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SCIENTIST-TEACHER INTERACTIONS : CATALYSTS FOR DEVELOPING TRANSFORMATIONAL CLASSROOMS

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By

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SCIENTIST-TEACHER INTERACTIONS:
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A Dissertation APPROVED FOR THE
DEPARTMENT OF INSTRUCTIONAL LEADERSHIP AND ACADEMIC CURRICLUM
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BY

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ABSTRACT

SCIENTIST-TEACHER INTERACTIONS:

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Robbie V. McCarty

Professional development leading to standards-based teaching practices in U.S. schools is a remarkably subtle and lengthy process. Research indicates that there are many effective tools for teaching through inquiry available to teachers (Lawson, Abraham, & Renner, 1989), but also that teachers continue to present traditional positivistic views of science (Hashweh, 1985; Maor & Taylor, 1995; Zucker, Young, & Luczak, 1996) and appear to view constructivism as a "method" of teaching rather than a way of thinking about learning (Tobin, Tippins, & Gallard, 1984). Teachers are expected to create enriched environments where students can develop the thinking skills of scientists (Roth & Roychoudhury, 1993) but the majority of teachers have never experienced such environments; the involvement of scientists in science education is encouraged by the NRC, AAAS, and NSTA. Teachers and students are expected to act as co-researchers, where negotiation, debate, consensus, and reflection are key. It is believed that scientist and teachers interacting as co-researchers could assist teachers in developing attitudes of freedom in exploration: the essence of science and a mindset that constructivism is a referent, or tool for critical reflection (Tobin, Tippins & Gallard, 1994). This study seeks to identify aspects of scientist-teacher interactions in the field that could serve as catalysts for developing transformational classrooms.

Multiple data sources were collected for this study: audiotapes and transcripts of laboratory interactions and informal interviews, written narratives from applications and funding documents, field notes, and personal communications. Data were simultaneously collected, analyzed and coded as a perpetual review of the literature was conducted as in the grounded theory methodology defined by Glaser (1967) and later by Strauss & Corbin (1990).

Findings indicate all four teachers valued field experiences in personal ways, developed new understandings of scientific practice and content, and anticipated using their new knowledge upon returning to their classrooms with excitement. However, the degree of implementation in classrooms varied according to common aspects of laboratory and classroom contexts. Theoretical literature, notably the Personal Construct Theory of George Kelly, coupled with these findings contributed to emergent theory regarding a hypothetical model for a professional development program of research.

SCIENTIST-TEACHER INTERACTIONS:

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CHAPTER I

THE RESEARCH PROBLEM

Introduction

The bulk of research in science education has been empirical: studies that tested hypotheses related to the effectiveness of curricula. "Effectiveness" was determined through large-scale evaluations, such as those related to the Science Curriculum Improvement Study ([SCIS] Allen, 1967; 1971; 1972; 1973; Renner, Stafford, Coffia, Kellogg, & Weber, 1973), or as one of the variables common to these large-scale studies. For example, other studies examined laboratory experiences (Abraham, 1982; Ivins, 1986), or specific methods of teaching science concepts (Marek & Renner, 1979; Schneider & Renner; 1980; Saunders & Shepardson, 1987; Ward & Herron, 1980). Hypothesis testing necessitates that research questions be strictly defined and that quantitative methodologies be used (Gall, Borg, & Gall, 1996; Roberts, 1982). A quantitative research design assures that statistically significant differences can be documented. According to Gall, Borg, & Gall (1996), quantitative research is "virtually synonymous with positivist research" (p. 28). The power of positivist studies is precision (Roberts, 1982): the ability to provide an accurate answer to a specific question under conditions that can be closely reconstructed. Positivist researchers consider findings from these studies to be applicable from sample to population; this type of research is "grounded in the assumption that features of the social environment constitute an independent reality and are relatively constant across time and settings" (Gall, et al., 1996, p. 28). Even among positivist science education research however, one finds results that are not constant across time and settings.

While many studies revealed that constructivist curricula resulted in gains in problem-solving skills, gains in achievement, and more favorable attitude toward science (Bates, 1978; Igelsrud & Leonard 1988; Kyle & Bonnstetter, 1992; Lawson, 1975; Lawson, Abraham & Renner, 1989; Lawson & Renner, 1975; Marek & Renner, 1979; McNally, 1974), others indicated that constructivist curricula and methods of teaching have not been successful in achieving the development of higher order and critical thinking skills among students (Gallagher & Tobin, 1991; Lazarowitz & Tamir, 1994; Maor & Taylor, 1995; Pope & Gilbert, 1983; Shymansky & Kyle, 1992; Tobin, 1990). Additional research involving laboratory experiences, considered an essential component of inquiry curricula (Larowitz & Tamir, 1994), also revealed disagreement regarding the degree of success and the relative importance of the laboratory. Findings of research on both inquiry methods and laboratory experiences varied for differences in curricula, setting, grade level, and experimental design (Lawson, Abraham, & Renner, 1989; Lazarowitz & Tamir, 1994). Speculation about the underlying reasons for discrepancies among inquiry-related studies spawned professional development programs designed to "fix" the problems. Among the hypotheses driving these programs were (1) that teachers implemented inquiry-based strategies incorrectly because of their underlying misconceptions regarding the theory base of the strategies (Marek, Eubanks, & Gallaher, 1990), or (2) that the reason some inquiry-based curricula "failed" in achieving widespread systemic reform might be linked to limited knowledge of the nature of science (NOS) on the part of teachers (Aikenhead, 1973; 1987; Lederman & O'Malley, 1990; Lederman, 1992, among others). The common assumption of both hypotheses is that the teacher is the key element.

Professional development programs which were specifically designed to better prepare teachers to use inquiry curricula arose (Marek, Eubanks, & Gallaher, 1990; Marek, & Westbrook, 1990); summer institutes and Fellowship Programs, such as those held at Genentech, New England's Science Center, the Virginia Living Museum (Discovery Quest), and Merck & Co. (Teacher Intern Program) in addition to many others held at various Universities, industrial settings, and museums attempted to explicitly or implicitly address the NOS issues (NRC, 1996). Other professional development programs, such as those sponsored through the National Association of Science Teachers (NSTA), National Association of Biology Teachers (NABT), and various Societies in scientific specialties (microbiology, chemistry, physics) continued to offer activities and opportunities for teachers to interact with individuals working in scientific fields, although stated goals for interaction were not necessarily aimed at a single inquiry, NOS, or nature of learning (NOL) issue, but were often categorized under the larger umbrella of Science Literacy as presented in the numerous Project 2061 documents (AAAS, 1989; 1993; 1997; 1999).

While the quantity of professional development opportunities increased, the quality of such experiences was a virtual potpourri. Dr. J.B. Kahle, in her address to the U.S. House of Representative Committee on Science (1997), described professional development as being in a condition parallel to the pre-standards science curricula in schools: "a mile wide and an inch deep" (Kahle, 1997, ¶ 1). She further described professional development as building upon a "training paradigm: short term, standardized sessions designed to impart discrete skills and/or techniques" (Kahle, 1997, ¶ 12). Clearly, these descriptors parallel the mindset reflected in the transmissive model of education even though the design format of the curricula presented in many of the programs paralleled scientific inquiry processes. Kahle goes on to say that the "TIMSS studies also suggest that these types of experiences do not result in improved content knowledge for teachers, or changed teaching practice, or enhanced student learning" (Kahle, 1997, ¶ 2). In addition, many of these professional development programs were not accompanied by research and were poorly evaluated (Synder & Frechtling, 1997). Among the programs accompanied by research, however, one finds that there are effective tools for teaching through inquiry available to teachers; the learning cycle, based upon the intelligence model of Jean Piaget (Renner & Marek, 1990), is an instructional tool that is well supported by empirical research (Lawson, Abraham, & Renner, 1989).

A study by Marek, Haack, & McWhirter (1994) examined the long-term implementation and use of the learning cycle by teachers who had attended institutes offered during the summers of 1985, 1987, and 1988. Selection for institute attendance for all three years was based upon "discord between their [teachers'] current science programs and what they thought their science programs should be" (Marek, et al., 1994, p. 49). The study was undertaken to determine whether teachers continued to use the learning cycle curricula from 3-6 years after their participation in the month-long institutes, and to identify factors that might influence teachers' use or nonuse of the learning cycle. External factors were defined predetermined to be "(a) requirements for time and materials, (b) reactions of administrators and fellow teachers, and (c) reactions of students and their parents to the learning cycle curricula" (p. 49).

Participants for this follow up study were from a pool of 75 teachers who had attended one of the institutes. Data were gathered via questionnaire administered through mailings and telephone surveys, and resulted in respondents constituting the final sample of N=55. Findings related to learning cycle use and external factors were reported as percentages of yes/partial/no responses, and indicated that all respondents identified similar external factors, but that these factors only served as obstacles for teachers who were not committed to using the learning cycle. The authors stated that "perhaps the single most significant result...was that 51 teachers (93%) indicated that they were still using the procedures and/or curricula presented in the summer institutes" (p. 50). This 93% value resulted from the combination of the high and moderate use categories, and included teachers who seemed to agree that the learning cycle approach is "a profound departure from the classroom practices of most science teachers who likewise have been educated by expository methods" (Marek, et al., 1994; Connor, cited in Marek et al., 1994); teachers who were committed to the learning cycle approach overcame challenges, while teachers who were not committed to the learning cycle approach pointed to these obstacles to excuse their non-use. The researchers were successful in determining the degree to which teachers reported continued use of the learning cycle curricula, and found that external factors related to time and materials, reactions of administrators, fellow teachers, students and/or parents could be potential obstacles. In reviewing the article, however, I wondered what data gathered during this study could be lying dormant—data reported but not analyzed because they were not pertinent to the specific hypotheses that guided the study. What else could these teachers be telling us? Fortunately, the authors of this study summarized the contents of the participants' narratives, and also included verbatim statements from the participants, so some of these thoughts were captured. The authors' purpose for the inclusion of these summaries and quotations was to illustrate how teachers were placed into the high, moderate, or low use categories; my purpose for examining these statements more closely is to consider what the language used by these teachers could reveal regarding their thinking--about the learning cycle, and the constructivist theory base upon which it is built. The use of quoted material as a secondary data source is appropriate for qualitative studies (Strauss & Corbin, 1990), and Marek (one of the author's of the study under review) examined language in a similar way to gain insight regarding children's learning in a later study. "The degree of understanding of a concept is reflected in the language of the students" (Marek & Cavallo, 1995, p.5). Surely this is also true for teachers and other individuals.

The teachers who were consigned to the high use category included "some teachers who taught non-learning cycle classes in other subjects but whose science classes were based upon the learning cycle" (p. 51). Teachers who reported using alternate methods were placed in the moderate use category. Statements reported as examples for placement criteria in the moderate use category included "I only use it about a third of the time" and "I teach only certain units in learning cycles because there is not enough time to prepare the labs for so many different classes" (p. 51). Teachers assigned to the low use category "reported no structured use of learning cycles" (p. 53), but some reported abducting the format to the degree of placing laboratory experiments first when introducing new material, and others reported using "learning-cycle-type questioning" (p.

52). I construe these statements to be indicators that some teachers, even those in the high use category, viewed the learning cycle as only a teaching method; I further construe that if these teachers truly understood the constructivist theory base of the learning cycle they could not use it only part of the time, or for certain units, or for only science classes. Perhaps some of the limited thinking stems from an early label given to the learning cycle; it was known as "the inquiry teaching method" (Marek & Renner, 1979). This label seemed appropriate at the time and was not meant to confine learning to a prescribed set of steps, but to reflect learning experiences that were vastly different than the lectures that were in mode at the introduction of the learning cycle. So, in spite of the early nomenclature, the learning cycle was not intended to be merely a highly structured method (Marek & Cavallo, 1997) for teaching science one concept at a time. The monograph prepared for the National Association for Research in Science Teaching (NARST), reveals the learning cycle as a way of thinking about learning that is flexible enough to include a variety of methods rather than being restricted to only one, and that can be used to develop concepts regardless of subject matter. (Lawson, Abraham & Renner, 1989). Therefore, the statements made by these teachers are somewhat troubling. Such findings and statements from teacher responses regarding the use of inquiry following their participation in professional development institutes reinforce the findings of more recent research indicating that some teachers continued to present a traditional positivistic view of science even when superior constructivist tools were provided: constructivist textbooks, interactive technology, and Project 2061 documents (Hashweh, 1996; Maor & Taylor, 1995; Zucker, Young, & Luczak, 1996); classroom teachers viewed constructivism as only a method of teaching (Tobin, Tippins, & Gallard, 1994).

Research related to the NOS is so abundant that numerous instruments have been developed in attempts to measure teachers' and students' understandings of the NOS. In fact, instruments are so numerous that Lederman, Wade, and Bell state, "it [instrument development] constitutes a distinct line of research" (1998, p.332). Regardless of the instrument used, however, Lederman et al. reported that four consistent findings were evident in NOS research.

1. Science teachers appear to have inadequate conceptions of the nature of science.
2. Efforts to improve teachers' conceptions of the nature of science have achieved some success when either historical aspects of scientific knowledge or direct attention to the nature of science have been included.
3. Academic background variables have not been significantly related to teachers' conceptions of the nature of science.
4. The relationship between teachers' conceptions of the nature of science and classroom practice is not clear, and the relationship is mediated by a large array of instructional and situational concerns.

(Lederman, Wade, & Bell, 1998, p. 332)

The inquiry studies cited early in this chapter were all based on valid deductions from acceptable methodologies and premises, but yielded conflicting results. Therefore, a paradox seems to exist between constructivist theory and the view of constructivism held by teachers who participated in professional development programs, or who used constructivist teaching tools. The NOS research illuminated areas where further investigation is warranted, and specified our continued lack of understanding regarding the relationship between teachers' conceptions of the NOS and classroom practice. Large-scale evaluation of Project 2061 and its related documents, which addresses the NOS and inquiry issues, also revealed "relatively few teachers strongly agreed with some central reform ideas...teachers did not perceive a very strong linkage of the workshop ideas to classroom practice" (Zucker, Young, & Luczak, 1996, p. 5). In response to contradictory findings related to inquiry curricula and concerns regarding the perception on the part of teachers that workshops and ideas, such as the NOS or "less is more" ideas, presented through Project 2061 are not strongly linked to classroom practice, the National Science Foundation (NSF) funded systemic initiatives (SIs). These SIs were designed to enhance standards-based teaching practices, which emphasize the NOS by including a historical perspective of scientific discovery, science processes, and science content. Early data "indicates that sustained professional development, focused on content, affects teaching practice and that the changes are retained" (Kahle, 1997, ¶23). In addition to the NSF's support of the SIs, the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), and the National Science Teachers' Association (NSTA) assaulted the archaic professional development procedures from another direction. Because science teachers are expected to create rich learning environments where their students can develop the thinking skills of scientists (Roth & Roychoudhury, 1993), and the majority of teachers have never experienced such environments (Dhondt, Telsch, & Tucker, 2000), these organizations renewed calls for scientists' involvement in science education. Although it is undeniable that there is an ambiance that accompanies genuine scientific inquiry, teachers cannot be expected to soak up this scientific essence as through osmosis. Therefore, the involvement of scientists, in and of itself, is not viewed as the definitive answer to the science education reform dilemma. Scientists and teachers must interact in such a way that they become co-researchers, building relationships where negotiation, debate, consensus, and reflection are key; the same types of interactions are championed as desirable for K-12 classroom teachers and their students. Such experiences, it is believed, could assist teachers in developing an attitude of freedom in exploration; this is the essence of science and of a mindset that constructivism is a referent, or cognitive tool for critical reflection (Tobin, Tippins & Gallard, 1994), and not merely a method for teaching science.

In the last decade or so, research has emerged that examines interactions and relationships among students, teachers, educational researchers, and scientists in classroom settings (Hashweh, 1996; Maor & Taylor, 1995; Roth, 1994; Roth & Bowen, 1995; Tobin & LaMaster, 1995), reflects a social constructivist basis, and is more holistic in design than past research. Standing on the foundation of the empirical, hypothesis-testing studies, researchers have new perspectives and freedom—freedom to ask different questions, questions related to the natural, unique contexts of individual settings accompanied by all of their complexities, rather than questions related to manipulated, replicable contexts. This research movement parallels biological research that establishes fundamental principles through in vitro studies, but must eventually move investigations in vivo—inside the living organism.

The school as a dynamic, complex system that is alive is reflected in the body of research related to alternative, or block, scheduling. These investigations provide examples of research studies that collectively attribute successes of block schedules to a variety of complex factors collectively labeled school climate, which must be attributed to the types of interactions and relationships formed in the schools (Eineder & Bishop, 1997; DiRocco, 1999; Fitzpatrick & Mowers, 1997; Shortt & Thayer, 1999), and could not have taken place in other contexts. Rather than testing hypotheses, researchers are generating propositions and reporting emergent theory involving conceptual relationships, and utilizing qualitative methods to gain insight into the problem from the perspective of the participants. Qualitative research, also referred to as postpositivist research, is "grounded in the assumption that features of the social environment are constructed as interpretations by individuals and that these interpretations tend to be transitory and situational" (Gall, et al., 1996, p. 28). The power of postpositivist research is in its scope (Roberts, 1982): the capacity to examine in careful detail (Costello, 1997), and to present an account of the particular events under examination in such a way that the reader is provided with experiences, and can empathize with the participants (Eisner, 1998).

Need for the Study

Systematic research involving scientists and teachers interacting in field or research settings is sparse. The pioneer literature is unidirectional; the examination of field experiences is limited to the potential impact on the professional development of teachers, even to the extent of labeling the experiences as internships (Svolopoulos, 1995), and excludes any effect on the scientists involved. The underlying assumption of the involvement of scientists and teachers in collaborative experiences is that teachers will gain a clearer understanding of what constitutes science and therefore be able to incorporate authentic science in their teaching practices (NRC, 1996; AAAS, 1993; Svolopoulos, 1995). However, understanding the nature of scientific inquiry is not the same as developing an attitude of inquiry, and "teachers' conceptions of science do not necessarily influence classroom practice" (Lederman, 1999, p. 916). In addition, although there is a variety of studies on projects that use the designation of partnerships (Alper, 1994; Wier, 1991; Wier, 1993; NRC, 1996), the NRC report indicates that several programs limited their success because full partnerships were not achieved (1996). But, what does a "full partnership" look like? Questions remain regarding the types of interactions that would maximize the probability that teachers will re-enter their classrooms with the desired attitude of inquiry. In addition, a true partnership recognizes the expertise of each member in a specific domain, and is formed to create an alliance through which expertise is shared. It should therefore be expected that the scientists involved in such relationships would gain a clearer understanding of what constitutes classroom science, and therefore be able to visualize ways to help teachers embed scientific habits of mind into the more rigid framework of teaching environments. These interactions designed to establish true partnerships among scientists and teachers are important social processes that should be investigated.

Purpose and Significance of the Study

The main purpose of this investigation is to generate theory: to develop hypotheses and predictions. However, the generation of theory is not for the sake of the theory itself. "Grounded theory questions also tend to be oriented toward action and process" (Strauss & Corbin, 1990, p. 38). This statement applies to the current study; the theory generated assists in (1) understanding interactions among a group of individuals (a scientist, science teacher educator/researcher, and four secondary school science teachers) working toward partnerships for inquiry as perceived by the participants themselves, (2) identifying the types of interactions with high probabilities for helping secondary school science teachers transform themselves into scientifically-minded individuals, and (3) developing a model for successful professional development experiences. Success in all three of these areas means identifying factors that move participants toward the development of scientific "habits of mind" ([Science for All Americans; Benchmarks for Science Literacy; National Science Education Standards; other Project 2061 documents] AAAS, 1989; 1993; 1996, others) that prove useful--as catalysts for future actions and interactions that promote inquiry and reflective practice regarding science education at all levels, and as ways of providing support for the continuation of such practices.

