, or something, and you already

know what it is." I responded, "Oh, so you know the answer already. That would be a bad question." She replied, "Yeah. It's not really an experiment." For her, a critical element in the experiment is the mystery, the uncovering of the unknown. In textbook labs, the results may be unknown to the students, but there is very clearly an expected result. Ultimately, the most powerful tool a teacher has is to motivate students to "worry" about solving problems and answering questions for themselves. When this responsibility is placed on the students, they can learn to think for themselves.

Chapter V

FINDINGS AND IMPLICATIONS

Multi-faceted Inquiry

Inquiry occurred in my class on multiple levels. Students were aware from the very beginning that I was exploring new ground, trying new methods, and trying to learn alongside them. Students were frequently asked for their opinions and views on the models of instruction, and spoke freely. Thus we engaged in an extended teacher-student dialogue, as described by Freire. This dialogue included many other commentators as well. My colleagues at the Lawrence Hall of Science provided me with a first-hand critique of many of my lessons. Members of my collaborative research group gave me critical feedback along the way. Jim Rogers provided me with a critical sounding board as I developed my plans, and as our dialogue was posted on my web site, a number of other teachers, both in Oakland and around the world, provided me with fresh challenges and insights. My colleague Norman Brooks likewise provided a valuable perspective, including his first-hand response to observing my students at work. This dialogue put me in a highly observant and analytical frame of mind, as I was reporting my findings and my dilemmas to a host of collaborators. Their observations prodded me to focus on my true aims, and move to adapt my

strategies to best achieve them. They further challenged me to explore more deeply some of the theoretical issues at play, such as definitions of inquiry, and the role of student questions in various models of science instruction.

Implications for Curriculum: Open-Ended Inquiry Through Kits

My experience clearly shows that for an open-ended inquiry model such as the investigation kits to produce true investigations, students will need an extensive background. I believe, based on my experience, that middle school students would need at least a full semester, if not a full year, of teacher-led and guided inquiry, before they would be ready to take on the autonomous investigations in the kits. Were I to attempt this approach again, I would design introductory activities as entry points to each kit, and make sure the kit was well-equipped to conduct further experiments. I described my ideas for improved kits in my November reflections on our experiences.

Inquiry Dialogue

November 26, 1997

I am beginning to get a feel for what the structure of a successful kit should look like. I think the thing I do not like about the kits as presented by Pearce in Science Workshop is that they do not offer a structured access point. In other words, I think many students, especially at the 6th grade, open a box of materials, and if there is no clear path for beginning, they are turned off. What I envision instead is a guided initial autonomous exploration, mediated by a subset of materials within a kit. For example, in the Optics kit, there are a wide variety of lenses, magnifying devices, mirrors, etc. There is also an optics bench, which is a set of metal holders that clamp to a meter stick,

and allow you to project images using a convex lens. This optics bench implicitly gives students a clear procedure to follow, and allows them to generate meaningful data, without any kind of sophisticated understanding of what they are doing. I anticipate that after they have done this investigation, they will have some basic knowledge that will enable them to access some of the other materials in the kit -- to generate more questions and investigations.

So my ideal kit would have an initial set of materials, containing a fairly clear set of questions, which ideally would be implicit in the materials themselves (as with the optics bench). Then it would have a deeper set of materials of greater variety, that would allow for more in depth investigation of the subject, along a pathway dictated by the students' interest and imagination.

From the students' point of view, a greater variety of kits increases the chance of a connection with existing interests and curiosity. Too many kits, however, proved to be unmanageable. For the teacher, the presence in the class of contemporaneous, separate investigations poses challenges and opportunities. Naturally there are many practical issues that will need to be addressed, relating to delivery of materials and coaching for the different teams of students. On the positive side, the teacher has a chance to focus the class' attention on processes common to all investigations. Topics like data collection and the creation of effective controls are important no matter the subject of the investigation. Thus whole-class instruction can focus on areas all students need to include in their investigations. Kits could also be designed to explore different aspects of a core content theme, allowing the teacher to develop a strong central focus for the class, supported by a variety of

separate threads of investigation. This could be accomplished with as few as four different kit designs, in use by students working in pairs. This would create sub-groups within the class of eight students investigating the same materials. These students could meet periodically to share ideas and review each others work, much in the way scientists working on the same problem meet to confer.