Research Questions

The current study began with my construction of a broad focus question followed by an iterative process of data collection and analysis. The question that guided the study: How do interactions in a lab setting assist participants in developing and utilizing scientific habits of mind in regard to science education? Constant comparative activity served as a devise for dissecting and attacking the research question through more narrow questions, progressively dictated by the tentative categories and patterns emerging from the data. Although "constant comparative analysis" is a term associated with Strauss and Corbin (1990), this iterative process of specifying one's ignorance is one of the main patterns of scientific practice (Merton, 1987). As the study developed and categories emerged, more focused questions included the following:

1. How do all participants in the study describe their field experiences and efforts toward partnership?
2. How do all participants develop constructs concerning science (its content, processes, and nature) and their personal roles in science education?
3. How do these interactions serve as catalysts for enhancing learning experiences, not only for students, but also for teachers, scientists, and others involved and interested in science education?

Limitations of the Study

Generalizations drawn from qualitative studies that use small samples are analytic, and contextual. The current study examines a specific group that has identified the development of partnerships for inquiry as a goal for their interactions—interactions that take place in a field setting. This goal may not be common to other scientist-science teacher collaborations, as some programs focus on developing lesson plans or teaching a lesson in a certain way. A laboratory setting differs significantly from other situations and contexts, and other differences may be related to gender, background, or career experiences of the participants; the science teacher participants in this group are all expert female teachers with several years of experience, most having far above the average science background. The scientist, too, is seasoned in his practice and his commitment to science education is personal and professional. In addition to my experiences as a teacher in secondary school science classrooms of both large and small schools and in university settings, I have worked in scientific settings, and also have a broad science educational background. Hypotheses generated by this study may serve as potential hypotheses for investigation when a group is comprised of mixed gender, male, or novice participants, but attention should be given to the particulars of the contexts in which these hypotheses are tested. One aspect of interpretational validity, however, is that a qualitative study be useful. The current study meets the "usefulness" criterion in that it could prove useful to researchers in all fields who seek to understand social interaction, discourse as artifacts of thought, and possible relationships between cognition and behavior; it is particularly useful to those involved in science education because it generates a model for professional development, and also because the research design reflects the scientific habits of mind under scrutiny.

CHAPTER II

RESEARCH DESIGN AND THEORETICAL FRAMEWORK

Introduction: A Dual Fit

I chose an interpretive research design as best fitting this study involving natural science and science education. Because little is known regarding the interactions among scientists and science educators at all levels, the research design that fits the problem is grounded theory. Glaser and Strauss (1967) formally developed grounded theory to meet the needs for building theory in sociology. At the time, emphasis on more positivistic research focusing on theory testing neglected the development of theory and social science research seemed to neglect the theory to practice connections. As a result, grounded theory was one of the approaches that attempted to pay close attention to the perspectives, beliefs, and concerns of the individuals involved in the study of the phenomenon in question. Building upon this theoretical framework, Strauss & Corbin (1990) declared "One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge" (p. 23). In the last decade, traditional science education research has also expanded to delve deeply into the perspectives of individuals dealing with situations and specific contexts—appropriately so. Whether or not to invest one's time and energy in a reform is highly individual, so a perspective-seeking, naturalistic design is more likely to reveal personal motivations and obstacles to change in relation to science education reform. Grounded theory is particularly fitting for this study involving the natural sciences and education because it is similar to both the creative, inductive method of science discovery and the way in which cognitive theories were conceived: from specific observations to proposed theory (Ausubel, 1963; Dewey, 1916; Kelly, 1955; Piaget, 1964; Vygotsky, 1978). As grounded theory assumes ensuing action, proposed theory is offered up for further development and/or testing through subsequent studies, as was the case with studies of children's learning. Claxton's metaphor of the tree of scientific knowledge (1991) illustrates how specific hypotheses are generated and tested from emergent theory, with creative processes and presuppositions grounding the subsequent growth (figure 1, p. 29).

The focus of grounded theory is discovery, with questions formulated toward action and process. The actions and processes of interest for the current study are science education reform, the dynamics through which effective partnerships are constructed, and the degree to which these partnerships can serve as catalysts for reform efforts. As in cutting edge scientific research, the discovery occurs as the researcher interacts with the data through a perpetual intertwining of data collection, data analysis, and literature review. Engagement in these activities, in turn, leads to the formulation of further propositions which involve conceptual relationships, more carefully defined questions, recognition of empty spaces in the data, and development and implementation of problem-solving strategies to best fill those voids. Sir Peter Medawar, designated a Nobel Laureate (1960) for his discovery of acquired immunity, described scientific reasoning as "a restless to-and-fro motion of thought, the formulation and rectification of hypotheses, until we arrive at a hypothesis which, to the best of our prevailing knowledge, will satisfactorily meet the case" (cited in Judson, 1996, p. 234). Such a description fits grounded theory as well as scientific reasoning. As I began to work toward a deeper understanding of grounded theory, I constructed a tree metaphor to illustrate the development of grounded theory through various stages, and elaborate on the importance of following stringent guidelines for research (figure 2, p. 30).

The theory that emerges from the data must be thoroughly grounded. Although data collected for grounded theory studies are most often restricted to the form of interviews, a more thorough grounded results from the use of multiple data sources and types. If only one data source is used, a "tap" root may ground the theory temporarily, but the first wind of challenge that blows will topple it. Even with two data sources, surface grounding may occur, but again a challenging force will distort or demolish the sprouting theory. Triangulation assures that the theory that emerges from the data is strong enough to withstand potential insult because it has a broad, deep stance; therefore, it is firmly grounded.

Large quantities of data alone, however, may not result in emergent theory. The grounding of data must be rich enough for the development of concepts related to the researcher's questions. It is for this reason that the researcher must give careful planning and attention to choosing a purposive sample from which to generate data.

Concepts are grouped together and classified as categories; categories are at first tentative, like tender shoots rising from the ground. These fragile categories are then re-examined as the researcher returns to the data, not to seek confirmation, but to challenge the categories and attempt to isolate flaws in them. This microanalysis is known as open coding (Strauss & Corbin, 1990), an apt description for a rising theoretical shoot as the ground is broken open by its appearance.

If the new growth is a category that withstands this probing, it is nourished by the data. and the category grows stronger and thicker. If the category cannot withstand the scrutiny, it is reabsorbed by the data set just as an unnourished sprout withers and gives up nutrients to become a small part of another rising shoot. This process is part of the axial coding process, which may provide support for a tentative category or alert the researcher to rethink the category (Strauss & Corbin, 1990). Once the categories are firmly established, they are examined for relationships to determine how one category is linked to others. Questions to guide this process might include the following. "Are two behaviors typically associated as demonstrated by the data?" "Is there a negative correlation, positive correlation, or no correlation evident among qualities or interactions?" This examination is another part of axial coding, providing dimension and allowing the researcher to visualize the reassembled data in a holistic manner. Additional questions to be answered here are: "Are verbal responses or other behaviors progressive?" "Does one behavior generally lead to a succeeding, predictable response?" "Do certain behaviors seem to appear together in a short period of time, suggesting some type of linkage?" Relationships or linkages are strands that run among categories and provide scaffolding for the emerging theory, just as the fibrous tissue of the tree provides a framework for its wrapping of bark.

As the framework of the tree is established, the upper portions require nutrients from the ground. Likewise, the roots require energy provided by the green shoots above ground. This back-and-forth transfer of nutrients and energy is evidence of interdependence. In grounded theory, the interdependence of data, established categories, and linkages among categories is evidenced through constant comparison or "constant interplay between proposing and checking" (Strauss & Corbin, 1990, p. 111). Relationships recognized through deductive reasoning are verified by the data repeatedly, assuring that the theory remains close to the data and represents the reality of the situation.

For the researcher involved in scientific discovery, the repetitive activities may range from searching the literature for relevant studies to designing follow-up experiments that specifically address a line of questioning. In the case of the social science researcher investigating phenomena involving human interactions, the activities will almost certainly involve formulating additional interview questions, returning to the literature or to video tapes, audio tapes, and field notes to search for new and relevant categories and new relationships among those categories (Strauss & Corbin, 1990) until saturation is achieved. This is where the researcher's theoretical sensitivity is of the essence. Through professional or personal experience as well as familiarity with the literature, one can grasp what is actually happening, or at least gain enough insight to develop specific questions to lead to a clearer understanding of the participant's perspective.

As the theoretical tree comes to fruition, a full coat of rich woody bark wraps itself around a fibrous framework. In parallel, as theory is established through stringent analysis and selective coding, a main story line wraps itself around the scaffolding of categories and linkages; a story line thick with the words of the participants.

Summary

Grounded theory is a rigorous analytical process through which theory is built upon well-substantiated empirical data. Large amounts of diverse data are collected, reduced to order through coding, delineated into categories, and examined for patterns and relationships among categories. Emerging theory is kept close to the data and checked to see that it closely matches the reality of the situation. Theory is elaborated in a vibrant narrative manner thick with the words of the participants themselves. Grounded theory was developed in order to contribute to the rigor and discipline of qualitative research, which elaborates on human interaction in a more intricate way than quantitative studies can do. Because theory is closely related to practice in areas of social science and health care, grounded theory is widely used for clinical studies. It is also appropriate for educational studies because learning, and therefore teaching, is profoundly influenced by the people we interact with (Vygotsky, 1978) and our minds/brains change as a result of the types of experiences we have (Jenson, 1998). These are social processes. So, although the majority of education research remains experimental or quasi-experimental (Lichtman, 1990), both the American Educational Research Association (AERA) and the National Association of Research in Science Teaching (NARST) have welcomed good quality naturalistic studies within the last decade, indicating that experimental research is no longer the only valued methodology in educational research.

The purpose of this study was to gain insight regarding the interactions among a research scientist and science educators where partnership was set as a main goal. Previous research involving scientists and teachers reported some effect on the teachers without regard to the effects on the scientists, which denies any claim to partnership. Much of the existing research in this area deals with limited data collected from questionnaires designed for general program evaluation (Svolopoulos, 1995), and such a focus on teacher effects did not allow for the examination of complex issues regarding cognitive processes that accompany the interactions among scientists and teachers. Therefore a void exists in our search for understanding. The effects on all participants, and the cognitive processes that accompany these interactions, must be examined in respect to all participants, including scientists and science teacher educators or researcher.

Participants of this study were simultaneously involved in building partnerships as they engaged in a quest for understanding the nature, processes, and content of science, and in considering how their experiences influenced their respective self-defined roles in science education. Examining these experiences required a perspective-seeking research design. Additionally, the major purpose of this study was to generate theory regarding cognitive processes as revealed through participants' discourses, stimulated by and through their interactions in a field setting. Insight regarding the effects of these interactions upon all participants addresses the void in existing research, which limits effects to teacher participants. Therefore, a grounded theory research design, requiring a dynamic interaction between the researcher and the data through constant comparison, was merited. The research design for the current study, however, does deviate from grounded theory in its purest form. In order to assure saturation of the categories, a pure grounded theory study deals with repeated purposive sampling until interviewees may number twenty-five or thirty, and is limited to interviews as the only form of data. A study involving this number of participants typically involves collecting data around a finite set of interview questions, which was not appropriate for the current study. In order to assure saturation of the categories, therefore, I conducted repeated interviews with each of the participants, and analyzed records of daily interactions over an extended time period. Incorporating multiple forms and sources of data with literature and my personal field notes allowed me to amass tremendous amounts of data in multiple sets, and achieve saturation of the categories. The exploratory nature of the study, analytical techniques, manner of presentation, and the underlying philosophy is true to grounded theory.

Setting

The study centered on interactions that occurred in a cell and molecular biology laboratory of a medical research foundation in the Midwest. This institution first implemented a research program for secondary science teachers in 1988 and designated them as "Foundation Scholars." The initial plan for this educational research program included selecting four to five teachers each year to participate in ongoing cutting-edge research projects, with each teacher placed in a different laboratory. The director of the current project believed that the needs of the teachers were not being met by this format and, in 1993, persuaded the administrators of the institution to allow modifications to be made under his guidance. The major modifications included grouping the teachers to maximize peer interaction, and providing initial research problems that were technically simple yet provided rich intellectual ground for understanding molecular biology fundamentals and foundations. These changes allowed the teachers to complete a project in the eight-week time period allotted, and the director also believed that this revised format would assist the teachers in transferring aspects of their experiences into their classrooms. This modified program became what is now designated as the "Summer Course" of The TeleScience Project (TSP).

The laboratory is one of several research laboratories under the direction of Dr. Paul Schelling (a pseudonym), the research scientist who participated in the study. Although the teachers primarily worked with bacteria and bacterial viruses, they shared laboratory bays with a full-time research team involved in molecular biology studies that used Caenorhabditis elegans (a nematode) as a model organism. It is common practice at this facility for teams working on different projects to share lab space when necessary. The laboratory is well equipped, however, specialized equipment housed in other areas is also available for use by any of the full-time or summer researchers.

Participants/Science Teachers

Each year, participants for the TSP summer course are selected from a statewide applicant pool. Since the 1993 modifications, applications have been solicited from the state's public high school science teachers via postal service. All teachers identified by the State Department of Education and the state science teachers' association receive information regarding the TSP opportunity and are invited to apply. The average number of applicants per year is thirty, from which four are chosen. However, it should be noted that successful teacher applicants are somewhat self-selected, as individuals who complete the application process demonstrate a high level of commitment at the outset. Many eligible teachers find the eight-week requirement during the summer prohibitive, and therefore do not complete and submit the application packet. In recognition of this commitment, the TSP provides a stipend, to replace potential summer earnings, and housing for the summer for successful applicants. Each scholar also receives a computer, modem, and printer for unlimited use in her/his classroom beginning the school year following participation in the summer course. Phone lines in each of the teachers' classrooms and Internet access are provided at that time, with any expenses incurred met by the research institution. Technology is provided to establish communication among teachers and TSP staff, and is critical for those teachers who are virtually isolated in rural parts of the state.

Committee members screen the applications individually; final selections are made as the committee meets collectively. The committee typically consists of the TSP Director, two former summer scholars, a member of the biomedical research institute's senior scientific staff (not always the same person), and the Director of Community Relations for the research facility. Criteria for selection includes information related to the types and length of teaching experiences, required essays, evidence of an ongoing commitment to professional growth, and letters from supervisors and peers. For the summer of the study, four female teachers were chosen. I sought IRB approval for the study; approval was granted for the research to proceed for a period not to exceed twelve months. (See Appendix A.) Each participant was assured anonymity and received an Informed Consent for Participation in Research form to examine and sign before data collection began. (See Appendix B.) Pseudonyms were chosen for each of the teachers and the scientist, while I remain named.

Participant Observer/Researcher

The most common role for the individual involved in any type of field research is that of participant observer. Although challenging, it is this role that I assumed for this study; this special, dual role enabled me to actively engage participants in activities and conversations in a manner that was least obtrusive and decreased the likelihood that the actions and interactions observed were affectations or exaggerations (Erickson, 1992; Jorgenson, 1989; Lather, 1991; Langenbach, Vaughn, & Aagaard, 1994). Duality is evident in the manner of presentation as well: I offer introductory material in a more detached, formal tone, whereas character development and vignettes used to illustrate interaction are personal and intimate.

As participant observer, I (1) collected data as a "watcher," and (2) participated in the activities in which the scientist-teacher research group engaged. All researchers bring into their studies certain biases and presuppositions. Taking a subjective stance brings my potential biases and presuppositions to the forefront; this allows for open examination and debate related to my construction of theory. This study meets the measure of interpretive validity as presented by Gall, Borg, and Gall (1996). These criteria, along with supportive quotations from other researchers, are listed in Table 1, page 31.

The extended timeframe of the study provided several advantages for my research. I collected data over a period of nine months, beginning immediately after the orientation of the teachers to the facility and extending well into the school year. This allowed me to collect of a broad base of data and return to participants when data analysis generated further questions. It also allowed me to establish camaraderie with the group so that informal and sequential interviews were natural. "Sequential interviews conducted in an interactive, dialogic manner that entails self-disclosure on the part of the researcher foster a sense of collaboration" (Lather, 1991, p. 77). Conversation among teachers frequently turns to sharing favorite activities, classroom catastrophes, general practices, and sharing of lesson plans, tests, other types of assessment tools, and favorite readings. Such was the case with this group as well. These conversations provided great insight into the ways that participants viewed the value of their experiences and led to the generation of further interview questions.

Constant comparison analysis was accomplished through the repetitive coding and re-coding of the data. I elicited help from the qualitative expert on my doctoral committee; within each participant case, we individually coded data sets to establish themes describing the participant's life as a science teacher. Then, for validation within each case, we checked themes across data sets, compared our coding, and finally engaged in "negotiating meaning" with participants regarding interpretations. "Negotiating meaning helps build reciprocity" (Lather, 1991, p. 61). It was the constant comparative method that contributed rigor and validity to this qualitative study through the establishment of properties, dimensions and relationships. Comparing data from different sources also revealed the validity of a category, and sometimes directed that it be relegated to a subcategory position under a larger umbrella category.

Multiple sources of data collected for the study assured triangulation, which in turn increased the trustworthiness of the data. Multiple sources make up the heart of any naturalistic study; and the richness of data collected during this research provided depth for the story line. "Data might be better conceived as the material for telling a story where the challenge becomes to generate a polyvalent database that is used to vivify (emphasis in the original) interpretation as opposed to 'support' or 'prove'" (Lather, 1991, p. 91).

Data Sources

Essays from the original applications submitted by the teachers, unstructured and structured interviews that were audiotaped and transcribed, audiotapes and transcriptions of daily interactions in the laboratory, field notes, and personal communications served as data sources. In addition, documents supplied by the program director (such as those submitted to funding agencies) that describe the program design and goals were perused, with an eye toward the generation of interview questions directed to the scientist.

I used a reflective journal to keep track of the research process, my behavior as well as my thoughts, as recommended by Bogdan & Biklen, (1992). Documentation of daily activities, methodological notes, tentative categories, possible lines of literature search, and tentative patterns established a paper trail that mapped the progression of my mental processes as I delineated categories. Each researcher brings personal biases, epistemologies, and philosophies to a study, regardless of how objective one's intentions may be. I periodically examined this reflective journal for evidence of biases, allowing me to deal with them as they surfaced, so that any preconceptions would not unduly affect the research. "Determining that constructs are actually occurring rather than mere inventions of the researcher's perspective requires a self-critical attitude toward how one's own preconceptions affect the research" (Lather, 1991, p. 67). The importance of keeping track of one's thinking during the process of research, through field notes and journals, is illustrated by Judson's statement regarding the process of scientific discovery: "Once the Humpty-Dumpty of discovery is put together, all the historians and all the sociologists can't really scramble him again—often not even the scientists who were most closely engaged, for their memories are the first to begin to be altered by the persuasiveness of the thing discovered" (Judson, 1996, p. 9).