As a curriculum designer, I was partly motivated to create a format that would not allow the teacher to seize the reins of the investigations. I felt that if the students were doing different investigations, the teacher could focus on themes common to all investigators. I think this is a format worthy of further exploration, particularly with students who have some background in inquiry, and are equipped with basic investigation skills.

Guided Inquiry

The tension between the goal of student autonomy and their need for structure and guidance is a necessary one. Guided inquiry seems an appropriate balancing point for my middle school students. If one is to give students a chance to define the questions to be investigated, one must be prepared to be flexible. Furthermore, the subject matter and available materials need to lend themselves to this sort of exploration. If the students

cannot experiment with materials firsthand, this approach will not work. To begin even guided inquiry, students need to have already experienced investigations. They need to have concrete experiential reference points for concepts like question, hypothesis, variable, control, and data collection. They need then an introduction to the materials, a chance to explore and become acquainted with the topic. Following this, the I Know/I Wonder lists set the stage for the generation of investigation questions. Students are then capable of designing investigations based on these questions. With coaching and group editing, these investigations can be the core of an exciting investigation sequence. Initial efforts will reflect a poor grasp of the nature of questions that are useful bases for investigation, but through teacher-led discussions and practical efforts to design investigations to answer these questions, students can learn how to render their questions investigatable. Teacher demonstrations, lectures and readings can also play a critical role in formalizing the students' knowledge, and introducing them to more abstract scientific explanations or theories regarding the subject of their investigations. Students who have done their own investigations are truly curious about their subject, and respond with real interest to teacher information. Authority is not eliminated from the equation, but is put in service of curiosity.

Students are not fixated on doing something they personally wrote. The source of the question is not essential to the definition of inquiry. All the students interviewed were happy to do investigations prepared by the teacher, or by other students, or even from a textbook. This does not make the source of the question irrelevant pedagogically, however. The direct involvement of students in the design process teaches them far more about how to investigate than they would learn from simply following someone else's directions. It also ensures that their own thought processes, their own ideas, are central to their experience. It is much more demanding of the students if they have to "think of questions and answers," in the words of one, but the result is students who actually know how to investigate.

It is important for students to engage in collaborative processes all along the path of the investigation cycle. The teacher needs to set the stage by providing models and training, so the students can be effective critics of one another. The students can then provide valuable advice to each other, and sharpen their ability to create workable investigations. Students need a chance at the close of an investigation to share what they have learned with each other. This is a chance to debate different understandings and come to consensus about what was actually learned, and should be part of the creation of a comprehensive conclusion summarizing their results. This conclusion

would crystallize what students have learned, and allow them to see how productive their investigation was.

Working class and minority students often begin middle school science with a low level of self-confidence regarding their ability to solve problems. Guided inquiry offers them a structure to build these abilities, and creates a bridge between the science content and the students' interests by focusing on questions and investigations of the students' design.

Going Further

For my practice, I feel I have discovered a valuable framework for guiding my students to successful inquiry. My students are still at the early phases of their development as investigators. They are, as yet, not capable of the autonomous inquiry I set as my goal early on. To be really competent investigators, able to define their own investigatable questions, design effective, controlled experiments, carry them out and reach scientific conclusions, will probably require several years of sequenced experience, along the lines I have begun. The structure I provided for their inquiry is like training wheels, and should be discarded when they have learned to ride for themselves. This research suggests the need to have an extended view toward building inquiry skills, and to have teachers of successive grade levels agree

on these goals and strategies if higher levels of competence and autonomy are to be achieved.

My teaching practice became unusually public in the past year. Colleagues visited, I asked for extensive student feedback, and posted my journal and comments from colleagues on my web site. This process greatly expanded my circle of critical collaborators, which had previously been limited to my collaborative teacher research group. I feel this accelerated my ability to learn from my experiences, and allowed me to effectively move ahead through difficult episodes. This also has the effect of sharing my insights along the way, creating a collective sense of ownership of the discoveries we make. My colleagues are not engaged in identical work, yet they can actively learn from my experience, just as I learn when they share their experiences, and their critique of my work. This collaborative community will be an ongoing feature of my work.

While guided inquiry provides a useful structure for framing student investigations, it does not answer all questions regarding science instruction. My students arrive with a diverse range of skills, interests and needs, and my instruction must be reinvented with each class. Basing investigations on their own questions helps create ownership, but what of the students who have no questions about the topic I have chosen? What of those students who are

alienated from the learning process and fail to engage in spite of these opportunities? My inquiry will continue to focus on the challenge of reaching all my students, and equipping them to think and act for themselves, individually and collectively.

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Appendix A: Investigation Kit Student Materials

1.	Science Investigation Kit Guidelines	83
2.	Scientific Investigation Log	84

Science Investigation Kit No. 28

Chemistry Discovery

Kit Materials

- various chemicals
- litmus paper

Directions

1. Think of a question you would like to answer. You can choose from the questions below, or think of your own question.
2. Read some of the Science Investigation Logs in this folder to see what other investigators have discovered.
3. Begin a Scientific Investigation Log form yourself.
4. Conduct your investigation. Collect data.
5. Complete the Scientific Investigation Log form you started.
6. Prepare a presentation of your data. Use graphs when possible.
7. Add your discoveries to the Student Discovery Log.

Some questions you may want to investigate:

- What can you make with this kit?
- What are acids and bases?
- Can you make an indicator?

The best questions are your own questions!

BE CREATIVE! BE CURIOUS!
HAVE FUN!

Scientific Investigation Log

Date 10/22/14 Period 3,4

Kit/activity Electricity

Name(s) _____

What question did you investigate? What can you make with this kit?

What did you do to answer your question? My partner and I made a electronic police siren. We used a couple of wires and stuck the wires in the holes of a board which generates the noise that sounds like it work

Sketch your experiment here

What did you discover today? What we were making "Spinal" siren. When we had a short circuit which the battery wires touched.

What new question will you investigate next? How does the circuit you made work?

Are you happy with your results today? Yes _____ No _____ Not sure ☒

How would your group rate this kit or activity? Great 10 9 8 7 6 5 4 3 2 1 0 Terrible

Appendix B: Guided Inquiry Portfolio Assessment

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5.	Investigation Number 2: Boiled Ice?	91
6.	Investigation #3: Dry Ice Cocktails (a)	93

Name _____

Period 1^o-2^o

Date Feb 26, 1998

Science Final Test

1. Put together all the work we have done on Dry Ice, in order, and attach it to this sheet. You should include:
 - a. I Know/I wonder notes
 - b. Investigation proposals
 - c. Investigations
 - d. Notes
 - e. States of Matter definitions

40 Points

2. You are given a balloon filled with an unknown gas. How could you test it to find out what kind of gas is inside it? Describe as many tests as you can, and what each test result would tell you. **20 points**

At first I would weight it to see how much it weight that could help because we had learn that light weight could be helium gas or just air.

We could also make a experiment about each different gas.

3. We worked with air, helium and CO₂ gas. Which is the densest? CO₂ gas

Which is least dense? helium

How could you prove this? 20 points

I could prove it by weight it, I could also put it in a balloon and see which one flows. If it flows that means it least dense and the one that don't flow it the densest. 16

4. Write the correct term in each rectangle blank. 20 points

20

Jan. 12. 1911.

~~Today~~

Class know	Experiment
It slides	Dose dry ice melt
It's colder than water ice	Foast ice in Air or in water?
Metal make dry ice melt.	
Make bubbles in water bubbles are full of Air	
Smokeing	

I wonder why do it go on make when it in the water and regular it don't? what will happen if we put dry ice in salt water?

Class wonder
why does it make bubbles in water? what would happen if you hold dry ice for a hour? How do they make dry ice? what if you add water ice in to dry ice?

I know dry ice is in comets when you put it in water it not melt it make sound when you put it on it, then it melt on it, then it click to the end when you put it in water for a long time it will click on things if you put it on things.

It's very cold.

Class know
It can burn
It only melts in water
It melts in Air

1. Experiment Proposal

Question: Why do the water go on smoke when dry ice is in the water?