Figure 1: Tree of Scientific Knowledge
Note: From Educating the Inquiring Mind: The Challenge for School Science (p. 66), by G. Claxton, 1991, London: Harvester Wheatsheaf

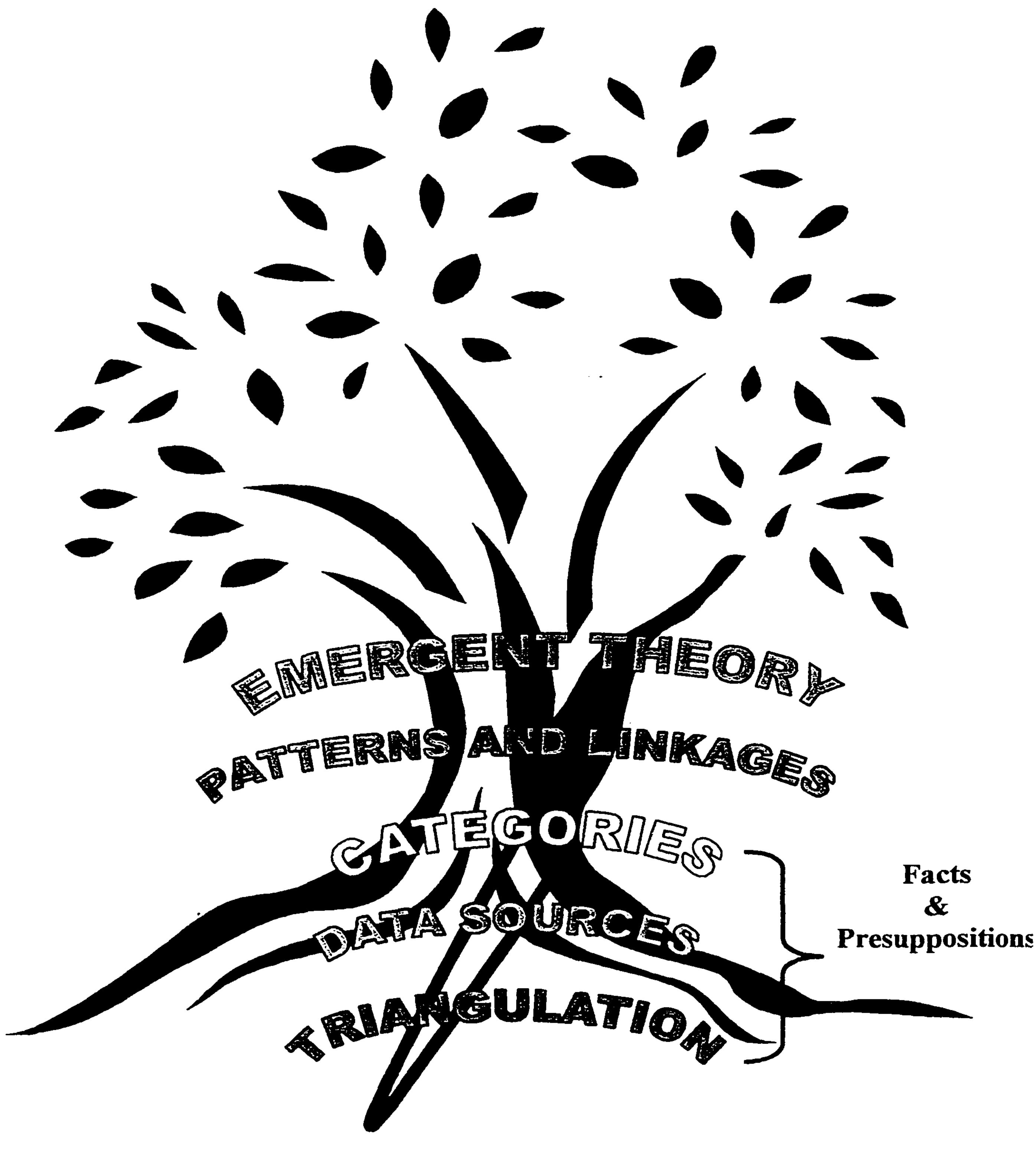


Figure 2: Tree of Grounded Theory

Table 1: Tests of Interpretive Validity

1. Usefulness: Enlightens readers regarding the situation under scrutiny; grounded theory is oriented toward action.
2. Contextual completeness: physical setting, activities, events and perceptions of them, social rules and patterns of order; multivocal: "several ways of seeing as a series of differing views rather than reducing all views to a single correct one" (Eisner, 1998, p. 49).
3. Researcher positioning: demonstrates sensitivity in relating to participants
4. Verisimilitude: "a style of writing that draws the reader so closely into the subjects' worlds that these can be palpably felt" (Adler & Adler, 1994).
5. Triangulation: multiple data sources, collection methods, and theories
6. Member checking: participants' review of statements to determine accuracy and completeness.
7. Chain of evidence: allows the reader to follow the derivation of evidence
8. Outlier analysis: looking for negative evidence and addressing it.
9. Pattern matching: testing theoretical propositions against research data.
10. Long-term observation: repeated observations to distinguish situational perceptions from consistent trends.
11. Representativeness check: determine how unusual occurrences, such as researchers presence, might have skewed the findings.
12. Coding check: criterion for analysis is consistent; category saturation is achieved.

(Gall, Borg, & Gall, 1996)

CHAPTER III

LINGUISTIC IMAGES: INDIVIDUALS

Introduction

In this chapter I have presented images of the participants; images developed from a compilation of sources. Data contributing to these images were obtained from a variety of sources: TSP applications upon which teacher selection was based, project descriptions and proposals submitted to funding agents by the project director, field notes, journal entries, personal communications, and audiotapes of daily discourses and interviews (semi-structured and structured) with accompanying transcripts. Data collection and analysis processes were simultaneous, each shaping the direction of the other: a true constant comparative methodology. Literature review was perpetual; related studies and theoretical papers were sought to challenge emerging hypotheses, illuminate other possible meanings of the data, and assist in the formulation of follow-up interview questions. A less tangible but strong influence in formulating this imagery stemmed from personal, educational, and professional experiences that influenced my ability to see from multiple perspectives. Such factors contributed to what Strauss and Corbin refer to as theoretical sensitivity (1990). One develops theoretical sensitivity as "imagery enters our heads as the residue of our everyday experience" (Becker, 1998, p. 15). This process is not static; rather it is cyclic, and theoretical sensitivity undergoes continuous metamorphosis and enhancement as one studies, writes, reads, researches, and interacts with others. Life experiences produce images; image formation enhances theoretical sensitivity; enhanced theoretical sensitivity made manifest by a new and informed perspective influences one's perceptions of life experiences, which in turn leads to the refinement and modification of one's images, and the cycle repeats itself. Such images are, by definition, colored with potential personal biases or imperfections.

> Thomas Kuhn taught us that our observations are not pure, that they are shaped by our concepts—we see what we have ideas about, and can't see what we don't have words and ideas for. So, in a strong sense, there aren't any facts independent of the ideas we use to describe them.
>
> (Becker, 1998, p. 18)

Acknowledging the potential for biased image formation, I sought to increase validity through participant verification as well as triangulation of data sources. The qualitative expert on my doctoral committee served as a consultant; we coded data from multiple sources independently, checked themes across data sets, and compared coding notes and results, then returned to participants for verification when one concept or idea was corroborated (Strauss & Corbin, 1990). Impressions offered by other participants and theoretical literature contributed to the refinement of what I have presented. The first linguistic image is my own. I prefaced the others with this personal view to give the reader insight into the mind that created the images of the other participants; "To position my own discourse; to mark a place from which to speak" (Lather, 1991, p.8). Next, I have introduced the research scientist, and finally I have offered presentations of the remaining participants in random order.

Robbie: Five years after graduating from high school I began my college studies at a small state college in the north central U.S., but only one year later my education was interrupted by a move to England. Although disappointed that I would once again put my studies on hold, three years on that small island provided me with many rich and delightful experiences. I resumed my studies as soon as I returned to the States and graduated with a B.S. (cum laude) from a historical women's university in the South, with a major in microbiology and a minor in chemistry. I subsequently earned a M.Ed. (concentration in Natural Sciences) from a state college in the Midwest with a well-established teacher education program, and am currently a doctoral candidate in Science Education at a large university in the Midwest that has a reputation for excellence in both academics and research. I am fortunate to be supervising interns in field studies, so I have many opportunities to maintain contact with secondary school science classrooms in public schools. I am employed as an educational consultant at the medical research foundation (MRF), where the major portion of the research data was collected. My role includes (1) providing the program director with an educator's perspective of the TSP and to help guide project activities, (2) sending supplies and equipment to secondary school science teachers who make requests, (3) providing advice and feedback on lesson plans, and (4) generally supporting teachers through any means possible. I love science and I love to teach; this job keeps me involved in both. I am active in several professional organizations, and continue to be engaged in professional development for teachers in leadership and learner roles.

Before beginning my career in science education, I worked in a variety of health-care settings. One position was in the pathology laboratory of a small hospital. As a histology technician (HT), I prepared and stained tissue slides for examination by the pathologist, assisted with autopsies in unattended deaths (The pathologist also served as the county medical examiner.), and also transcribed dictation of gross and microscopic observations related to the tissue specimens. While working in this laboratory I passed both written and performance-based examinations, and earned a HT registry with the American Society of Clinical Pathologists (ASCP). As I worked closely with this doctor's doctor, I found that my love and admiration for scientific investigation was enhanced, and that my excitement for teaching science was fueled. I worked in the lab during the day and began to work toward my teaching goals by attending evening classes. As a non-traditional student, I earned my teaching certificate and completed a Master's Degree in education with a concentration in the natural sciences. The education and background experiences for participants, including my own, are summarized in Table 2, page 62.

My first teaching job was in a small school with a student population of 300 in grades K through 12. By far, the majority of my students at this school were white, but I did have a few Latino students. (See Table 3, page 63, for specific demographic data.) A traditional schedule, with 45-minute class periods, demanded that I taught six different classes each day (grades 7-12). Although it was very hectic, I had the advantage of teaching the same students for several consecutive years, so I learned to know my students well. While teaching in this small school I was chosen as a Foundation Scholar for the summer, and came to the MRF for the first time in 1993. I was part of the experimental group for what is now the TSP, and I have worked and learned here many summers since. After nine years as the only science teacher in this rural school I took a position at a high school in a neighboring town.

This high school served approximately 800 students in grades 10 through 12. The student population was somewhat diverse, as the district served dependents of military personnel. (Demographic data for each school discussed is summarized in Table 3, page

63.) I taught there for three years, with teaching responsibilities that included Pre-AP Biology I, Biology II, AP Biology and AP Environmental Science. Block scheduling (4 X 4 form with 80-minute class periods and courses changing each semester) allowed me to include extended laboratory investigations and activities in my science classes. I served as science department chair for two of the three years of my employment there, and worked with six other science teachers.

I formed a close partnership with a teacher who was certified in biology, chemistry, and physics, as I am. Together we developed a plan for an integrated biology/chemistry class, presented our plan to the instructional council, and team-taught the class for two years. Students who enrolled in this course stayed with us for a full academic year on the block schedule and received credit for introductory courses in both biology and chemistry. The course received recognition at two National Association for Science Teachers conventions and teaching it was both enjoyable and academically satisfying. My colleague is a dynamic teacher who recently earned her National Board Certification in Chemistry.

My reasons for participating in the TSP during the summer of 1999 were many. First, having witnessed the revision and evolution of the TSP during the previous five years, I was anxious to put the project through the test of formal research to determine the extent to which its goals were met. Second, I sought social and academic nourishment because I thoroughly enjoy teaching and sharing classroom experiences with other teachers. My past experiences working in the lab at the MRF with other teachers had proven to be rewarding both personally and professionally, and I felt certain that the summer of the study would be as fruitful. Third, I hoped to begin building a network of professional science educators interested in collaborating to development and evaluate practical and intellectual tools for enhancing science education at all levels.

I did not have a molecular biology project of my own; I functioned as an assistant in the projects of all teacher participants. In the early weeks of the summer my role was that of a liaison: interpreting instructions for experiments, assisting with the design of practical plans for carrying them out, and locating materials in the lab. In the latter weeks the other teachers and I developed strong peer relationships as we utilized incubation and "wait times" required by the molecular biology experiments to brainstorm plans for classroom strategies, and ways to modify each teacher's favorite lesson plans. Modifications were geared toward increasing student-teacher interactions and open-ended experiences for students. Establishing camaraderie with the group allowed me to return to the participants for informal and sequential interviews in a manner that was natural; a practice that was essential to my research related to the social sciences, and specifically to my role as participant observer.

I am an assembler. I fasten new ideas to old ones, sometimes overlapping, sometimes joining them seamlessly, and sometimes creating tentative bridges until a more sound construction can be achieved. I envision all of my experiences as connected and reflect purposefully on things that I have previously learned to find ways to apply them in new situations. I often make multiple interconnections simultaneously, and I am surprised when others do not see things as I do. I have learned to use the tools of analogy, metaphor, and model as I struggle with my own understanding. Therefore, these same tools have become the natural brushes that I use to paint pictures of the vision in my mind's eye during discourses with colleagues or with students.

Philip: Early in his undergraduate studies Philip chose a science career. He had entered a comprehensive, major public university that provides undergraduate and graduate education in more than 150 fields of study, conducts both theoretical and applied research, and has a reputation of being among the best in the world. His original intention was to become a physician. However, a required general education course made a major impact on him and pointed him in a new direction. He explained.

> All of a sudden, my universe expanded. As it happens, the comparative anatomy...that's the course that turned me around. It was absolutely unforgettable.... It became less and less important to me what happens to your tonsils when you get an infection and more and more important to understand where tonsils came from evolutionarily.

After completing his B.S. degree, Philip earned his Ph.D. in biochemistry from the University of California, Berkeley. He then did post-doctoral work at Einstein College of Medicine in New York. Philip subsequently joined the faculty at Einstein as an assistant professor of molecular biology. After achieving and holding the rank of full professor there for six years, Philip relocated to the Oklahoma Medical Research Foundation: the setting for the current study. Philip's position is Member and Head of the Molecular and Cell Biology Research Program: a program that comprises 7 research laboratories, employs 50 people, and operates on a budget of $2.6 million per year. The National Institutes of Health (NIH) and the National Science Foundation (NSF) have supported his scientific research; the TSP, which evolved under his direction, has received funding from several corporate sponsors in addition to grants awarded by the Howard Hughes Medical Institute (HHMI). His list of honors and awards in science are numerous; his service to education was recognized through his receipt of the Renner Distinguished Service Award, an honor given to him by the state Association of Science Teachers.

Philip's current scientific research has to do with regulation of gene expression in bacteria. His most recent research interests involve the interaction of cellular proteins that lead to the development of specific structures.

> I've always worked with bacteria. I'm very impatient, you know, and you can do experiments in bacteria in 24 hours.... A flagellum is a good example of that [how proteins react with each other to form structures in cells]. At the end of every bacterial flagellum there is, literally, a motor induction system. It's a rotary motor that turns, uses streams of ions to turn this motor...literally screws the bacterium into the medium. It's quite an amazing machine...cells are just chock full of these things. And, we're actually only just now beginning to appreciate, not just how orderly cells are—we've always known that—but what complex machines they are. And we need to know an awful lot more about the principles of those machines.

Philip is a master. I give this title with dual meaning: artist and teacher. Philip, as master artist paints story-images of scientists as natural components of experimental procedures and outcomes; the study of genetic inheritance enriched by the cultural inheritance that led to the original discoveries. To segregate the history of science from the outcome of these elegantly simple experiments or from the processes of performing those experiments, for him, is to destroy their essence. The following account of Philip's decision to become involved in the TSP illuminates the artist in the scientist.

I had just gotten the second edition [of Phage and the Origins of Molecular Biology] where John Cairns had written the preface and at the end of the preface he very eloquently (Cairns is really a superb writer). He pointed out that the people who made this revolution in biology were dying. Delbruck was gone, Luria had gone...and pretty soon the rest of us would be gone. And immediately prior to that, in this preface, he described an event at Cold Spring Harbor [New York], where all of the scientists and the janitors and the groundskeepers and God knows who all, put on Shakespeare's A Midsummer Night's Dream. And he describes how one would walk out from these air-conditioned laboratories and into this hot and humid night and see these people rehearsing--and it really was like walking into another world. The hot and humid, heavy atmosphere.... I've been at Cold Spring Harbor, at night, in the summer, and I know what he's talking about! So, that really struck me, what he said you know, all of these people are gone and the rest of us are going pretty soon, too. And I thought to myself 'My God, what a terrible shame.' History would probably look back on that period of maybe 30 years, a twinkling in time, when all of a sudden we understood to an extraordinary degree, the chemistry of heredity.... And then it occurred to me, and this must have been a flash, I can't pinpoint it, somewhere in all of this meditation...it occurred to me--that their legacy could be that high school students could re-discover some of these principles for themselves.... And realizing that the important part of what they left behind, their intellectual legacy could be kept alive.

To be called a master by those who teach is indeed high praise. The four teacher participants in the TSP described Philip as a teacher for whom they developed great respect because of his content knowledge, but also because of his patience, skill, and encouragement. He crafted an intellectually rich learning environment as he led them each through the process of discovering scientific principles and practices. His chief tool was critical discourse, his primary probe was a question sculpted to the specific needs of the moment.

> Martha: The hours that he spent with us just talking--discussing our results, their meaning and application, was a tremendous learning experience. He encouraged us to step out on our own ideas and to ask 'what if...' and then experiment. Either he is an instinctual teacher or he has developed some wonderful skills.
>
> Julia: Philip is one of the best teachers that I have ever met. If he was ever disappointed with my efforts or performance, he never conveyed that to me...patient and encouraging, personable; qualities that I believe are important in any teacher.
>
> Diane: I was impressed with his knowledge and enjoyed listening to him...discussing and explaining concepts, taking as much time as necessary. I found the experience to be everything I had hoped for and more.
>
> Sherry: ...and you roll your eyes and you're like 'Aw, come on--It's Monday. It's early. I don't want to think about this.' But, yeah, it's the way he would ask--You'd ask a question. He'd ask a question to extract an answer out of you. He was trying to pull from prior knowledge, something you had read or something you had seen before--which is what all of us should be doing with our kids [students].

> It was his questioning I think that made the experience. He wouldn't give you the answer.... We just had a really good time. I learned a lot.... We were playing; playing within parameters.

This last statement about play intrigued me. I had heard this before and had seen references to play in much of the biographical information of scientists. When I pursued this topic with Philip, he agreed that it is a strand in science and elaborated on the idea of science as play.

> This business about play is also something that recurs very often; the outcomes, but also the process of science is very aesthetically pleasing. Delbruck gave a talk at the Academy of Sciences, where he referred to work on bacterial viruses as 'a fine playground for serious children who ask ambitious questions'. I think that's...one of the best descriptions of science. There's play, but not play the way that most people think of.... To me the term play implies a certain intellectual freedom. Which is basically the freedom to explore, but freedom to explore in a direction, that is, by asking a serious question.

Julia enjoys spending free time at a small cabin in southern LeFlore County, where two small creeks merge to forge a path to Mountain Fork. She took a great deal of pleasure in sharing photographs of this area. In fact, this area that is such a big part of her life served as the source of Julia's summer research project.

Pursuing her love of language, Julia studied French in college, and then took advantage of an opportunity to attend a university in France during the summer preceding her junior year. She found that attending a university in France was quite different than her American college experience.

> To be honest I was a bit intimidated when I first went to classes. We [American students] weren't prepared for having to stand and respond to questions in an auditorium-type setting. Our class was sort of like an amphitheater in Grenoble and everything was totally in French. We really hadn't learned a thing about proper etiquette. Their classes do a lot of oral discussion and testing—more like defending your thesis kind of thing.

Julia returned to the U.S. for only one semester, and then she went to Florence, Italy, to study during the spring of her junior year. School in Italy was similar to what she had experienced in France, but Julia wasn't quite so taken aback by the format this time. She described her Italian friends, who studied law and medicine, as very autonomous in their studies; not spending much time in class but rather digging through books and studying constantly for exams. Julia enjoyed her experiences so much that she went back home just long enough to earn the money to return to Europe.

> I worked about eight months, saved up enough money for a one-way ticket, and went back to Italy. I stayed there about eight years. I traveled as much as I could; [I] spent a couple of summers in Tunisia, went to England, Switzerland, and various regions in France and Italy. It's funny, even when you have to work and you don't get to run around as much as you would like, every day is a vacation. You meet new people from all over the world and learn continually.

During her time in Italy, Julia spent some time in the import-export business, and then functioned as a foreign correspondent, office manager, and surgical assistant for a plastic surgeon. She also taught English at an American University in the evenings. When Julia returned to the U.S. on a more permanent basis she worked as a surgical technician and completed a second undergraduate degree, then went on to earn a research Master's degree in biology. Shortly afterward she began her teaching career.

Julia had fifteen years of teaching experience. For the first year she taught health occupations at a vocational school; the next two she spent as a traveling teacher of French serving three different schools. She spent the last thirteen years at the school where she was employed at the time of the study, a small school in a very remote area of the state. The student population, pre-K through 12, was approximately 300, with little diversity (See Table 3, page 63.); Julia's teaching assignments were demanding and varied, largely because there was only one other science teacher at the school. Every year she taught Chemistry I, Biology I, and French. She alternated physics with anatomy and physiology, occasionally taught zoology (whenever student interest was high enough to make a class), and coordinated the academic enrichment class.

Julia spoke of her desire to be involved in scientific endeavors through fieldwork and collaboration leading to scientific publications, but her language insinuated that this had been a lost dream. Her participation in the TSP offered a glimmer of hope for restoring the dream, at least in part.