2.

I think because it too cold!

3.

I will need a cup, a piece of dry ice not that big the size that we was looking at that day, wa half way of the cup.

1

Question: Why do dry ice cut whe we put a penny on it?

2.

I don't know why!

3.

We will need dry ice that is kind of thick but small and a penny.

Name _____

Date

Jan 12, 1998

Period

10 - 20

Dry Ice Investigation Plan

Your Plan is our Guide! We need good plans if we are going to learn from our experiments.

1. Question: Why do the water go
on smoke when we put dry ice
in the water?

2. Hypothesis: (what do you think is the answer to your question?) Because the dry ice
is too cold!

3. Materials needed: Cup, a piece of
dry ice, water half way of
the cup, some to measure
the water's diameter.

4. Procedure: Take a cup, put
cold water in half way
of the cup, then put
the 'diameter' on the
dry ice to see how
cold it is then put it
in the cup then wait
for what cause the water
to go on smoke.

5. What will be measured? The water
see how cold is it and
how cold is the ice.

6. What data will be collected? how long the
smoke lasted.

You Judge...

Can the question be clearly answered by an experiment?

yes

Does the hypothesis answer the question?

maybe

Are materials clearly described in terms of exact size and quantity?

Are materials all available?

yes

Is the procedure clear?

yes

Could you follow these directions easily?

Is it safe?

yes

Is there a control (a standard setup to compare to?)

Are all possible measurements being made?

Will the data answer the original question?

Name _____ Period 1-2 Date Jan 14, 1978

Investigation Number 2: Boiled Ice?

Investigation designed by Jenny Tse

Question: What will happen to dry ice in boiling water compared to room temperature water?

Hypothesis: I think it will melt in boiling water
in the room water it will go on smoke.

Materials: hot plate, two beakers with 200 ml of water, 2 pieces of dry ice, 15 g each, thermometer, balance and tongs.

Procedure: Boil the water in one beaker. At the same time, add dry ice to the beaker of boiling water and the beaker of room temperature water. Use tongs to remove the dry ice after 3 minutes to weigh it. Record the temperature of the water every three minutes.

Results:		
Boiling water		
	Temperature	Mass of dry ice
time 0	100°C	41g
13 minutes	73°C	
26 min.	60°C	12g
39 min.	48°C	2g
412 min.	85°C	0
Room temp. water		
	Temperature	Mass of dry ice
time 0	18°C	24g
23 minutes	7°C	10.5g
36 min.	5°C	7.3g
59 min.	2°C	4g
12 min.		

Conclusion: What was the difference between the way dry ice behaved in boiling water compared to room temperature water? Summarize data to support your ideas.

It was different because when we put the dry ice in the boiling water it melt really fast but the one in the room didn't melt that fast.

Then when we put the dry ice in the boiling water it taken an extra time then the room water.

But the ice in the boiling water stop first but it was still boiling.

Graph title: (Mass of Dry ICE in water)

Appendix C: Student Interview Transcripts

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Student Interview

March 31, 1998

Setting: Mark Twain Middle School, Room 215, lunchtime.

Interviewer: Anthony Cody

Ray: African American boy, 11 years old

John: European American boy, 12 years old.

Note: These are not the student's actual names.

AC: How did you like working with the kits? What was good about that?

John, It was fun for a while but you started doing the same thing over and over again and it got kinda boring.

AC: Remember when I was trying to get you to come up with a question? What was hard about that?

Ray: We needed more ideas. Like we should have had the whole class give you ideas. It was kind of hard making the question.

John: Some of the kits it was easy to make the question, with some it was hard. With the hydraulics, it was Legos, and it would usually fall apart. If we could have switched kits -- sometimes traded, that would have been a little better.

AC: Remember when we shifted gears and we started working with the helium and then the dry ice? What was good or bad about that?

Ray: That we got to make our own questions, and if you make your own questions, you will remember it, what you had did. We wasn't in the book, we was like touchin' it. We were doin' experiments. That was good.

AC: Sometimes you do experiments with a book, too.

Ray: But when we were doin' hands on science, we got to make our own questions. We got to have fun, and learn.