> At one time, I had hoped not only to teach, but become in some way involved in research--perhaps doing field work, collaborating in the actual writing of scientific publications, or being involved in international communications within the scientific community. While teaching has been and continues to be very rewarding, I have come to the conclusion that for scientifically minded individuals, there is not only a greater tendency but a [sic] inherent necessity to be aware and share in scientific knowledge. Unfortunately, the kind of remote region

in which I reside, while a biological paradise, has not been conducive to the sharing of such ideas much less collaborating in research.

Julia's initial interest in the TSP was both personal and professional. She explained that she learns through public television and reading scientific journals, and wanted to share those learning experiences with her students and colleagues. Unfortunately, she frequently found both groups uninterested. A high degree of apathy among students was discouraging for Julia. Nevertheless, she had continued to be involved in professional development through her participation in workshops almost every summer, in spite of the fact that her school had a very small budget for professional development. She attended the majority of these workshops at her own expense, and she hoped to regain a sense of excitement about science from her participation in the TSP.

Julia's project involved the isolation and characterization of bacteria from the creek close to her cabin. She found an unusual purple-pigmented bacterium that became the focus of her experiments. She successfully mutagenized a culture of this bacterium, selected a mutant that was not pigmented, performed nutritional studies, isolated the pigment, and analyzed it through chromatographic techniques. Julia also contributed samples for bacteriophage hunting, and was thoroughly engaged in her project.

Julia is an analyst. She is very careful about the terminology that she uses and the questions that she asks. Her analytical behaviors were especially evident in the first few weeks of the program; she seemed reticent to give voice to questions until she could formulate each carefully and incorporate it with any related topics from her past experiences. Impressions of Julia offered by other participants were in agreement with my own.

Sherry: Julia was analytical and compulsive about doing something--and I think she was really trying to understand.... My impression was that she thought—'You're supposed to get this kind of result, and it's just bugging the heck out of me'--because you're not getting the result that you wanted.

Philip: She was very persistent. She was very inquisitive. Julia wanted to know exactly why something--why we were doing a certain thing. And, I think that in general it can be mildly frustrating to suggest an experiment whose purpose is so obvious to me--and I have to check myself and say, 'Wait a minute. These people don't have 35 years of background...'

Sherry: Fall and spring semesters meant full-time enrollment at a major university for Sherry. During the summers she enrolled at a local junior college for the first two years of her college life and she has continued her affiliation with this junior college as an adjunct instructor in biology. Sherry completed a B.S. degree in Arts and Sciences at a large university in the state with a major in biological sciences, then went on to earn a M.S. with a major in curriculum and instruction education at this same institution.

Sherry had 15 years of teaching experience, all at the same high school; the student population had consistently approximated 1,250 for grades 10 through 12. The school district served dependents of a military base located in the area and, as a result, many of Sherry's students were from different social, ethnic, and cultural backgrounds. (See Table 3, page 63, for demographic data.) In addition, many of her students traveled extensively and seemed to be, in some ways, more sophisticated or at a cognitively different level than their peers. While this diversity added interest to the classroom, it presented quite a challenge for Sherry to meet such an array of needs, abilities, and learning styles. Sherry taught Biology I and Honors Biology I on a 4 X 4 block schedule. Both of these classes were established for the sophomore level, so Sherry had to maintain focus on the basic concepts and skills at the introductory level of biology.

Sherry's professional development experiences during previous summers included working in research laboratories of a medical facility, experiences that she thoroughly enjoyed.

> What I liked about working in the labs was being around people who are really 'eaten up' with science.... These people were very motivated in their field about what was going on and I had been dealing at that time, I had no honors classes, so I was dealing with your general biology kids [students] who didn't really care whether they passed the class or didn't pass the class, which was very depressing.... Being in the lab kept me from burning out.

During these laboratory experiences Sherry functioned largely in the role of a technician. The major flaw in those experiences was that they did not add any new tools for use in her classroom, in part because the techniques and equipment were so sophisticated and costly. So, for Sherry, a goal for participation in the TSP was to add new teaching tools and strategies to her existing repertoire.

> The description of the program implied the techniques and equipment used could be applied in the classroom. I have reached a point in my career where I would like to instruct my students differently from the way I was taught. I want my biology students to know the content of biology, but I want to incorporate more

> inquiry methods to teach the content and hopefully achieve longer student retention.... So this program was especially appealing to me.

Sherry had also been active in presenting professional development opportunities for other science teachers, a responsibility that she assumed as a classroom teacher and not only because she is the science department chair at her school. Later in the fall, when Sherry and I attended a National Association of Biology Teachers (NABT) conference together, I became acutely aware that Sherry was preparing the materials she had gleaned from each session for sharing with her colleagues back at school. The activities, strategies, and resources that she tended to adopt for use, therefore, were selected through this filter of responsibility.

> I put these "kits" together so the other teachers can take them and go. It helps them to do labs, but these aren't even inquiry labs, except some of the things I've picked up here.... My teaching includes written notes, written homework, and labs. I am trying to incorporate more inquiry type labs as I obtain them from workshops—but it takes so much time.

Sherry worked with Martha on a project culminating in experiments that demonstrated recombination in bacterial viruses. The process started with the mutagenesis of a T4 phage stock, and then proceeded through a series of selection experiments. Selecting for both R2 mutants and temperature-sensitive mutants allowed these teachers to develop a more thorough understanding of the processes involved. At the completion of their project they had constructed a simple genetic map.

Sherry is a <u>seeker</u>. Her seeking at times seems to her to be a most precarious juggling act. She was seeking ways to engage and excite her students about science, show students how science connects to their daily lives, teach them skills necessary for success in college, and balance all of that with teaching them how to think; a big accomplishment if she could achieve this balance. Sherry identified higher education as a factor contributing to the difficulty of the balancing act. She viewed higher education as stuck in a traditional model of schooling while touting inquiry to K through 12 teachers, such hypocrisy complicating her discordant task.

> I'm frustrated.... I need something. I need...to become comfortable with that idea of not telling them [students] everything. I'm doing basic science. I'm teaching them the dredges that nobody else wants to have to deal with. They're supposed to know all that stuff before they go to college, you know? And, I think a lot of times the reason I pick certain things [to include in a course] is because they gave me such a problem when I was in college.... I just kind of sometimes feel that we're going to do them [students] a disservice if we don't give them some of the memorizing, some of the listing, some of the defining.... Colleges do that. We may be talking about how we need to teach the kids; that we need to do this inquiry...but I guarantee you that they [college professors] are not changing that style of presentation.... Then these college professors get these kids and they say, 'what do you mean you don't know the definition of such and such? Didn't your teacher in high school teach you anything?' And we get slammed again....

Sherry voiced long-term goals that included earning a Ph.D. and receiving the Presidential Award for Excellence in Science and Mathematics Teaching. She continued to work toward national certification during the summer simultaneously with her TSP lab work; a major undertaking requiring huge chunks of time for documenting activities and reflections about her teaching through narratives and videotapes. However, like most teachers who have dedicated their lives to their profession, Sherry was seeking recognition and direction for continued improvement. This, too, proved to be somewhat of a dilemma.

> Nothing like being suspicious, but I think they [the National Certification Committee] are looking for 'Are you up on the latest, on your latest educational fad in science [education]? Do you know your little terms about what your learners are?' You know, and I wonder what they're after. And yet, I'm supposed to be doing all of these inquiry style [lessons].... And what I really want them to do is give me some feedback. They don't do that, you know. They will point out weak areas [in the portfolio] but they don't offer guidance. Is this a test, or are they really trying to help teachers who want to learn?

Martha makes her home on 100 acres near the Cimarron River. This chunk of land provides her with not only a conventional picture of "home," but also with her own personal outdoor classroom. She explained that she perpetually seeks resources to help her identify the flora and fauna of the area and has shared this knowledge with her students as it has unfolded. She loves animals and has spent time at both small and large animal veterinary clinics observing and learning; her interests were reflected in her varied educational background. Although she is now a science teacher, Martha earned her B.S. degree in home economics education and community services with an option in vocational certification. Martha did not begin teaching immediately after earning her degree, but instead went on to enroll in more coursework in the sciences. She completed 35 hours of science coursework above her B.S. degree, including the majority of required coursework for pre-veterinarian students. When Martha began her career in education her duties included teaching home economics and coaching. She coached the girls' basketball team for two years and the team turned their losing streak around. Martha viewed this experience as another task that needed to get done.

> I never aspired to coach, although it did let me interact with students on a different level. Running laps can do wonders for discipline problems.... I can't say that I miss coaching at all. I have been offered the opportunity to get back into it and I declined.

Martha found that the home economics classroom did not offer her the challenge that she was looking for, a challenge that certainly accompanied the position that she held at the time of the study. Her teaching assignments ranged from general science at the eighth grade level to chemistry and AP Biology at the senior level. As a member of the faculty of a small rural school for eight years, she has assisted in serving a student population averaging 310, with the greatest diversity coming from socio-economic status rather than ethnicity. The majority of students in this school are white, but a small contingency of Native Americans, and a small group of Latino students adds an additional cultural dimension to the campus. (See Table 3, page 63 for demographic breakdown.)

Martha has continued to involve herself in learning activities through workshops in university settings designed specifically for teachers, and through presentations at zoos and museums aimed at the general public. Her involvement in professional development during previous summers has included chemistry and biology institutes at a major university. Long-term goals for Martha were to continue to improve her teaching, earn a

Master's degree, and develop exciting curricula that use the diverse plant and animal resources found in the state as a research base.

Martha's goals for participating in the TSP related directly to her students. She stated her belief that a need to include more experimentation and research opportunities for students exists, although she recognized that laboratory experiences are not always equated with true research.

> By far, the majority of training I have received as an educator involves lab work that follows a prescribed set of instructions, and arrives at an expected conclusion. This process does have merit as part of an overall program. It is not, however, satisfactory as the highest level of skills practiced. I need to offer my students the opportunity to generate questions and then follow an inquiry process to find answers and generate new information. In order for me to offer this to my students, I must gain a better understanding of the research process.

Martha is an activist. In the vernacular, she might be called "a mover and a shaker." The needs of her students were inextricably bound with her own, and once Martha identified a need she developed a practical plan to fulfill it. Accounts of her accomplishments at school, taken from letters of recommendation written by her principal, reinforced this image of Martha. She had submitted grant applications to the state to purchase books and equipment for AP classes resulting in an award of $15,000. Her small school had never before offered these advanced classes, but Martha felt that the needs of her students warranted the huge time commitment necessary to prepare and teach these courses. She recognized that AP Biology requires the inclusion of laboratory experiences, but voiced her opinion that these activities "do not have a strong research component" and saw the need to modify these experiences, as well as those in other courses, "to be even more challenging and motivating."

Martha's tendency to shake things up extended to her lab work during the summer as well. Once an idea was voiced, there was no backstroking with Martha; she immediately began to plan and move everyone into action.

> Martha: I will do this [current task], and then I will make the [nutrient agar] plates. That won't take me long. Do we need to do top agar? I've not done that.
>
> Robbie: Just follow the recipe you put on that sticky note. The only thing different is that you add your minerals after it cools, just like you would if you were adding an antibiotic.
>
> Martha: OK.... I'm going to make the R-top and LB....Now, back to that Ames test. You guys, if you have things at home...stuff for your garden or farming stuff that you want to test to see if they are mutagenic, just bring in a sample and I will test them. Then we can talk about how it might work in class.

Martha's enthusiasm was as high in regard to the mundane tasks of preparing media and sterilizing test tubes as it was in learning a new procedure or interpreting data. Her very presence in the lab seemed to energize everyone, as illustrated in the following comments.

> Julia: Martha provided a lot of enthusiasm...especially where computer technology was concerned. She very willingly shared labs and lessons that she felt were successful. She is an achiever and an encourager.
>
> Diane: I was in awe of Martha at first. She was filled with so many good ideas and was so adept at using the computer. I felt a little inadequate. That feeling did

not last for long though, as I learned that there were things that we were doing that she was just as unfamiliar with as the rest of us, and she was okay about not knowing.

Diane's pathway to teaching was a somewhat scenic route, with a variety of experiences along the way. She explained to me that even as a child she had been fascinated with science and by the time she entered junior high she had already decided that she wanted to become a cardiologist.

> I would read biographies of cardiologists like Christian Bernard, who did the first heart transplant, and I would picture myself repairing holes in infants' hearts and other congenital defects, and even doing heart transplants.

By the time she reached high school, however, Diane had decided that she could possibly be a nurse, work in a lab, or in some area of scientific research. When I inquired what prompted her to lose the vision of herself as a cardiologist—a career that had seemed so exciting to her—she related that it was really a matter of practicality, and of family traditions.

> I guess it [the decision not to pursue cardiology] would be my family's support—I didn't have any. I had zero.... They [my parents] thought that what I needed to do was find a husband and have a bunch of kids.... I was a girl and in my family there definitely were the gender stereotypes.... Money was needed for sending my brothers on missions [church related] and for paying for their educations.... They did what they could to raise me and get me out of the house. I graduated from high school.... I was 17....

Her search for independence led Diane to Yellowstone National Park, where she loved working outside among the "natural wonders." Then a move to Vail, Colorado, required that Diane change her line of work for a time. She worked first in quality control, then advanced to field work where she tested radar guns for police use, then finally moved into a mechanical drafting position within the same company. Although she was not well trained in this area, she was a quick study and learned a great deal from the engineers with whom she worked. After approximately a year at this job, Diane left Colorado for the state where she now resides, and soon became pregnant with her first child. She worked as a waitress for a short time, but shortly determined that she must work at home for health reasons. She cared for two small children while she awaited the birth of her own child, and loved it. The birth of a second child completed her family, and it was not until both children were in school that Diane finally took the opportunity to attend college.

Eight years after graduating from high school Diane began her college education. She was a very successful student and completed her B.S. degree with honors (biology major and a chemistry minor), from a small college in the southwestern portion of a state in the Midwest.

Diane has taught for five years in a high school with a student population averaging just under 1,100 for grades 10 through 12. The school district serves dependents from a large military base in the area, which contributed to the diversity of the student population. (See table 3, pg. 63.) Diane's teaching duties were limited to teaching anatomy and physiology, but she hoped to expand the curriculum to include genetics and microbiology. Five years was also the total of her teaching experience. This coupled with the fact that she taught only one subject, identified Diane as a novice compared to the other teacher participants, even though she was well beyond the induction period. Diane seems to be a very dedicated teacher; she stated that she spends a great deal of time doing extra things with and for her students. Her involvement with students extended beyond the classroom through volunteer work as a coach for cross-country running and sponsor for the honor society. Student participation in these programs increased after Diane became involved with them, to the delight of her principal.

Diane's reason for participating in the TSP involved fulfilling the needs of her students, as she perceived them. Teaching human anatomy and physiology (in isolation from other organisms) at the high school level has become controversial and is not supported by the National Science Education Standards (NRC, 1996). Physiology cannot be thoroughly understood without knowledge of biochemistry, which students are not likely to have at the junior or senior level of high school. In a typical anatomy class "learning" is synonymous with memorization; recalling the names, locations, and functions of body parts and their structural components is a major goal of the course. The model of learning which prioritizes the recall of factual information may be called traditional, meaning a transmissive behaviorist model; it may make use of diagrams, labeling exercises, and color templates as teaching aids, but the conveyance of facts is the essence. Used exclusively, these are practices reflecting a mindset that Philip declares as "anti-science!"

Diane voiced her belief that she is like many of her students. She described herself as "a visual learner," but said that she also learns quickly when "hands-on" activities are available. Each year Diane has provided cats for dissection in order to incorporate active involvement by her students as they learned about the mammalian body, but even dissection activities are fact-driven. Diane believed that she made consistent attempts to create meaningful experiences for her students, although found designing such experiences to be highly challenging; she expressed feelings of inadequacy. Both the ideas she expressed and the language she chose as her means of expression reflect the transmissive model of teaching that has become her mainstay.

> I want them [students] to learn to use and appreciate the scientific method to formulate hypotheses, design and conduct experiments, record and interpret data, and form conclusions. I need training on how to successfully implement this type of teaching into the classroom.

Diane involved herself in learning activities through her attendance at science workshops and seminars. In the past she attended seminars on epilepsy, breast cancer, AIDS, heart disease, and diabetes. She also took advantage of Project Wild workshops at a wildlife refuge close to her home. Diane reported a long-term goal of pursuing a graduate degree, perhaps "in a biology specialty like human physiology."

Diane's project, like Julia's, related to a body of water. The high school where she was employed at the time of the study adopted a nearby lake as a field site. Each teacher in the high school was involved with projects learning about and reporting on the biotic and abiotic factors in the area. Diane was the only teacher who had not participated as yet, so she was delighted to have an idea for a valuable contribution. She examined a variety of environmental samples (soil, water, and manure) to learn the procedures to use the following school year when she would collect similar samples from different animals at the lake. Initial tests compared the quantity and type of antibiotic-resistant organisms in each sample. Further experiments involved the extraction of a plasmid from several of the samples, transformation of a laboratory host strain of bacteria using one of the smaller extracted environmental plasmids, and gel electrophoresis to determine the numbers and relative sizes of the plasmids. Diane also engaged in hunting for bacterial viruses and bactericidal proteins, called colicins, from these natural sources. She produced lysates (liquid cultures) of bacteriophages in high concentration, and with the help of scientific staff successfully obtained electron micrographs of the phages she isolated.

Diane is a <u>scholar</u> in a very traditional sense of the word. A mindset that stresses the importance of facts is compatible with teaching anatomy and physiology; during the summer activity in the laboratory it became apparent that Diane wants to know the facts.

> Diane: [I must]...outline everything...keep it all straight...study on my own...refresh my memory and learn the more technical aspects. If I had known what I was going to work on, I would have studied before I came.
>
> Sherry: I think she reminds me probably most of a student. You know, a real motivated student, the kind you wish you had in class all the time, real excited about doing all of the things. I think she was just real excited...just real awed....
>
> Philip: She was, like other teachers, reticent, awed by this big research institution, all this equipment.... My response to her was...somebody should have had this young woman when she was an undergraduate in her introductory biology, a lab course, ...because she has that enthusiasm.

Diane worked very hard on her own project and utilized the library to help find information on the other projects. Diane did not feel comfortable with the chaos of not knowing and attempted to impose order onto her activities. She was conspicuously silent during discourses involving the planning of experiments and interpretation of findings, but was quick to interject fragments of anatomy and physiology facts as opportunities arose in general conversation. One such opportunity presented itself as Julia and Diane were anticipating the second of three injections in the hepatitis series of vaccinations made available to summer scholars who have not been previously immunized.

Julia: It's time to go get our shots.

Diane: Is it intramuscular? Or like a tetanus?

Julia: I just know I'm really sore in my arm.

Diane: Well, is it subcutaneous, like in the fat part of your arm, or is it in your deltoid?

Julia: I think it's in the deltoid.

Diane: Those hurt.

Julia: Yes. It does.

Diane: I know that on the first one my arm was so sore that I couldn't hold this pipette up.

Julia: It may not hurt by this afternoon.

Diane: Robbie, have you had your hepatitis B?

Robbie: I need to have a titer done.

Diane: Oh, so you've had it in the past.

Robbie: Yeah. But I can't remember, honestly, whether I finished the series or not

Diane: Oh, I see.

Martha: My girls got sick and didn't get to finish theirs. They wouldn't give it to them when they were sick.

Robbie: So, do they have to start all over?

Martha: Yes, and I'm sure dreading it. My younger daughter had a pretty good reaction to the original one. And so she's really dreading it.

Robbie: I'll bet.

Diane: What kind of reaction did she have?

Martha: She...we got to the part...they kept her the waiting time...[her daughter fainted].

Diane: Oh yeah! You told me about that.

Martha: Well, she went down.

Diane: I remember that now.

Martha: And, she has a real high pain tolerance. She never cried when they gave her her shots...any of her immunizations.... Both my girls have had stitches and they just sat there and watched them stitch them up. The pediatrician said that both of them have a very high tolerance for pain.

Diane: Girls have more of a high tolerance. You know girls require more anesthesia to go under than a boy, and boys require more analgesics, or pain relievers, than girls.

When Diane did enter the discourse involving the projects it was not in the planning or analyzing. Rather it was when she found canons from trusted volumes to provide safe borders for her statements. For her, the facts and the history, the end result of science, were the most important. Process was secondary.

Philip: So, if that's [Julia's purple bacterium] fluorescent...across the top maybe it requires oxygen, too....

Diane: We looked this up and it says that it fluoresces in the presence of tryptone.

Philip: Tryptone?

Martha: No. What it said was...

Diane: Yes. Tryptone. And it said that it turns blood agar clear.

Martha: It also said that it's pathogenic.

Diane: It is only pathogenic to immunosuppressed people.

Philip: Well, we don't know that that's what it is for sure.

Martha: No. We don't.

Diane: Oh. Well, we should have checked those books out.

Table 2: Education and Background Information

TEACHER	TEACHING POSITION	YEARS TEACHING	SCHEDULE TYPE	EDUCATION AND/OR BACKGROUND
Sherry	Biology I Honors; Biology I (grade 10)	15 years	4 X 4 Block: 80 minutes daily for one semester	B.S./ Major: Biological Science; M.S./Major: Curriculum and Instruction Education
Julia	Chemistry; Biology I; Academic Enrichment; Anatomy & Physiology; French I & II (grades 9-12)	15 years	Currently on 4 X 4 Block; Plan to revert to traditional schedule for the next school year)	B.A./Major: French B.S./Major: Biology M.S./ Biology (Research)
Diane	Anatomy & Physiology (Grades 10-12)	5 years	4 X 4 Block	B.S. /Major: Biology Minor: chemistry
Martha	Chemistry I & II; Physical Science; General Science; AP Biology (grades 8-12)	12 years	Traditional: 45 minutes daily for entire academic year	B.S. /Major: Home Ec.Ed. and Community Services; Vocational Certification; 35 additional science hours
Robbie	Life, Earth, & Physical Science; Biology; Chemistry; Physics Anatomy & Physiology (Grades 7-12)	9 years	Traditional	B.S. /Major: Microbiology Minor: Chemistry M.Ed./ concentration in Natural Sciences; Ph.D. Candidate, Science Education
Robbie	Biology I Honors; AP Biology; Anatomy & Physiology; Integrated Biology/Chemistry	3 years	4 X 4 Block	As above

Table 3: School Demographics

School Demographics	Sherry	Julia	Diane	Martha	Robbie	Robbie
Student Population	1250	300	1087	310	300	800
African American	15.5%	0.0%	32.9%	0.0%	0.0%	13.1%
Latino	18.6%	2.0%	9.8%	3.5%	2.0%	19.7%
Native American	1.2%	4.0%	4.3%	15.0%	1.0%	1.9%
Asian	2.2%	0.0%	2.8%	0.0%	0.0%	2.0%
White	62.5%	94.0%	51.2%	81.5%	97.0%	63.4%

CHAPTER IV

FINDINGS: DRAWING LINES

Introduction

Discourse, in modern times, has come to simply mean verbal expression. How tragic that our era has sought to represent weighty words with over-simplified definitions. In earlier times, when words were carefully crafted to stimulate imaginative pictures, discourse represented a swiftly moving process or power of reasoning (Costello, 1997); a vision of thought coursing through the mind that paralleled a vision of blood coursing through veins. I stand on this earlier definition of discourse to examine participants' conversations and interviews as artifacts of thought. There is artwork among these artifacts; lines drawn as people sought to communicate; lines separating objects and interactions into categories (Becker, 1998). In this chapter I have presented those categories, developed as my own theoretical sensitivity functioned as an overlay, making the lines visible among participants' words as they engaged in discourses during and about their interaction in the TSP.

Defining Partnerships

The data that defined partnerships were collected through personal communications (conversations, e-mail, and letters), field notes, and semi-structured interviews accompanied by their audiotapes and their transcripts, and field notes. Excerpts from these sources follow short explanations of my perceptions of lines drawn.

From the very beginning of the summer I saw lines among Philip's words and actions that encouraged relationship building. These lines defined a configuration that is natural to science: a grouping of the teachers together to foster a sense of community where teachers felt safe to engage in experimental risk-taking and free-flowing conversations. He explained why this was so important to him.

> It's that kind of peer interaction that actually formed the basis of science. You don't practice science in a tower all by yourself...Science is a very social activity, very community-oriented. It's extremely important to have contact every day all day with your peers. And so putting these teachers together has been wonderful. The total of what they can accomplish together is much greater than what they could accomplish separately because of these interactions. Of all of the things I've learned, that's one of the most important. And there's still a persistent sentiment out there that the way to do this [get scientists involved in professional development for teachers] is to park a teacher with a scientist and they go out and do these experiments together, and I just don't think that's optimal. What teachers tell me their needs are to have experiences that 'fit' more closely with the needs of their students.

The value of working together, rather than isolated in separate laboratories, was immediately clear to the teachers. Even though Martha had more science background than the average high school science teacher she was apprehensive and unsure of her qualifications for participating in the TSP. However, once she learned that she would be working with other teachers she immediately increased her comfort level. This allowed her to take intellectual and emotional risks in the laboratory and as a result she gained confidence. Smiling warmly and tilting her head to one side, Martha explained that knowing that she would have other teachers as colleagues for the summer vastly changed her attitude and approach to the laboratory experiences.

> Teachers won't let each other fall. And, if somebody does, they'll pick you up. It's just in our nature to do that. So the minute I found out that we'd all be working together I knew I'd be all right.

At school, teachers feel isolated so they need little or no prompting to share school concerns, classroom strategies, and favorite activities when they are together. In fact, teachers taking part in this study stated that opportunities for sharing are prime reasons for attending workshops and participating in summer programs. I asked Sherry about the summers she had spent in other labs and, after taking only a moment to reflect, she told me what a great time she had. Even though she had been the only teacher in the lab, she found it rewarding to be immersed in a scientific setting. But, Sherry also found that there is a powerful difference when teachers interact. "Working in a lab is kind of--you hate to say it but, when you're at the low end of it--it is routine." She picked up a micropipette and delivered imaginary liquid into imaginary test tubes in a repetitive motion as she continued.

> You're doing the same process, and they'd [full-time researchers] get kind of tired of doing that kind of stuff too, but there was just that interest there...it was neat because...I was in with those people who love science.

At this point Sherry returned the pipette to its rack on the benchtop. I perceived this as a signal that moved the context of the conversation from "those other labs" to the TSP.

> But with the teachers, we were looking at 'How can we do this? How can we use this in our class? How can we implement some of these processes? How can we implement this idea into a class?' And, I didn't really think that much about doing

that [asking how the experience could influence the classroom] when I was in the other labs. We [teachers] learned off of each other about how we did other things that had nothing to do with what we were doing in the lab.

I was accepted within this "teacher group" because of my teaching experience; Philip's inclusion was not immediate, but rather earned as his interactions with the teachers shaped their images of him in such a way that he could be mentally brought inside the group as "one of us." (Philip's teacher image was presented in Chapter III.)

Within the teacher group that grew to include all six of us, subgroups of more closely defined relationships formed as work on the molecular biology projects progressed. The lines that I visualized for each participant were unique. Explanations for the placements of such lines follow: guesswork given credence because of my theoretical sensitivity and participant validation.

One might think that relationships would form most easily between individuals having common educational backgrounds, teaching experiences, or personalities. While I found that one or all of these could be contributing factors for the determination of relationship lines, I saw the boldest lines flow from common cognitive struggles. Individuals working closely to solve specific problems and design new questions for further research built stronger relationships than those working together on occasional problems and protocols.

Diane and Julia were personalities of the same type. Although I have described Diane as a "traditional scholar" and Julia as an "analyst", both chose their words carefully and meticulously, and I could envision Diane becoming more analytical with additional years of experience. They spent time together outside of the laboratory, and shared scholarly and analytical experiences. Diane's lines of relationship originated from those experiences. With a serious expression and a soft intenseness in her voice, Diane showed me several pages of notes from the front of her notebook, offered as tangible proof of what she told me.

> The first week or two we [Julia and Diane] worked together every evening for several hours at a time trying to figure out just exactly what we were doing.... We would outline everything we were doing to keep it all straight.

Julia's relationship line simultaneously connected Martha to her and separated Sherry and Diane from her. The placement of this line was based on school size and her perception of school needs. Julia explained that large schools and small ones have unique problems, and teaching methods are "necessarily different." Counting on her fingers for emphasis, Julia talked about her duties at school.

> Six different preparations.... Every year I teach Biology I, Chemistry I, and French, [and I] alternate [teaching] physics with anatomy and physiology.... I teach Zoo some years and teach general or physical science some years...and then I have an academic enrichment class, sort of like an honors, where I help the students work for competitions, on the quiz bowl team.... They work on ACT scores.... It's not just me--that's just part of small schools. Martha is the same way. She has to teach junior high and she teaches high school.... So, we have much more in common...you can't have more than one section. What are you going to do, have three sections and put one student in each section?

I did not see a common line among Martha's words. Instead, they delineated a relationship constructed through daily interactions with Sherry. With a half-smile that said more than her words, Martha explained the value of working with Sherry.

> I really enjoyed working with Sherry. She and I approach things in very different ways, and our thinking was often in opposite ways. I felt that this was very good...an excellent opportunity...to see how someone else approaches and solves problems.

Both of these women have strong, pragmatic personalities and neither separated their own learning goals from that of their students. As Philip grabbed his coffee cup and sat down to chat with me, I saw a line rapidly appearing among his words--a line that categorized Sherry and Martha as belonging to a specific type.

> This is another phenotype--Sherry and Martha. These are real pros. They've been teaching a long time.... Both of them have the quality that you don't always find in the teachers that come here in the summer, that to me is really very important.... [Sherry and Martha are] Quite remarkable; [Sherry and Martha are] very, very critical. By that I don't mean <u>criticize</u>. I mean that what you told them was filtered through a critical intelligence. These were people whose specific purpose for coming here was to be better teachers. And to do that they wanted to be able to present the things that they thought were important in ways that were better for their students, things that were illuminating and very practical....

Sherry's words traced over the same line that I saw as Martha's relationship line, and further defined the thick connection between them. The twinkle in her eye and her slight chuckle characterized this relationship even more than her words.

> I mean, we [Sherry and Martha] interacted. We worked with each other and worked off of each other to try and figure out.... I still, I don't remember what it was, but I think we argued on that for days.... It was fun.

This arguing that Sherry mentioned was a process that seemed to delight Philip. I queried him and in his answer found lines connecting the outward manifestation of critical discourse with intellectual exchange and pleasure; outcomes of successful relationships and characteristic of science itself.

> When I hear two teachers arguing with each other, it doesn't matter to me whether they're arguing about the biology they're doing or arguing about their own profession. Then I know there is intellectual stimulation and exchange—always--that has to be exciting. Even if they don't change anything, there's a new perspective that wasn't there before. An intellectual exchange of that kind, with a colleague or a peer--it's an addiction. It's fun, it's always fun.

Erudition: Inside the Science

In this section I have attempted to provide a series of animated vignettes representative of the two months in the laboratory: scenes sketched through progressive discourses guided by Philip. As I saw him carry out this invisible artwork his words joined the tangible artifacts of molecular biology that mediated learning this science; its practice, principles, and nature. All of the projects were multifaceted and much too involved to be entirely represented here. I chose to present portions of discourses involving bacterial viruses for this section because each of the teachers worked with these bacteriophages at some point in their investigations. This common component seemed the simplest way to bring the reader inside the science. The sources of data for this section were audiotapes and their accompanying transcripts coupled with my impressions in the form of field notes. These were records of daily interactions rather than responses to pre-defined questions. I have presented this section as a series of vignettes; each vignette is prefaced with information that sets the stage for the scene that follows it. In these prefaces, setting the stage often required an explanation of events that had transpired between scenes, events that left artifacts behind that led to the event depicted in the vignette to follow. It was my intent to describe the laboratory setting in a way that reaches beyond the physical, to present the image of the laboratory and its artifacts almost "as if" the laboratory itself were another participant. Indeed, it is a dynamic setting where pieces of equipment are frequently described by researchers in personal and intimate ways, ways that view the equipment as almost an extension of the researcher. I chose an active format for the scenes and narrative texts that accompany them for two main reasons. First, I wished to preserve the dynamic nature of the interactions so that the reader experiences them. Second, because this science is often negotiated through scraps of conversation and molecular biology jargon, I wished to provide clarification of the content and contexts of the discourses. The lines of discourse are intermingled with explanations for the line drawing activity as documented in my field notes and written into the narrative text so as to separate data from interpretation; a type of running commentary as I step in and out of the scenes in my dual role of participant observer. I have included short clarifications of terms or actions as bracketed inserts to the records of discourses. I have given examples of the concepts and procedures pertinent to these discourses in Table 4 (page 113) for the reader who wishes to peruse the specific scientific content.

Introduction to the Vignettes

Early in the summer Philip's interactions with the teachers were somewhat didactic; he packaged information and protocols in a way that could be easily used in formulating research questions or projects. However, as each participant began her own line of investigation, becoming more comfortable with her surroundings in the process, his interactions and instructional styles oscillated among didactic, Socratic, and inquiry as appropriate for the situation. The durations of discourses with Philip decreased as time passed while discourses among the teachers increased. As teachers began to function autonomously, thoroughly engaged in designing ways to pursue their investigations, they were clearly in the throes of discovery.

Initially the group discussed the cycle through which viruses infect cells, replicate, and are released to infect other cells. Philip asked questions to determine the general level of knowledge on the topic and we all agreed that we wanted to learn more about what goes on inside of cells once viruses infect them.

Scene I: Beginnings

The lab is neat and tidy. Sterile pipettes in metal canisters are in rows at each workstation ready for use in measuring a variety of liquids. Unopened boxes of test tubes and micropipette tips occupy shelves above the newly washed benchtops. Water baths, very recently activated, are just beginning to warm freshly drawn water, but the shaking incubator is still and quiet. We six are sitting, huddled in the intimate space between two lab benches, thinking aloud. Among this mental chatter I perceive a line between two possible assumptions, or alternative hypotheses. This line will help generate questions that will drive experiments.

Philip: You can assume that a cell already contains all the things that go into making the viral coat or that they are synthesized at the direction of viral genes after infection. It's got to be one or the other. So, what happens to viral replication if you add to the cells a specific inhibitor of protein synthesis? Perhaps a substance like chloramphenicol. Do you still get protein synthesis? Or, do you have to have ongoing protein synthesis while the virus is replicating?

Julia: And wouldn't the chloramphenicol inhibit the cell reproduction as well?

Within Julia's question I see a statement. By coupling information about what she knows (that anything inhibiting protein synthesis will have an effect on the bacterial cell) with a question (whether the cell must reproduce simultaneously with the virus infecting it), she is defining the limits of her knowledge and directing the discourse to satisfy her wondering. Philip picks up the cue and offers Julia reinforcement for her statement while emphasizing that she has not addressed the specific question being discussed at the moment. I see his words becoming a line--a line pointing to a way to begin answering the question.

Philip: Yes, of course. It would inhibit protein synthesis in the cell, but the question that we're asking is whether the structural components of the viral coat are already in the cell at the time of infection or whether these components have to be made de novo after infection at the time of introduction of viral genes. It's actually kind of an important question when you get down to what a virus actually is. And, it's very simple to answer that question with a simple plaque assay....

End: Scene 1

The plaque assay is a technically simple molecular biology tool. Making slight variations in the procedure (using different host strains of bacteria, incubating at different temperatures, or using different concentrations of virus) provides one with the flexibility to ask an infinite number of questions related to biological systems and to gather both qualitative and quantitative data. A plaque assay provides both empirical and inferential evidence; direct observation of a zone of clearing [plaque] in a population of host bacterial cells spread evenly on the surface of the agar plate [lawn] leads to the inference that causative agents exist within that clear zone. Similarly, direct observations of plaques that have different sizes, shapes, or varying degrees of clarity lead to the inference that different causative agents exist in each plaque. (See Figure 3, page 114.)

Teachers perform plaque assays, excise the clear areas [plugs], treat the excised plugs with chloroform to kill any host bacteria picked up from the plates, and then repeat the plaque assays.

<u>Scene II: Virus Hunting</u>

Racks of test tubes fresh from the autoclave are alongside petri dishes that show signs of scientific molestation: holes where plugs of agar were removed from them. Stacks of freshly poured agar plates, some red and some yellow, are found at the ends of lab benches; soon they will be bagged and carted to the cold room. Martha cradles several petri plates as she removes them from the warmth of the incubator and carries them over to the benchtop. Sherry and Philip begin to examine the plates individually, then Philip puts the plate he has been examining back on the benchtop and waves his hand in a gesture toward the entire set of plates.

Philip: What this says is that all plaques have lots and lots of plaque forming units [entities that have caused the plaques: AKA virus particles, bacteriophages, or pfus] in them and those plaque forming units are separable. If you take a plaque out, chloroform it, vortex it, and plate it, what happens?

Sherry: You get a whole bunch of other pfus.

Philip: Right. So, this is an interesting fact. Delbruck once asked Albert Einstein whether, in Einstein's view, this experiment proved that there was a particulate character to a pfu, if there was something, some entity? And Einstein thought about it for a while and said 'Yes. This seems to be the case.'

In essence, Philip is saying "Don't just take my word for it. Delbruck, one of the founders of molecular biology, asked an authority that I know you recognize, and now you can see for yourself." He goes on to masterfully summarize the findings in succinct statements; simple lines that add to the clarity of the principle.

Philip: So, a plaque consists of pfus and therefore must involve massive amounts of replication. That's one thing, one important thing, that this experiment says. The other thing this experiment says is that a plaque can contain any number of different numbers of pfus. You have some as low as a few hundred thousand and you have some as high as tens of billions....

Martha: But is a clear zone always a pfu?

Philip: This doesn't have to be true. [A plaque does not have to consist of plaque forming units, or entities.] It may seem to you that of course it does. But it doesn't have to be true. What were you thinking?

Martha: Antibiotics, maybe?

Sherry: I've seen clear zones around those antibiotic discs.

Sherry reveals knowledge gained from prior experience that she views as relevant and Philip validates Sherry's prior experience with his response. In addition, he extends the line of discussion to encourage a deeper understanding. He is essentially saying "Yes. Your experience with antibiotics is relevant, as it gave you a similar initial finding, but that protein antibiotic can be differentiated from this phage through subsequent platings."

> Philip: Yes...Some bacteria secrete proteins that have the property of killing other bacteria. [Antibiotics are a class of proteins.] And if you drop a colicin-producing bacterium on a lawn of cells like this, you're going to get a plaque when colicin-producing bacteria produce colicins, the colicin proteins will diffuse out and kill the sensitive bacteria and make a plaque.... But, if you now pick that plaque [excise the clear area and lift it from the plate] and kill the bacteria with chloroform and ask 'Can you reproduce this plaque?' The answer is 'No, you can't.' It is a protein, and when the protein is gone, it's gone and there is <u>no replication</u> involved. So, this may seem trivial, but it's not, because the alternative outcome not only can be imagined but can be demonstrated experimentally. And it <u>was</u>, in the 1930's, with the discovery of these colicin-producing bacteria.

<u>End: Scene II</u>

Diane engages in some virus hunting activities by chloroform treating small aliquots of horse, cow, and chicken manure as well as several samples that Julia brought from the creek close to her cabin. After treatment, Diane plates the samples on different bacterial strains isolated from the manure samples and also plates the creek samples on a lab strain of E. coli. She leaves some samples untreated to examine for colicin activity and plates them on the same bacterial strains that she uses for the treated samples.

Scene III: Viruses or Natural Toxins?

The scents of yeast and amino acids mingle with the smell of agar melting in a bath of water inside the microwave. At the end of the lab flasks of broth that nourish bacterial cultures circulate rapidly on the shaking incubator. The "whoosh" of air flow ceases as Julia turns the fume hood off to examine purple pigments separated by solvents. As Philip arrives in the lab he asks, "What's up?" This has become a morning ritual of sorts. It generally means, "tell me whatever you want to." Now (about the third week into the summer's activities) the response frequently includes statements that have little to do with the biology, but rather about families, children, school frustrations and successes, or funny stories. However, Diane is anxious to share the results of her phage hunt and is the first one to respond and capture his attention. She begins to show Philip the plates right away. "Those are with chloroform," she says as she pushes a stack of petri plates toward Philip. She has rapidly picked up on this way that researchers have of giving others permission to examine their experiments. By telling him that they are chloroform treated Diane is letting Philip know that she is looking for clearing due to viral activity.