AC: You know how we're doing science now with Dr. Brady and Dr. Shaw? How does that compare to what we did with the dry ice? Is it better or worse?

Ray: It's better because we have more people to help us.

John: Not to me. It's equal, because we used to make up our own science experiments and they make up some for us too. It used to be that some teachers used to make up experiments that you really didn't want to do, and they (Dr. Brady and Dr. Shaw) have experiments that you do want to do.

AC: So its ok if the teacher is making up experiments as long as they're good experiments

Both: Yeah.

AC: And if you're making them up, are they good all the time, or are sometimes they bad?

Ray: Sometimes they're bad. If you have a bad one, she'll (Dr. Brady) stick to the one you want to do, but she'll make it more...She'll let you do what you want to do, but you have to follow procedures.

AC: When you started this semester, did you know how to do a scientific experiment?

Ray: No.

John: Well, kind of. Not too well. In elementary we had to listen to what the teacher said. She wouldn't let us do our own.

Ray: She would just give you a book, with instructions, and if it worked, it worked.

AC: Do you know now how to do a scientific experiment?

John: I know a lot better than I did back then. I learned to do experiments by creating my own questions.

AC: What does it take to have a good scientific experiment?

John: A good question, procedure...

Ray: Hypothesis.

AC: What makes a question good?

John: I don't know.

Ray: A question that you could measure stuff.

John: Questions that you could find out the answers to them by doing the experiment, not a "why" or a "how" question.

AC: OK, so a good question. What next? Then what else do you need for a good experiment?

John: You need a question that could be answered.

AC: Ok, a question that could be answered. Then what? Then what do you do? Let me give you an example. Let's take plants. What's an experiment you could do with plants?

John: If they could live without water or they could live without soil.

AC: So let's say your question is "Can a plant live without water?" How would you set that up?

John: You would plant it in some soil, and keep it there without water. You might still give it proteins and minerals and stuff, but you don't give it water.

AC: So you would just have one plant?

John: You would have one without the water, and one with soil and water.

Ray: You would see which one lives and which one dies first or something.

AC: How come you need the one with the soil and the water.

John: Because it's the control. That's how most people plant their flower, so that's the regular way to grow a plant, and then you could compare it to a different way to grow a plant, and see what's different between them.

Ray: If you only do it the way people usually do it, then you still won't know if you put it in water, if it will live or not, or if you put it in soil, if it would live or not, you wouldn't know that.

AC: What was your favorite thing that we did all year long?

John: I liked the dry ice experiments. It was something that I never did before. I never worked with Dry Ice before.

Ray: I liked the helium.

AC: Did you feel like we really found out about dry ice, even though we were doing all kinds of different things?

John: We found out a lot about it.

AC: What do you know about dry ice now?

John: That dry ice is not a liquid.

Ray: It's a gas.

John: It's a gas that gets frozen, so it sublimates. The gas is carbon dioxide. To freeze it, it has to be below zero celsius. Instead of turning to liquid when it melts, it just turns into gas.

Ray: Yeah, like when we put it in water, gas comes from it, and it gets smaller and smaller.

AC: Did you learn anything about the density of the materials? Remember when we were weighing balloons?

John: We learned that some gases are heavier. Like helium is really light, and carbon dioxide is heavier, and I can't remember, but I think natural gas was heavier too.

AC: What does it mean if you say something is denser?

John: Usually it's heavier, if it's a gas, it's heavier than air.

AC: Let's talk about solids and liquids. What if I have a block, and I put it in water, and it sinks.

John: That means it is denser than the liquid.

AC: If it floats?

John: The liquid is denser.

AC: And if I way the same amount of liquid and solid, and the solid floated, which would weigh more?

John: If it floated, the liquid would still be denser.

AC: If it sank?

John: Than the solid would be denser.

AC: What if I had a whole gallon of the liquid? And I just have this little bitty solid. And it sinks. Is it heavier than the liquid?

John: No.

AC: So what do you mean 'It's heavier'?

John: Well, if it was equal amounts it would be heavier.

Ray: Yeah, but if it was more liquid, it's gonna be heavier than the solid.

AC: Does it change whether it floats if I change the amount of liquid?

Ray: No, it will still sink.