Philip: So you're looking for phage here? [This question is really an acknowledgement that this is a virus hunt, and signals that he understands what she is telling him.]

Diane: Yes. And, the ones up above there are the same things without chloroform.

Diane means that she has set up the experiment in a way that will provide the possibility of finding a substance, like a colicin, produced by bacteria that, like a phage, is made apparent by a clearing, or killing, of the plating bacteria. She is essentially trying to find cases to fit both hypotheses generated about agents that cause plaques. Philip shows genuine excitement as he says "Whoa! What have we here?" and points to clear killing zones on Diane's plates. Although he has seen this plaque phenomenon innumerable times, sharing the excitement of Diane's "new" discovery recaptures some of the stirrings of the first time that he discovered it for himself.

Robbie: That's on K12, looking for phage. [K12 identifies the lab strain of E. coli that was used for plating bacteria.]

Philip: Well, you've got them.

Diane: Uh huh. I see them!

Philip's smile and the slight nod of his head confirm the discovery and reveal his pleasure at the same time. Diane thought that she had found phages, but wasn't sure. Now that Philip agrees with her she allows her excitement to show. However, the excitement in Diane's voice seems to turn toward uncertainty bordering on disappointment as Philip makes an additional observation.

Philip: Wait a minute. This is chloroformed. How come this stuff is growing in the middle? [There is unexpected bacterial growth inside the clear zone.]

Diane: Well, see. That's what I was wondering.

Philip: You know what it might be, actually? Spores.

As Philip offers this guess as to the reason for what has shown up on the plates he also lets Diane know that one doesn't have to have all the "right" answers to proceed with science. In fact, Sir Francis Crick himself said that the only way to proceed was to be bold enough to make oversimple hypotheses (Judson, 1996). Philip is basically saying, "This is one possibility, but it might not be the only one. It's okay to accept a possible explanation, especially if it is not essential to the questioning you are pursuing."

Robbie: Oh. Yeah, those samples have been around awhile.

Philip: Spores won't be killed by chloroform. You put them down on the plate and they're in fat city cause they're sitting in the middle of all these nutrients. So, they'll just germinate and start growing. Well...It is still possible that these are colicins, produced by spore-formers, but I really think they are virus.

Philip examines the plates for another moment, and then puts them down on the benchtop before continuing with the next order of business—which is making certain that he understands the conditions that produced the plaques being observed. His modus operandi is to make a statement then immediately begin to examine it for validity. He makes certain that he understands the source and circumstances under which the experiment was set up through a series of questions and answers.

Philip: Now make sure I understand this. So this is, the plating bacteria, is an isolate derived from horse and you're spotting onto it chloroform-treated samples?

Diane: Yes.

Philip: So, these viruses are actually rather specific.

Philip: Did you test only one E. coli strain from the lab? Just K12, and all these others are different? This is an enteric isolate from a horse. [Pointing to a separate group of plates] What are these guys? [Pointing to another stack of agar plates.]

Diane: This one is chicken. And this is my #4 from the dairy cow.

Diane refers to her lab notebook. I see that it is important that she is certain of the source before she confirms it. As she makes the confirmation, Diane again consults her notebook and this time is looking to me for agreement as well. She can feel more sure of herself if she does not stand alone. Philip is very pleased that Diane has found substances from environmental sources that cause clear killing zones within a lawn of bacteria. This is just what she wants to do as her part of the school's lake project.

Philip: So, this thing was <u>in fact</u> a natural isolate. What were the two samples that had phage in them?

Diane: It was the horse--and that was the garden soil.

Philip: So now if your students were to go out and collect fresh samples from around the lake, barnyards, or wherever they get them, that's how you go about isolating stuff. And, you know if you <u>were</u> to see something like a colicin, what you would look for is something that would give you a plaque-type response unchloroformed, but nothing when it's treated with chloroform.... If the plaque-forming ability persists in a chloroformed sample, probably it is a virus. [Philip picks up a plate that is approximately three-fourths cleared and points to it.] Now that's a ferocious virus! Probably there's a good titer [a large number of pfu/ml]. What we're going to do next is pull those plugs out, put them in a milliliter of broth, vortex, chloroform again, take the supernatant, and titer [determine the concentration of how many pfus/milliliter of liquid].... You've already identified a titering strain. [A strain of bacteria that is sensitive to the isolated phage.] It's E. coli K12. So, what you're looking for is how many and what kind, both quantitative and qualitative.... Take pictures of the plaques. If you can get lysates [a concentration of the phages in liquid] you can titer them. In terms of just going out and surveying the kinds of microbes and viruses, this is really nice....

End: Scene III

A trick used by scientists who intend to find out about how something works is to break it. The reasoning is along the lines of the following examples. If one breaks the chain on a bicycle one is likely to find out how important the chain is to the bicycle system. Likewise if one removes an electronic chip from a PC, one is likely to find out the chip's role in the overall operation of the machine. Scientists involved with experimental genetics use this trick with model organisms, too. However, breaking the machinery of an organism requires different tools than breaking parts of a bicycle or a computer. Using chemical tools called mutagens (substances that induce changes in a model organism's genetics), molecular biologists obtain mutants: organisms or entities with altered genotypes [genetic codes that are present in the DNA] that can be inferred from observable phenotypes [characteristics that are detectible]. Inducing somewhat random mutations, selecting mutants on the basis of altered and specific attributes or characteristics, then using those mutants as tools for digging out answers to biological questions are activities that largely define the work of molecular biologists.

Martha and Sherry first treat a lysate of a T4 bacteriophage with a "mild" mutagen (2-amino-purine) that induces point mutations [changes in single nitrogen bases in the organism's DNA]. The ability to form plaques on strains B and K12 E. coli but not on the K12 lambda strain is characteristic of the R2 mutants they want to select. In addition, the plaque morphology is different on each of the remaining two strains that can serve as host cells. Next, they select R2 mutant phage through a series of platings on the three different strains of bacteria. Finally, they take a single plaque, chloroform-purify, and re-plate it.

Scene IV: Researchers' "Tricks"

Racks of warm test tubes with black-striped autoclave tape and newly sterilized pipette tips are still on the metal cart used to deliver them from the autoclave room. The lab is filled with the smells of working experiments: agar, broth, bacteria, and ethanol. (Philip has often said, "You know you've been doing this too long when the smell of rapidly growing E. coli is a good thing.") Populations of bacteria swim in flasks of nutrient broth labeled with various dates and names. Petri plates cover most of the benchtop space, some with "happy faces" drawn on them. The mutant hunt is successful!

> Philip: If you pull the plaque out and measure how many of those [points to the plaques and refers to the entities that caused them] will be R2 mutants, they'll all be R2 mutants. So not only is this thing replicating, but it also has an element of inheritability. This is not just a plaque assay. You can really ask some very profound questions here. That's why we do this rather than some other procedure.

The "we" refers to scientists working in genetics. The implication is that the teachers working on this project will be doing what "we" scientists do and not only collect numbers of plaques to put in a data table—like too many "school science labs" do--because they are asking a profound question. Likening them to full-time researchers helps to build the partnering relationship while simultaneously learning the science. Philip goes on to emphasize the power of this experiment to demonstrate an essential biological principle. Underlying this emphasis is a desire that teachers might use this experiment to lead their students to personal understanding in the same way that the teachers themselves are constructing their own understanding.

Philip: It is the simplest system that provides evidence of inheritability. The essence of all biological systems is contained right in those plaques. The ability to replicate and the ability to replicate faithfully is evidenced right here.

Martha: I have a question. I've got bacteria spread out over here. I've got virus spread out over here. Now, each one of the clear places represents a place where a virus infected a bacterial cell. We would not be able to see just one virus infecting one cell, right? What happened is that [one] virus replicated and the viruses that were produced from that replication went out and infected more cells. Or, got out and ate those other bacteria.

I see a line separating what Martha really knows from what she thinks she knows, but the line is tentative. Voicing her understanding in what seems to be a repetition of what has just been negotiated will allow that line to be easily reinforced if she is correct and erased or adjusted to be more correct if she is in error. At the same time I see a line that connects Martha's own curiosity to questions that she anticipates from students, based on many years of experience. These lines connecting Martha with her students are common in her discourses.

Philip: Yes, that's why they are called bacteriophages. The name means to eat and that's exactly what they do. They eat the bacteria.

Martha: Oh, that's good! My question, and this is what the kids are going to ask me--and I'm kind of wondering myself, is why they do not just keep eating? Or, why is that not clear by now?

Philip: So what you want to know is why the whole plate's not clear [he seeks affirmation that he has understood Martha's question clearly].

Martha: Right! If I put it in the incubator and just left it, would the whole plate just be clear?

Philip: That depends on the virus.

This line places Martha's question in a specific context, and shows the need to know more specific details before an absolute answer can be given. As Philip explains that some viruses will "just obliterate anything on the plate--and you really don't want those in your lab," we all laugh. We know that there is no real danger of human infection because these viruses are specific to bacterial cells, but such phage activity would "play havoc" with student experiments. Small skits depicting students' ideas of sterile technique have been prevalent throughout the experiments and recalling them adds to our mirth.

Martha: Then they would, right? [The viruses would cause the whole plate to be cleared.]

Philip: The reason that a plaque size is limited, as I mentioned before, is that some of the cells almost die. They're overcrowded, they've got nowhere to go; they're running out of nutrients. They're not really dead but they're not happy cells. Therefore, the virus just can't replicate. In fact, the cells aren't even replicating. [Philip offers explanations for the negative case—a case when the plate would not be completely clear—to help Martha visualize what is happening as the cells and virus particles interact. An unspoken direction in his explanation is "If you want to, try it and see." I love this attitude!] Now, you can increase the size of these plaques. And, the way that you do that is just put a higher amount of virus on the plate. And, the virus will simply just diffuse out.

Martha: So, what they're doing is, since this is three-dimensional, they're really going out in all directions. They're not just diffusing out in a linear manner.

Martha is formulating a visual mental model. She raises her hands and extends her fingers in all directions as though to literally draw her model in the air. As Philip picks up one of the plates and holds it up to the light, he directs Martha's attention back to the original observation.

Philip: Here's one. See this plate?

Martha: Yes, but I thought that was just where the bacteria had been washed off by the condensation falling from the lid of the plate while it was in the incubator.

What she's saying here is "Yes. I saw that but I also formulated an interpretation for my observation that told me it wasn't important." Philip addresses Martha's interpretation by using it to preface another explanation, a way of giving her words value and strengthening the climate of partnership. Then, he extends the learning experience to indicate the importance of separating empirical data and inference; not recording the observation because of an erroneous inference can cause one to miss something. Finally, he gives a gentle instruction that says, 'If you improve your technique your data will be better.'

Philip: The bacteria have been washed, but they've been washed over by the virus. It's because they've infected physiologically active cells. So as the cells grow the bacteria are able to replicate more efficiently. Now if you get the plate wet enough it will cream everything. The ability to see a plaque is often a consequence of <u>how</u> you do the assay. This combination of circumstances is really great for using the R2 mutants.

Julia: Would you go back just a minute to what you said about the viruses and their lack of sensitivity to chloroform?

Julia has a question about something that the rest of the group has already achieved agreement about. As she directs Philip to a previous statement for an opportunity to reinforce and/or clarify her understanding, he sees that Julia holds a misconception and chooses to deal with it in a very direct manner. He uses this direct approach because the misconception deals with a factual understanding of what is accomplished by chloroform treating. I think he is a bit surprised at the necessity of clarifying this at first. If this were a misconception regarding a biological process, rather than a fact regarding the structure of the cell, his typical response would have been to suggest an experiment and/or ask a series of questions to lead Julia through the construction of an understanding.

Philip: Yes?

Julia: Now, you said it denatured the protein of the virus.

Philip: Chloroform? No. What chloroform mostly does in this situation is it dissolves the membrane of the cell.

Julia: Of the cell?

Philip: Chloroform will have an effect on viruses with a membranous coat. Some viruses do have a membranous coat. But for viruses composed of protein and nucleic acid they can get away with being in chloroform as it has no effect, due to the fact that the chloroform dissolves the lipids in the membrane of the cell.

This line clarifies the structural components of cells and viruses to reinforce the idea of how the chloroform works on the lipid component of the cell membrane and not viruses that have only protein coats. Philip's words and tone draw this line in such a way that Julia is not embarrassed or made to feel inadequate.

Julia: So, it's essentially dead?

Philip: It's totally dead. It's gone. The cell's just dissolved…because it doesn't have a membrane anymore. You essentially just stop everything when you add the chloroform.

Julia: Okay. I've got it now. Thanks.

<u>End Scene IV</u>

Cognitive commitments can sometimes get in the way of learning. At times when data and expected outcomes or theory appear to be in conflict, the first inclination for the teachers (who rely more on facts than on data in their daily professional lives) is to examine why—not to understand the conflict itself, but usually in an effort to find out what they did <u>wrong</u>. The following is an example of how participants handle such a conflict between data and expectation and engage in challenging the "known."

<u>Scene V: Cognitive Commitments</u>

The beep of the microwave indicates that soft agar is ready for preparing more plaque assays. Rays of sunlight stream through an east window, lighting two flasks of LB agar on the benchtop. Their amber contents give the lab a golden glow that borders on ethereal. Dry baths, test tubes, and open notebooks are scattered on every benchtop, the dark surfaces barely visible from underneath the petri dish remnants of experiments. Martha, Sherry, and Philip are trying to make sense of their data.

Philip: The important thing is no plaques on K12 lambda.

Martha: And we've got that.

Philip: You've got that a ton of times. So, call those R2 because that is the defining characteristic.

Martha: All of these, however, have huge clear plaques on K12 and cloudy plaques on B.

Martha pulls another stack of plates toward the front of the lab bench and begins to spread them out. As Sherry begins to speak, the inflection in her voice indicates that something is puzzling her. Martha's voice too indicates that something is amiss. Martha hands off the plates to Philip, physically giving both permission and a request for his examination.

Sherry: And nothing on lambda.

Martha: Still nothing on lambda, but there is a big difference. Here, look at them yourself. #10, #11, and #12 all look like those. [Martha taps the petri dishes with these numbered labels as she speaks.]

Sherry: And all of those look alike.

Sherry points to three plates and Martha separates them from the remaining stack of plates by moving them toward Sherry. This body language signals a shift in focus for comparing observations. The puzzle is beginning to reveal itself--If this is a mutant it should not plaque on lambda, but the plaques look different on the other two bacterial strains than the confirmed R2 mutant they identified on the other plates. The puzzlement seems to creep into Philip's voice as he speaks. Again, I see that he wants to be certain that he understands the data and the experimental conditions that produced it.

Martha: And nothing on lambda. Now, on a couple of them we had like one or two that we figured were contaminants or something. But, see the difference? We got two different...

Philip: Different classes. These do not plate on K12 lambda?

Sherry: None of those do.

Martha: All we ever got was number nine; there were three very tiny ones, on #12 two very tiny ones.

Philip: Those could be revertants.

When one breaks biological systems, they sometimes don't remain broken. Cells, and these phage, have repair mechanism that fix the damaged genes—without the courtesy of telling the investigator that DNA is being repaired--so the characteristic that defines them as mutants is no longer evident as they "revert" back to "wild type." Sherry lets Philip know that the data doesn't match the predicted outcomes, and her tone of voice says that she is not very happy about that.

Sherry: Okay. But our results--weren't we supposed to get on B clear ones and on K12 cloudy ones?

Philip: Yes. Yes. So, here's what I would do. It's this question of this plaque morphology business that I don't understand...

Philip is frowning slightly as he taps on the lids of the petri dishes. He is mildly perturbed at not really understanding this data, but it certainly doesn't halt the progress of the experiments. Martha's tone of voice has an edge of frustration in it. She wants to be able to explain the data, and the cognitive conflict between her expected outcomes and her empirical findings is making her uncomfortable.

Martha: Look on number seven. They're just the opposite from what we got on number one.

Philip: I would say that if you had mixed plaques, clearly mixed—big ones and little ones—the little ones are probably the wild type.

Martha: but we don't. See. It's just that they're different on different plates. On #1 they're just the opposite. We got big plaques on K12.

Philip: I would re-plate those. Those sound like R2 mutants, but I would just make sure.

Philip continues to frown slightly as he looks at the petri plates, but his eyes indicate that his thoughts have turned inward. He is quiet for a moment, and then the light intensifies in his eyes as he begins to speak again. He has thought of a possibility. As he explains, he also reassures Sherry and Martha that their plan to examine recombination and genetic mapping is still on, even if the specific attributes of the phage are currently in question. This line says that science can't wait until all aspects are explained. The quest continues!

Philip: Heaven forbid! Maybe those revertants are not really--I think you guys are getting different R mutants! We can still do crosses with <u>those</u> even though they will plate on K12 lambda. The K12 lambda business is important because it allows you to measure very, very small recombination distances. For big recombination distances you don't need that trick. You just look at plaque morphology. As long as it breeds true, you can tell a little plaque from a big plaque. By all means continue this...You're on the right track. That's exactly what you want to do. So, let me make fresh overnights and on Monday we'll just re-plate these guys on K12 and on B, but we'll add wild type phage so there's a mixture, then we can tell.

Sherry: On the same plate, so we can compare them?

Philip: Yes.... I think you could have two different classes of R mutants. Remember that I told you there were three different R regions where you get rapid lysis mutants?

Philip's voice reflects more certainty now that he may have a reasonable explanation for the data. Looking over Martha's shoulder, Diane begins to actively involve herself in the discourse and Julia steps closer to the group as Sherry holds up two plates for her to examine. In this nonverbal communication, permission is granted for Julia to offer her own observations.

Diane: Yes. I remember.

Sherry: Yes.

Philip: As far as I'm aware, only one, the R2 region, has this property of not plating on K12 lambda. But, the others do not have that property. They make big plaques but they plate out on K12 lambda. So, by that criterion, all the things you've got there [points to the first plates that were examined] are R mutants. And so the question that we're still kind of stuck with here is the plaque morphology. It <u>looks</u> like an R.

Julia: Those are cloudy around the edges, and those others are very clear.

Philip: No question. But those are both big plaques

Sherry: So, I'm just trying to make sure that we have the strains right.

Philip: Well, this is a known R2 mutant on K12 and it has really tiny plaques. So, I'm not sure what is going on here. I would re-pick a plaque on B that really looks like it's a good R plaque and just re-plaque purify it. Because some of these were so close together...your plaques may be mixed.

Philip wants to eliminate the possibility of mixed plaques, and the best way to do that is go back to the first isolation. He wants to be sure that they are dealing with a pure lysate: one that contains only one type of bacteriophage.

Martha: Yeah. See, that's the one. That's what I was showing you, but it's backwards from what it should be.

Philip: Well. It is backwards, but --

Martha: From what I expected, anyway.

Philip: But it's backwards for the R2 region, but this may not be the R2 region.

Martha: OK. I think I see what you're saying.

Philip: There are, I think on T4 there are three regions that you can mutate.... We need to find out about the other R regions, whether you get the same pattern. I'm not sure what is going on here, but we'll sort it out.

End: Scene V

The way to "sort it out" is to first consult the literature, in this case a linkage map of the T4 genome, to find the facts about the characteristics of the R mutants. Second, to re-trace the steps leading to the selection of the mutant, starting with square one.

Scene VI: The Sorting

Discarded petri plates lie jumbled in a large cardboard box lined with a red "biohazard" bag. The black surfaces of freshly washed benchtops are again visible, with notebooks lying open. The white board displays tables of data, duplicated from these notebooks, to facilitate group analysis. Philip comes into the lab and immediately begins to share the information he has located.

Philip: This is a linkage map of the genome of T4. Exactly what you're doing.... Notice that there are three loci...and if you do crosses between different R mutants, sometimes you get monster recombinants. If you don't, the two R mutants you're using are in the same locus—R1, R2, or R3—and if you get big recombinants you're using mutants that are in these different loci. Now, I don't think...mutants in all three regions have the same phenotype with respect to B, K12, and lambda. Picking up here [pointing out the specific areas of interest on the map] are groups in these respective loci, only one of which is R2. And, you can assign which of those is R2 by plaque morphology, especially plating on K12. And, that's what you should be paying attention to—big plaques—if they form big plaques on K12 as well as B, it's probably an R mutant, but not an R2 mutant.

This line underlines an assertion that we are now dealing with different types of mutants, but since we now have pure lysates we can use that fact to our advantage in the process of mapping. Making this assertion is what allows the research to proceed. However, Martha still believes that her mutants are supposed to be R2 mutants. She is having great difficulty seeing anything else.

Sherry: Okay. So, R2 mutants will be large on B, small on K12.

Philip: And they don't plate on lambda.

Martha: But, see. We got some that are just the opposite. They're large on K12 and regular on B.

Sherry: Are you saying these may be different <u>kinds</u> of mutants, maybe?

This line is a slick way for Sherry to help Martha expand her vision. Sherry clarifies the information that Philip has given in the form of a question to prod Martha without making her feel that she is the only one who doesn't know.

Philip: The only characteristic of R2 mutants is that they don't plate on K12 lambda. <u>Some</u> R mutants <u>do</u>, and you guys showed me that on that last set of plates. They're in other R sections.

Sherry: You mean the other regions that you were showing us on the map.

Diane: Yes. They're in that book.

Philip: Yes. Exactly what I mean. So, don't throw those away. Don't think you've done something wrong. You're simply isolating mutants. Never, ever listen to anybody who contradicts your data! And don't marry your ideas, because sometimes it's essential to get rid of them....Now, let's be absolutely certain what we've got. Those were original plates and these were taken from?

S: Taken from B. Yes.

P: Then you're fine.... It's the original selection that I'm...that's what's <u>critical</u>.

S: Right. Yes, the original selection was from B.

P: OK. The original selection. In other words, the mutagenized T4 went on B.

S: yes.

P: <u>Here</u> the mutagenized T4 is growing on K12, and I'm going to be very interested to see what those look like. And what I would really be interested in is to cross these against that known R2 mutant. Those recombination frequencies

> should be very high because these should not be R2 mutants and they should map far away from the R2. They're R mutants, but not R2 mutants.

End: Scene VI

Not erroneous facts but cognitive commitments to expected outcomes put limits on our collective vision. Once the "known" facts are sorted out (from the literature) and the line of what we know is extended, we collectively negotiate our understanding until we are able to see not just R2 mutants, but that the selection of mutants does not eliminate other classes of R mutants. This experience depicts exactly what Kuhn meant by "not being able to see what we don't have ideas for." But, going back to square one works; it broadens the scope of what can be seen. It works so well that Sherry and Martha successfully show recombination in their mutant phages and also perform experiments related to complementation. This strategy of returning to square one is a trick that is not new to Philip. He explains.

> Square one is the most important one. Whenever I'm doing a series of experiments, outside of this project even, and things aren't working and I just can't get through the impasse, I go to that observation and I do that experiment. It always works. It works just fine. What I do is I go back to the first observation. What was the observation? What was the circumstance? Then, I can go right from there back to square fifteen or wherever, and I can fool around and figure it out. So, it's always nice to go back to square one. Square one is terra firma. It's bedrock.

Defining Roles

Just as partnerships were developed through the interactions of the participants, so too were images of personal roles in science education. The lines connecting various individuals that identified how participants defined these roles emerged as participants responded to informal interview questions, which were audiotaped and transcribed. Teacher participants were asked "In what ways did you (do you) view yourself as a scientist?" I then asked them to describe the roles of a scientist involved in education and the roles of a science teacher. I also asked Philip to discuss his role in science education and share with me what he gained from interaction with the teachers through the TSP. In addition to responses from those questions I have included excerpts from discourses that influenced the way that I redefined, and continue to modify, my own role in this section of text. It is important to realize that while the redefining of roles began with discourses in the context of the field experience, they continued to be redefined as participants extended their discourses throughout the school year. Philip's role as well as my own must be perpetually redefined by the needs of the teacher participants. Those needs have continued to be revealed in increments, both to the teachers themselves and to those of us who continue to be involved with the TSP.

Among the lines drawn by Diane and Julia I saw sketches in which each woman depicted herself as a scientist, however both of these women limited their "scientist" portraits to the laboratory context.

> Diane: While at the OMRF, I viewed myself as a scientist. Working in the lab setting is what contributed to that feeling more than anything. Performing experiments, and having to wait until the next day for the results, was exciting.

> Trying to predict the outcome of the experiments, and at times, actually most of the time, getting results I did not expect really made me feel like a scientist. Using the scientific method in the lab setting would make anyone feel like a scientist. I think many teachers of science do not view themselves as actual scientists because they find themselves teaching facts rather than how to apply scientific inquiry into their lessons.

Even Diane's sketch of herself as scientist revealed to me that she continued to think about science in traditional science-teacher ways: experimenting, predicting, using "the scientific method" were terms that she sprinkled about in her response, but did not signal true understanding. I found it paradoxical that Diane should conclude her response by identifying a potential obstacle for "many teachers of science" that matched my assessment of her obstacle—or excuse.

Diane defined the roles for the scientist involved in education with lines that placed him outside the classroom, and labeled him as a source of information as discoveries are made; scientists do science and supply teachers with the information resulting from those processes. Her own role, as a science teacher, was defined with lines that connected her to the traditions of the past; teachers get information from resources and pass it on to their students. Then, as if an afterthought, Diane added a statement consistent with the mindset of the scholar who provides an answer dictated by what she thinks the mentor wants to hear.

> The role of a scientist involved in education is very important. The scientist does the research, forms theories, and comes up with new ideas, but scientists are not always good teachers. The role of science teachers is to take what scientists have

discovered and teach it to their students. Teachers must present the information in such a way that it is understandable. They should provide their students with ample opportunities to experiment and to form their own conclusions.

Julia explained that she did feel like a scientist, but added that she also placed herself in a student role. Julia defined roles by drawing lines that sometimes made connections between herself and traditional ideals, and at other times made connections between herself and transformational ways of speaking. Her desires for the future of her classroom practices clearly require continuing interactions with the TSP. Julia also expressed her conviction that private industry has a major impact on what schools are able and equipped to do.

> Julia: During the summer, I felt more like a scientist and a student and much less like a teacher. I gained new awareness of how my students must feel at times. I believe because of the experience, I am more careful to explain things clearly.... The scientist has a crucial role in education. The science teacher can keep up-to-date on advances through the scientist and convey that information to their students... Frankly, I would like to try eliminating the textbook entirely and replacing it with a reference book of key concepts and otherwise rely on computer technology, a laboratory manual, equipment, and supplies. I believe the scientist's input would be crucial for this to be successful, but we are headed in that direction anyway. So, why not go there effectively? Of course, this all requires funding and the state and nation will eventually fund those things which are economically advantageous if the private sector insists on it loudly enough.

Neither Martha nor Sherry would accept the title of scientist, even though the question was phrased to lead them to do so. Both their personality traits and their extensive teaching experiences contributed to the lines they drew firmly; lines that defined them as educators and not as scientists.

> Martha: I do not really view myself as a scientist. I see myself as an educator responsible for encouraging young people to consider that they might want to become scientists...I think that science is all around us, and they [students] need to see that.
>
> Sherry: I never really did view myself as a scientist. I'm a teacher. I'm not a scientist.... I don't really think of myself as a scientist, because my interpretation of a scientist is somebody who is doing original research, who's out there finding an answer to something that is not known to the science community.

Martha's lines defining the roles for both scientists and teachers are very similar to Sherry's lines. For both women, scientists, teachers, and students are collaborators, with the teacher functioning as both a conduit between scientists and students and as a motivator and guide for individuals, who happen to be students.

> Martha: The role of a scientist in education is to help educators remain aware of what happens in the real world of science and to serve as a role model for students. It is very helpful when that scientist is in a position to aid educators in applying real world science in the classroom...The role of a science teacher is to be knowledgeable and enthusiastic about science and to relate that to her students. It is to use all methods available in order to foster mastery of concepts, critical thinking skills, and the drive to seek answers to their own questions in her

students. And, finally, to remember that she teaches students, not subjects...I believe that secondary science courses should be apparently relevant to the real world and classes need to achieve a balance between theory and application...foster an enthusiasm for the field of science, encourage student-generated questions, and build a desire and an ability in students to seek answers to their own questions.

Sherry: The role of the scientists is probably to provide an opportunity for teachers to <u>do</u> science...If they [teachers] had an opportunity to work in a lab under a scientist and go back to actually doing science. You know, we [classroom teachers] don't <u>do</u> science. We really don't...and for kids [students], they [scientists] could let them [students] know what they think kids would need to be prepared for kids to come into research, or what their research involves...if they could do it without being too far over the students' heads...but they can really help the teachers... My job as a science teacher...I am supposed to teach them...very basic concepts...my job is to try and teach them how scientists think...to be skeptical...which is that scientific method business...

I learned, through continuing dialog between us, that Philip's vision of his role in science education has continued to evolve with each successive year's group of teachers. It is apparent to me, from my own experience and from the interactions that I engaged in during this study, that teachers gained a great deal from the TSP, but the gains to Philip seemed less obvious. His comments and actions indicated that his excitement grew as he anticipated each new group of teachers like a small boy waiting for his playmates. He seemed to regain a sense of wonder and delight as participating teachers discovered biological principles and, this too has been a recurring experience each year. As Philip commented that he "learned a lot" from the teachers, I asked him to probe further into the details of his learning. In so doing, Philip explained that he had developed a new awareness of the challenges that teachers must meet; he learned about more than just school science.

> I'm grateful to them for--for taking the veil away from something that was a complete mystery to me, and I think to most people. What happens in a high school biology classroom? Everybody says that it isn't good, but most people don't have a clue about what actually happens there. Exactly what do teachers have to contend with? Just the range of abilities of the students in these classes is huge...And, how many adolescents out of, let's say twenty adolescents, how many does it take to screw up a whole classroom? Two? Maybe only one. Two could finish you! So, it's not easy. And I never, before I did this, I never really appreciated exactly why or what it is that's going on.... My role is to accommodate my interactions with each of them according to each of their own interests, abilities, and preferences [during the eight weeks of the summer].... Every summer--I get so encouraged to see once again the quality and professionalism of Oklahoma's public school teachers. And after five years you know you begin to get the message that these people are professionals. And, if the teacher needs supplies, it's got to be sent out the very next day. You know, the teachers can't wait a whole week once they get started. You've got to use FedEx...[to provide continuing support and supplies].

Philip believes that he can provide teachers with information regarding the basic concepts and principles of biology that should be taught as they seek to trim curricula. His beliefs are reinforced by the consensus offered in the Project 2061 documents (AAAS, 1989, 1993, 1997, 1999), that he has come to view as tools to understanding the needs of science education. But he also realizes that it is sometimes difficult for him to fully comprehend the cognitive levels of students and the impracticality of certain experiments for classroom use. In this area, the expertise of the teachers prevails.

> We've always had the idea that we're not—that what we can—we're not imposing...we don't know best. Or, I don't know best. Actually, you do, because you've been there. I don't know best about how to do these things in the classroom...I tend to get off on the, shall we say less practical aspects, of some of this stuff...they [Sherry and Martha] really took me to task...with this complementation/recombination business and, you know what? They were right! They were absolutely right. That the complementation is subtle--the concept is very subtle. The interpretation of the data is very subtle...I would be very leery about expending valuable time in the high school classroom...doing these complementation experiments...just from what you all have told me...I think you have to be so ruthless with what you actually teach to kids. I mean you can't make arguments that...well, this is very, very important. Yes, it's important, but what we're really talking about is what are the <u>most</u> important concepts, and experiments, that can be done in the least amount of time with the least expense...and be absolutely clear so that students understand. So, for the teacher, I think that's a tall order. The recombination experiments were different...a piece of

cake—beautiful experiments.... But they were absolutely correct about the principle of complementation.

Philip and I have negotiated our roles in the professional development of science teachers, and rather than a separate role for scientist and science teacher educator we see one. The role is a fluid one; metamorphosing in response to the perceived needs and accomplishments of each teacher. Basically, we perceive our activities as ongoing research: practicing science relative to science education. "The key to successfully transforming education so that students guide their own learning lies in educators' abilities to transform themselves, to change their perceptual orientation" (Caine & Caine, 1998, p.43). We believe that our role is to assist in that transformation, and each participant's needs were (and are) very different as negotiated relevancies of the field experiences meet classroom realities.

Negotiated Relevance/Classroom Realities

Participants negotiated the relevance of the concepts, processes, and instructional strategies throughout the summer's investigations. Each of the teachers valued their summer experiences, expressed enthusiasm for introducing students to the practice of science, and entered their classrooms in the fall of the year with a new enthusiasm. In general, teachers working in small rural schools utilized more experiments from the TSP than their counterparts in larger schools, possibly due in part to their high degree of autonomy. The extent to which transferring the practice of science from field experiences to science classrooms was accomplished, however, was different for each participant. This section reports negotiated relevance and plans for classroom changes, as indicated by discourses during the eight week field experience, and compares them with aspects of the field experience that were transferred to the teachers' classroom practices in situ, as indicated through personal communications and informal interviews.

Diane spent the entire summer determining the procedures and activities that she could use to involve her students in the lake project her school had adopted. She negotiated the relevance of the experiments that she did and the principles she learned on the basis of that project and deliberately made plans to follow through in the fall. Unfortunately, Diane did not see a way to make her experience "fit" into her daily classroom activities. The project, after all, was an extra thing and not part of her anatomy/physiology class. Diane did not contact me during the school year to request supplies or materials. Neither did she contact me for help regarding lesson plans or activities. In fact, any contact that I had with Diane through this school year was initiated by me. As the result of a phone conversation, I learned that a major problem with our communication was that Diane did not have an Internet connection. Although the TSP provided her with a computer and would have paid for a local internet service provider (ISP), her school was in the process of being wired with a T1 line and, on the advice of the school district's technology adviser, Diane decided to wait for the installation of the appropriate cables. Although I was accessible to her by phone or conventional mail, she did much of her preparation and research at odd hours and hesitated to contact any resource people during those times.

Even though her plans for working on the lake project did not work out, Diane felt that her participation in the TSP did have an impact on her teaching.

> Diane: I have shared my experiences with my students. They have gained a sense of excitement...I use the inquiry method in our discussions of the different topics

we cover. I want the students to form their own opinions, to think about possibilities, and to form their own conclusions in everyday matters.

Robbie: What do you mean by "the inquiry method"?

Diane: Oh. Questioning, you know. More interactive. I don't just tell them [students] things. I try to get them to tell me, then I reinforce or correct.

Questioning rather than transmitting information was a very small, but important, step for Diane. It was evident that Diane felt that she gained something of personal value from her participation in the TSP, however, because she requested a chance to return to the TSP laboratory for one month during the summer of 2000. She did not give up on the lake project, and explained her plans to collect samples for investigation upon her return. In addition, she stated that she anticipates teaching an introductory biology course in the 2000-2001 school year and feels that she can develop lines of inquiry to guide her students through that course using the strategies and experiments she can work out during her follow-up month.

Julia made every effort to develop her understanding of procedures and principles related to her project while engaged in experiments in the TSP laboratory. She wanted to be sure that her understanding had been developed to such a degree that she could repeat experiments with her students. Although unsure of how to get started, with a little encouragement and assistance from Philip and me, Julia was successful in enhancing her teaching through the use of laboratory experiences. Almost immediately she began to request materials and supplies, help with lesson plans, ideas for alternative equipment, and help finding resources for purchasing supplies and equipment for her school. She contacted me at least twice each month throughout the school year and was able to lead her students through the processes of making selective media, selecting antibiotic resistant bacteria, and testing those organisms of multiple resistances. For example, she once asked:

> Robbie, could you send me some LB and some MacConkey agar? I think about three sleeves of each should get us started. Also could you send me some phenol red indicator [a substance that changes color based on pH of a substance, indicating whether it is chemically acidic or basic]...? Is the Micrococcus luteus easily isolated and recognized or do I need to get a pure strain from you? I was wondering if the DH5 or K12 would work just as well as I already have those strains, but I can't remember whether the DH5 and K12 were both gram negative and antibiotic resistant. If so, to which antibiotics? Please refresh my memory.... I have one question on the tryptic soy broth. Do I need to sterilize the soy broth in a pressure cooker or just mix it in the distilled water...? By the way, the kids that did the antibiotic resistance really seemed to enjoy it. They also did a lot of reading and reporting from the readings we xeroxed. Do you have any suggestions as to other studies they might do next?

Julia prepared a presentation for her school board early in the fall semester to share her experiences and to elicit help in getting equipment, supplies, and support for making some changes in the science curriculum. Her affiliation with the TSP was advantageous for her in many ways. According to both Julia and to her principal, not only did her participation in the TSP contribute to the community's view of her as knowledgeable, but also gave her an opportunity to work with one of the developers at the OMRF to prepare a grant proposal for submission to a major industrial firm in her area of the state. She voiced her hope that she could extend her supply of equipment if she were to be successful in receiving that funding.

> I am sending...[a] needs list so that you and Philip could go over and modify it. I have tried to include equipment and materials that we are lacking in for Biology, Chemistry, Physics, and Anatomy and Physiology [sic]. With your expertise, I am sure you will see some things that I haven't even thought of. You might send me back your revised copy just in case I already have some of the equipment here.

From her requests and follow up conversations, it became clear to me that Julia's changes in classroom practices focused more on incorporating experiments and activities than on developing an attitude of inquiry. Although she expressed disappointment that, although the school had previously been on a block schedule, she only had 45-minute class periods for the 1999-2000 school year, she seemed somewhat ambivalent; almost relieved that she had an excuse to provide experiments and activities that were structured in a way that allowed her to share her own experiences, but did not allow students opportunities to design their own. Even her future plans dealt more with knowing what to provide and teach rather than in how to design meaningful experiences and interactions.

Julia, like Diane, requested that she be approved to return to the TSP laboratory for one month during the summer of 2000. The goals that she identified for achieving during that month were: (1) to refine her knowledge of specific protocols and techniques for investigating microbes in her area, (2) to work with me on the preparation of manuscripts to be submitted to teacher journals, and (3) to prepare media and reagents [solutions of chemicals necessary or useful for specific tests] for use in her classroom the following school year.

Martha deliberately and pugnaciously planned ways to use what she learned during the eight-week field experience classroom with her students. I cannot recall a day passing without Martha saying "Now, if we're doing this in class..." or "When we do this with our kids..." and "I'm trying to think of all the stuff I want kids to come up with when we finish this." Her negotiations included summarizing important biological principles clearly illustrated from her experiments, determining how to break up long experiments into segments requiring smaller time frames, how to test common household and farm substances for mutagenic properties, and finding examples that more clearly illustrate concepts that she wants her students to understand.

> I wrote all that out because we talk about functional groups in chemistry.... The change from a ketone to an alcohol group is what changes on some of these...with aminopurine...tautameric shift...we talk about protonation and how a proton movement...you see it as a hydrogen.... And this...I mean it's very easily seen. The hydrogen moves from this nitrogen to make an OH group. So, we do that in chemistry and I've never had any practical way to show it.

Martha was very successful in changing her teaching practices. She contacted me via e-mail or phone almost every week throughout the school year to request materials and supplies to use with the two classes that she had the most freedom to design. She explained:

> My micro class brought natural samples yesterday and we did spread plates. Today they did streak plates to try to isolate colonies. That is a very enjoyable class.... I need some LB and MacConkey plates if you have them. My class brought in natural samples and we streaked them out on LB and

MacConkey. On some of the plates, of MacConkey, some of the colonies stayed white and some picked up the red dye of the MacConkey. I remember ours doing that too. Can you give me an explanation of why this happens on the same plate...Can you send me the E. coli B, K12 and lambda and some T4 phage? We did not find phage in our natural sources so I want to start them working with the knowns that

we worked with this summer. We are going to start by investigating the differing plaque morphology on different types of E. coli.... It is slow going in Microbiology but we are learning. We are doing plate lysates right now to get more phage. I am out of R-top though. Could you send me some?