AC: Well, that's cool. You guys learned a lot.

Student Interview

April 1, 1998

Interviewer: Anthony Cody

Setting: Classroom at Mark Twain Middle School; lunchtime

Cathy, European American girl, 11 years old

Samantha, African American girl, 12 years old

(Note: not actual names)

AC: What was good about working with the investigation kits and what was bad?

S: The experiments were good, but it was bad because I couldn't find everything I needed.

AC: What were you working on?

S: The water, to test the water. I don't know what it's called.

C: Same thing here. The experiments were, like the mapping one, some things you couldn't find the answer for, or you couldn't think of a certain kind of question.

AC: What was hard about thinking of questions?

C: With mine, I had plants, cause I put different materials on them, and first it was like, what could I do with that? Then after that, with different materials, then after it happened, you said after you finish one question you have to think of another one.

AC: So what happened with that first experiment?

C: Well, some things grew, some things didn't. Some things basically died.

AC: So you did have some results.

C: Yeah, I had some results, but it was hard because some things didn't come out results... and we couldn't figure it out.

AC: What about when we shifted gears and started working with the helium and the dry ice. Do you remember that? What was good or bad about that?

(Both girls are smiling and laughing a little at the memory)

Samantha: I liked working with the dry ice because I never worked with it before. It was new to me, and I learned more about dry ice. I don't know.

AC: What were you going to say, Cathy?

C: It was just fun.

AC: So it was just a fun material to work with?

C: And you learned, too.

AC: What did you learn about dry ice? Can you tell me anything about dry ice?

Sam: It is very, very cold -- so cold that it actually burns you.

AC: What else? What is it?

S: Is it water?

AC: So it's the same as water ice?

Both: No.

S: I think it's colder. I think it was like 8 degrees below zero, and...

AC: What does it turn into? What happens when you put it in water?

S: It just fogs up.

C: It fogs up, and then it's almost like the same ???, it melts.

AC: What does it turn into?

C: Liquid.

AC: It turns into a liquid?

S: Yeah.

AC: What about helium? What did you learn about helium?

S: I didn't really learn anything about helium.

AC: What's the difference between helium and air?

S: Yeah, helium is lighter.

C: Are they inflammable?

S: One of them is flammable.

C: Remember what you did with the cup?

S: Then when you turned out the lights -- I forget -- no that was dry ice.

C: Oh, yeah, with the candles and the fog.

AC: What do you remember about the candles and the fog?

C: That the candles went out.

AC: Which one went out first?

Both: The smallest/lowest.

AC: What did that tell you?

C: Like the steam came off of it and hit it.

S: It's like carbon dioxide.

AC: It was carbon dioxide that put it out? Where did the carbon dioxide come from?

S: From the dry ice.

AC: So what did the dry ice turn into?

S: Carbon dioxide.

AC: Does it turn into a liquid?

Both: No.

AC: When we worked with the investigation kits, I was always after you to come up with a question. When we worked with the helium and dry ice, again, you guys came up with the questions, and you also came up with the experiments, remember? So how did you like that way of working?

S: I like when you tell us a experiment and then we come up with questions and do our own experiment after.

AC: So it was better when we did it with the dry ice? Is that what you mean?

S: Yeah.

AC: From my point of view, what I thought I did differently is we were all working together as one class, to figure out the questions, and then we kind of talked through what the question was, but then you guys still came up with the experiments. Compare that to what we've been doing here with plants.

S: I like working with the dry ice better.

C: Yeah, it's funner.

AC: I'm trying to separate the dry ice, maybe you liked dry ice a lot, just because it's fun to work with dry ice. I'm also interested in the way we design the way you're working with the materials, because the way we're doing it now, we're bringing it in, the teachers are bringing in the instructions and procedures. What we were doing with the dry ice, you were making up the procedures. Between those two methods, which do you like better, or what's good about each one?

S: I like how we do it now, with the plants, how she tells us what to do. I like that better, because I kind of learn more, I learn more about the plants, faster.

AC: So you learn more, faster?

S: Yes.

AC: OK, What do you think?

C: I like the plants here because it's sort of easier, and just that you don't have to really worry. They give you questions and all you gotta do is find the answers. You don't have to think of the questions *and* find the answers.

AC: Did you know how to do an experiment before you started this class in September?

Both: No.

AC: Do you think you know how to do a scientific experiment now?

Both: Yes.

AC: How do you do a scientific experiment?

Cathy: First you gotta think of a question, then once you get the question, you've got to think of materials...

AC: Now what makes a question work? What is a bad question?

Cathy: A bad question is when you really don't... like, say you had to think of an experiment to do for a science project, or something, and you already know what it is.

AC: Oh, so you know the answer already. That would be a bad question.

Cathy: Yeah. It's not really an experiment. A good experiment would be where you have a very good question, and as you're doing it you should take... Some good experiments is when you have basically a control.

Samantha: A good experiment has to have a control, you have to have all your materials, and a control...

AC: What would be an example of an experiment, say involving plants?

Samantha: Can plants make their own seeds?

AC: So how would you set that up?

Samantha: You would get like a plant, then let it grow. In two weeks you would have to open it up, and see if you can see any seeds, and if they do, that means they make their own seeds.

AC: What about the control? You both said they needed a control.

Samantha: You check on it every...

Cathy: Like you said, you could cut it open, but if it don't have seeds, what if it needed more time to get seeds?

Samantha: Like each week you could open one to see if you get seeds.

Cathy: Yeah, so you'd have a couple different ones.

AC: How did you learn how to do experiments?

Samantha: First you showed us how, then we had to try it on our own, then we did the whole thing by ourselves, like when we did that one for the science fair -- then we did the whole thing by ourselves. But the other ones we did in the classroom, and you kind of helped us.

AC: So did you feel when you did the science fair project, that you knew what you were doing?

Both: Yeah.

AC: What was your science fair project?

Samantha: I had liquids, to see if the hydrometer would go higher.

Cathy: I had, could I make an electrical magnet stronger?

AC: And what did you try doing?

Cathy: I just tried different things, like cause the wire is hooked up to the battery and then you gotta hook it to the nail. I tried different kinds of nails, and then I tried different lengths, and how many times I wrap it around, and I found my answer.

AC: Samantha, you were using a hydrometer to test, what?

Samantha: Different liquids, and find out the most dense. Like I was trying to see which liquid was the densest and which liquid was the least dense.

AC: If the liquid was dense, what would the hydrometer do?

Samantha: I think it will go up, and if it was less dense it will go down.

AC: Let's talk about density for a second, because we did a lot of work with density at the beginning of the year, remember that?

Samantha: With the liquids, colored.

AC: Let's say I have a solid object, and I put it in a liquid, and it floats. What does that tell you about the density?

Samantha: If the object floats, it's denser.

AC: What is?

Samantha: The liquid.

AC: The liquid is denser?

Both: Yes.

Samantha: The liquid is heavier than the object.

AC: And if the object sinks?

Samantha: That means the object is heavier.

Cathy: The object is denser, and the water is less dense.

AC: What does dense mean though? Why does it sink? What does it mean to be denser?

Samantha: I think it's heavy.

AC: What if I have like a gallon of liquid, and I just have a little weight this big. Is the weight heavier than the water?

Both: No.

AC: But it sinks, why?

Samantha: I don't know.

AC: Can you say why it would sink, even though it's not heavier than all the water?

Samantha: Because of the density in the liquid, I think, or something..

AC: If the teacher knows the answer but you don't know the answer, is that still a good answer.

Cathy: Yeah, it's alright. So long as you don't know the answer, its an experiment for you.

AC: Would you be as curious about it if it was not your question, but something the textbook told you to answer?

Cathy: Not really, because if it was an experiment about, say plants, and you weren't interested in plants, and you didn't really want to find out about it, and you had to do an experiment about it, it wouldn't be that interesting. But if you got to pick your own topic or subject, I think it would be more interesting.

AC: If you were just following experiments the book told you to do, would you know how to do your own experiment?

Cathy: No.

AC: How did you learn to do an experiment?

Cathy: At first you were telling us how, so we sort of picked up on it, remembering it, then you had us do our own experiment, so that's how we learned.

IMAGE EVALUATION TEST TARGET (QA-3)

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