Martha's administrators, as well as everyone who worked with her in the TSP, described her as both knowledgeable and enthusiastic. So, it came as no surprise to me that she was able to make major changes in designing these classes. Especially, as she said, "Robbie and the lab are just a mouse click away." In addition, although she did not employ the same degree of laboratory work in her other classes, she was able to incorporate an attitude of freedom in class discussions and research. She desired to expose her students to the OMRF environment, so she arranged a field trip to the OMRF in the early spring, where students toured some of the labs, learned some of the history of the facility, and spoke with one of the research scientists concerning the new discoveries related to Alzheimer's disease. These recent discoveries, made at the OMRF, were current news items at the time, and piqued her students' interest. Martha continued to keep in touch, said she is still in contact with Sherry and asked me about her as well. The mutant phages that Martha and Sherry isolated were used by a teacher at a school specializing in science and mathematics who wanted to teach her genetics students about recombination this year.

Sherry negotiated plans for using the mutant phages in her classroom, redesigning lesson plans to lead students through investigative processes, using the computer as a teaching tool, and using additional experiments she had performed during the summer to teach the fundamental principles of biology. She and Martha returned to the lab where they had spent the summer during the week before school started to make media, which we stored in the cold room until they called for it. Sherry was very excited about being able to just send me a "shopping list" and get her supplies in the mail the next day.

> I want to take these kids and have them swab stuff...I'm sure that's the first place [the cafeteria] they will want to go...there are always some kids who have questions that are not the same questions as the other kids...once you have an additional electronic resource you can refer them to it so they can find answers for themselves...they're gonna mess up [when they do these experiments] and when they do they have to figure out how to find the answers...and when we want to do the recombination thing all we have to say is send us mutants R11, R2 or a T. S. (To which Philip responds "and hold the pepperoni.")

But "the best laid plans of mice and men" go by the wayside. Sherry did not use any of the experiments, nor did she significantly change her teaching practices. Sherry does not feel that the obstacles for her have been institutional, but rather the trap of her own mindset. Sherry was engaged in cognitive conflict, struggling to transform herself from the teacher she has always been into the facilitator and inquirer that she desires to be.

> I think I'm really more frustrated now [after participating in the TSP] than I was because I know what can be done. I know other approaches to doing what I do. But, it's the idea of breaking out of the mold...out of the ruts that I've laid for myself, because that's the way I was shown and that's the way I was taught and...it's a nice comfortable little rut...I think I'd have to start from day 1, like you were talking about with your kids. How you start off with the swab plates and you go through all the cell processes, and you talk about...and it ties together wonderfully. I really like the idea. But...assessment...I think it would have to be different... it's a problem of the mechanics...Give me something that I can take in my hot little hands.

Sherry and I continued to be in contact throughout the school year, even though her needs were not supplies and materials. She sought my help in beginning to revamp some of her existing lesson plans and activities and asked me to critique several components of her National Certification portfolio. Sherry expressed an ongoing desire to drastically change her teaching style and to redesign her Biology I class as experimental biology: a class through which her students could rediscover fundamental biological principles just as she did though the summer. She was then, and is now, still seeking, but voiced a strong need for continued collaboration in order to succeed.

> And, working with you...I always looked at you as, as a mentor and a teacher. Tell me what to do, Robbie. OK? That's what I want.. OK? Just treat me like....Lower yourself for just a second here. You can be Ms. Inquiry with your students, but

tell me how to do inquiry with my students. (Both of us laugh.) I value our relationship the most. Because, I'm looking at you....I'm being a parasite, is what I'm doing...And, I want to just suck it all out of you so I can...Yep! Because I like what you do. I like the way that you do it. I think that the way you teach...You are truly skillful in teaching the process of science...And, I think I just need to be in your class, maybe. Of course, you'd probably frustrate me, because I'd probably be the one to just yell, "Tell me how to do this. I don't want to learn how to do it. I want you to tell me how to do it." It's like I would have my big yellow pad and take it back to my classroom and say "OK. Number one. What do you think would happen if...."?

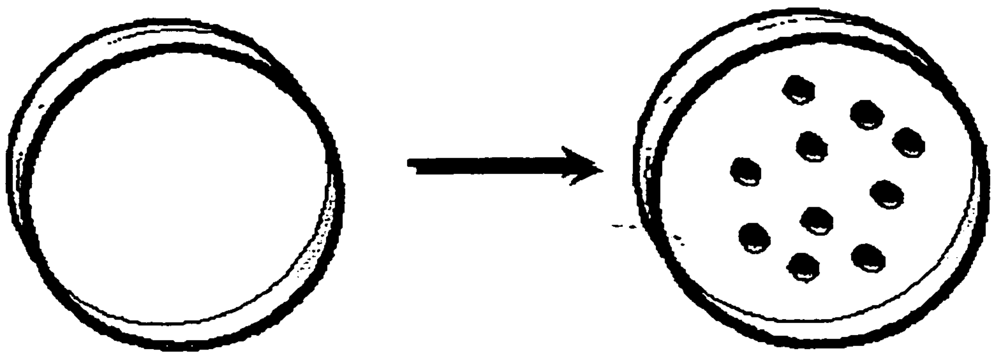
Table 4: Science Concepts

Three simple procedures lead teachers to discover multiple biological concepts.

PROCEDURES	BIOLOGICAL CONCEPTS
1. Growing and infecting broth cultures of host cells 2. Performing serial dilutions 3. Performing plaque assays	Chloroform destroys cells but not viruses because cells have a lipid component in their cell membranes, whereas most viruses have only a protein coat surrounding them.
	Mutant phage can be isolated and identified by an altered phenotype (for example loss of the ability to infect K12 lambda) accompanied by the inference of an altered genotype.
	A plaque can be caused by entities, such as viruses, or by chemical substances, such as colicins or antibiotics.
	Plaques that are caused by phage activity will cause other plaques to form when picked, chloroform-treated, and distributed among bacterial host cells.
	Experiments that yield quantitative data allow investigators to ask more specific questions.
	Plaques caused by colicins lose the ability to cause other plaques even when picked, left untreated with chloroform, and distributed among bacterial host cells.
	Bacteria and viruses exist all around us, as evidence by their isolation from environmental samples.
	Spore-forming bacteria are protected against agents like chloroform.
	Bacteriophages are host specific.
	Experiments that yield qualitative data are the basis for primary isolation and selection of entities under investigation.
	The size of a plaque does not indicate the number of viruses it may contain.
	A bacteriophage can produce thousands of progeny in a very short period of time (2-3 hours).
	Phages can be mutated by allowing them to replicate in the presence of a mutagen, and therefore must have genes: mutagenesis.

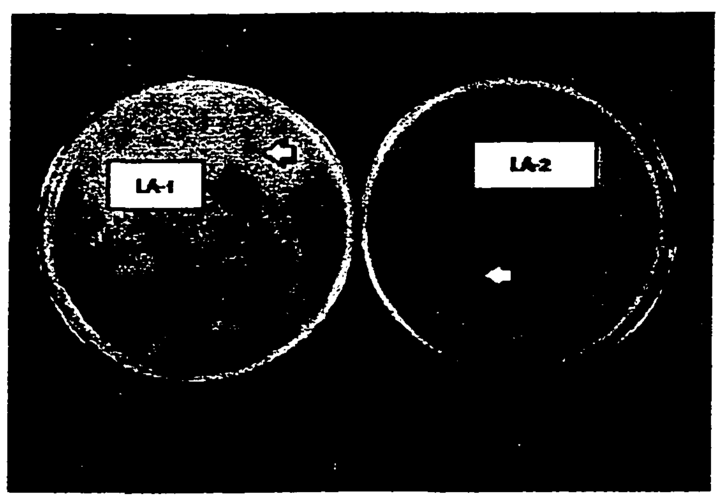
Figure 3: The Virus Plaque Assay

The Virus Plaque Assay



Layer of susceptible host cells and dilution of virus applied to surface of nutrient agar plate in a layer of dilute agar.

Each plaque represents cell lysis initiated by one virus particle (agar restricts movement so that virus can infect only contiguous cells).



LA-1: Plaques are large (4 mm) and turbid.	LA-2: Plaques are small (1-2 mm) and clear.

CHAPTER V

AN ACCOUNTING

Organization

This chapter provides an account of major findings through a narrative intertwined with relevant theoretical literature, and is followed by an interpretive narrative account that presents the logic through which the theory and plan for action emerged; a way of accomplishing what Eisner (1998) describes as "accounting for" what one has given "account of" (p. 35). The presentation of nascent theory is likewise interwoven with a review of relevant literature, in this instance literature is treated as an additional data source, and is useful for probing, validating, and scrutinizing emergent theory (Strauss & Corbin, 1990). As grounded theory studies are oriented toward action, the final section of this chapter presents a guide for acting on, and for testing theory generated by the current research.

An Account of Findings

Description of participants' feelings, rather than facts and specific experiments, dominated the discourses related to their experiences. The language used by participants to describe their experiences aligns with language used in the brain-based teaching literature to depict environments that enhance relationship building (Caine & Caine, 1995; Gardner, 1983; 1993; Jensen, 1998; Rogers & Renard, 1999). The four teachers, Paul, and I each felt that our experiences were intellectually and emotionally safe yet challenging. In addition, as learners and as respected experts in our own fields, we found our experiences to be personally stimulating and rewarding. We all gained new insights from our learner perspectives: the teachers gained ownership of their experiments, and offered direction for the project as a whole; Paul and I gained insight regarding the intellectual and physical tools required by these teachers for classroom science teaching, and also found that we were successful in meeting some of those needs. Paul and I also believe that we are now better able to develop strategies to address additional needs as they arise and are identified. In summary, all participants felt valued, as well as personally and professionally challenged and enlightened.

In seeking to understand why feelings dominated the experiential descriptions and how this contributed to meaningful learning, one must be informed by neurological research. Knowing that the brain does not naturally separate emotions from cognition, either anatomically or perceptually" (Caine & Caine, 1994, p. 45) contributed to my understanding of the physiological basis for these feelings. "When we feel valued and cared for, our brain releases the neurotransmitters of pleasure: endorphins and dopamine" (Jensen, 1998, p. 33). This knowledge also enhanced my perception that these feelings were inextricably interwoven with the activities and artifacts that produced them. "It is the total human who construes, not merely his brain or his guts" (Kenny, 1984, ¶ 18). "People often judge an activity as meaningful when it satisfies deep-rooted human emotional needs" (Glasser, 1998, p. 78); the pleasure of meeting challenges successfully as participants worked through difficult protocols and research questions contributed to meaningful learning.

Partnerships were built through common cognitive struggles: negotiating protocols, time and material management, and the interpretation of data on a daily basis; these were interactions that connected partners by threads of reasoning. Our thoughts actually change our body's chemistry, which in turn determines what environmental stimuli we attend to (Kotulak, 1996; Pert, 1997). When these stimuli are in the form of on-going discourses, with accompanying body language and nuances of tone, and related to specific problem-solving tasks, the immediate social and academic feedback again stimulates the production of the chemical neurotransmitters that increase the joy that we find in our work. In turn, this enjoyment cements the relationship between individuals participating in the discourses.

Diane and Julia shared cognitive conflict at the beginning of their field experiences as they attempted to shore up their background knowledge and learn new procedures and tasks. Sherry and Martha, on the other hand, shared cognitive conflict on a daily basis throughout the eight-week summer experience and beyond. Their relationship was built and reinforced daily as they struggled to develop ways of attacking new research questions that sprang from the analysis of each succeeding day's data. Sherry and Martha have continued to correspond and interact, both as friends and teaching colleagues. Their relationship has endured; the repeated cognitive conflicts that Sherry and Martha shared during the summer in the laboratory were valuable and pleasurable to each of them, and they continue to seek more of the same types of interactions. Relationships built with Paul continue to center around cognitive struggles related to the science; relationships between each of the teachers and me provide opportunities for working through aspects of science content and protocols, but are most heavily weighed toward thinking through strategies for increasing student understanding of the essence of science through engagement in scientific practices. It should be noted, however, that the degree to which the relationships with Paul and me remain active varies according to each teacher's perceived needs, which I elaborate later in this chapter.

Participants developed constructs concerning science as science was done, through the processes of argument, challenge, and dissention, but ultimately settled by the appropriate experiment: an iterative process of logic and action. The negotiations and debate were required elements of interaction, for it is through these energetic exchanges that the next logical question was articulated and the appropriate experiment to act upon was identified. Roles in science education for all participants were, and continue to be, defined according to identified needs. That is, through increments of revelation resulting from discourses and interactions among co-learners as relationships developed, and incorporating perceived student needs into the overall revelation as the school year progressed. These assertions concerning science and role definition speak to the social, collaborative nature of both scientific investigation and learning. Working together simultaneously increased the confidence levels of the teachers and challenged the ways they thought about learning science—science that goes beyond mere content or processes. A most important aspect of this social interaction is the intertwining of content and processes. Statements regarding the meaning of the data (content or facts) were objects to be poked and prodded through critical reasoning processes as well as experimental ones. It is the content that provides focus for the technical and reasoning processes; these cannot be separated if science is truly to be practiced. But the combination of these, in this inextricable way, is greater than the sum of content and processes—it is science. The most successful discoveries of fact (content) in science have resulted from the ways in which scientists challenged one another's thinking; Judson (1996) reports stories of repeated quarrels among famous scientific teams. One such pair was Watson and Crick, who engaged in intellectual quarreling with each other and with other scientists as they unraveled the final pieces of the DNA architectural puzzle. Intellectual partnerships were built among our summer research participants through these same types of quarrelsome interactions, heavily fraught with emotion, and steeped in the essence of science as critical discourse and cognition co-evolved.

In regard to learning, and therefore teaching, the theory developed by Vygotsky is perhaps the most well known of those emphasizing the importance of social interactions. In proposing to explain human cognition, especially the intellectual abilities that are unique to humans, Vygotsky declared that such abilities "are a copy from social interaction; all higher mental functions are internalized social relationships" (Vygotsky, 1981, p. 164). Vygotsky further explained that there are zones of learning: the zone where one can accomplish individual problem solving, and the zone of potential understanding (zone of proximal development) that can be achieved first through collaboration, then internalization. The term he chose to describe the process of reaching this higher zone of understanding through social interaction was scaffolding (Vygotsky, 1974; 1981). Wells voiced agreement when he explained "it is by attempting to make sense with and for others, that we make sense for ourselves"(1999, ¶16).

During the interactions centered on the scientific experiments, discourses also occurred that encouraged reflection about teaching roles and practices, and about the roles and practices for Paul and me in regard to our interactions with teachers. We had previously acknowledged that practicing science in the classroom is not identical to practicing science in the laboratory, but during the summer we also learned to more fully depend upon the expertise of classroom teachers when evaluating specific experiments for classroom use. More importantly, however, we determined that performing specific experiments was not the thing that mattered; it was the way that our teachers learned to build cognitive roads as they tunneled through the problems represented by the experiments that was essential. Building constructs, whether related to subject matter, learning processes, or role definition, resulted from critical interaction, and is what I have presented as "line drawing" in the previous chapter.

Negotiating the relevance of field experiences to classroom practices enhanced the impact of the laboratory experiences, but negotiations in the field were implemented only to the degree that each teacher could make connections between her own learning in the laboratory context and student learning in classroom contexts. I do not doubt statements that all four teachers perceived their experiences as valuable in personal ways; each teacher developed new understandings of scientific practice and content, and anticipated putting their new knowledge into use in their classrooms with excitement. Claims regarding the impact of their experiences upon their professional lives, however, warrant further examination.

Diane, the least experienced teacher (five years), was limited to teaching anatomy and physiology in a school that served a diverse student population of approximately 1,100. She reported the incorporation of questioning techniques abducted from her summer experiences into her classroom behaviors. However, through personal correspondence with her, I believe that Diane made no substantive changes to her classroom practices, for I continue to wonder how these questioning strategies were actually implemented—something that I cannot "see" from outside the classroom.

Julia and Martha, with 15 years and 12 years of experience respectfully, taught in schools that served approximately 300 students in grades K through 12, and continue to have teaching responsibilities that include multiple science courses. In spite of having to prepare lessons that vary both in specific content and in grade level, Julia and Martha reported changing their classroom practices to reflect both the activities and attitudes of inquiry inherent in the field experiences. Again relying on e-mail requests for supplies and assistance as well as other forms of personal communication, I perceived a difference between the two teachers. Julia reported more "hands-on" activities in her classes than she had previously utilized, but the types of questions that accompanied her requests for materials and supplies were limited to the specifics of scientific protocols. When Julia replied to my requests for follow-up, she determined that the activities were successful because "the bacteria grew just as expected," or "the experiments all worked just fine." I believe that Martha, on the other hand, contacted me to rehearse specific questions and allowed me to see how she was thinking about guiding students through the activities with "questioning minds." After completing the activities Martha reported, "We really had a good time. These kids came up with questions that I never anticipated. It was great!" There was clearly a difference in the cognitive experiences of the two classrooms, although the experiments were very similar.

Sherry, with 15 years of experience, taught in a school that served a diverse student population of 1,250, but was responsible for teaching only 10th grade biology. Even though her lessons were designed for only one grade level (sophomore students), and limited to beginning biology content, Sherry did not feel that she had significantly changed her teaching practices to reflect her summer experiences. She voiced frustration in knowing that her classroom could be different but not visualizing a way to make the changes necessary to make the transformation. Moving her from a "more traditional classroom" to "a community of inquiry" would require help that went beyond the offer of materials, equipment and advise already inherent in the TSP. Even though Sherry does not feel that she has the ideal inquiry classroom, I have interacted with her enough to know that her skeptical, questioning personality does not allow her to quite fit the traditional mold, either. However, she is not where she wants to be, and that is the important thing to note here.

Emergent questions resulted from my contemplation of these findings, and were largely driven by Sherry's frustration and cries for help. Sherry had engaged in critical discourses with the other participants, and exhibited critical thinking on a daily basis during the summer portion of the TSP. In spite of these experiences, however, Sherry felt that her inability to make the changes that she desired in her classroom practices was "a mindset thing." Sherry's self diagnosis led me to seek information related to cognitive processes that enhance or deter teachers from implementing changes in classroom practices. In the next section I present a line of reasoning that runs through the processes of questioning, proposing, and checking emergent theory and hypotheses with literature; it is a line that reflects my quest for understanding.

An Interpretive Account

A concept can be defined as "a unit of thought which exists in a person's mind" (Lawson, Abraham, & Renner, 1989, p. 13). Concepts are organized into systems determined by the individual's perceived connections among them, forming neurological bundles that we might call conceptual systems. Conceptual systems are under constant reconstruction as a result of daily life experiences, and are stimulated to reconstruct themselves more rapidly in enriched environments (like the TSP laboratory experiences). As epistemology is the term applied to the conceptual system dealing with knowing (descriptive), or knowing how one knows (procedural) (Lawson, et al., 1989), I have no qualms in declaring that participants' epistemologies changed. The issues open to debate are the extent, quality, and observed evidence of the changes that occurred.

Knowing may also be described as "an individual's personal stock of information, skills, experiences, beliefs, and memories...is always idiosyncratic, reflecting the vagaries of a person's own history..." (Alexander, Schallert, & Hare, 1991, p. 317), and may not depend on any type of external validation of how one knows. This lack of need for external validation of one's constructs can be understood by recognizing that one construes simultaneously on "multiple 'somatic' levels, including physiological, vegetative, emotional, behavioral, etc." (Kenny, 1984, ¶15). Theoretical concepts have defied explanation because they "are imagined and function to explain the otherwise unexplainable" (Lawson, et al., 1989: 15). However recent advances in neurotechnology offer tangible evidence for these postulations of conceptual organizations. The current brain research tools of Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) allow us to track brain activity during problem solving experiences. "We can see thoughts with new imaging devices that spy on the living, working brain, and we can eavesdrop on individual brain cells to listen to their chatter" (Kotulak, 1999, p. 12). We now know that the brain modifies itself structurally and the mind is construed as the process through which modifications and connections are made; new synapses appear after learning (Jensen, 1998; Kempermann, Kuhn, and Gage, 1997). Furthermore, "it doesn't matter to the brain whether it ever comes up with an answer. The neural growth happens because of the process, not the solution " (Jensen, 1998, p. 36). The way that this neural growth has now been described is congruent with the tenets of constructivism, as it has come to be understood through the interpretations of Immanuel Kant, John Dewey, Jean Piaget, Lev Vygotsky, and George Kelly. Kant declared that one only develops knowledge by using fundamental in-built cognitive principles, and referred to these pre-existing principles as "categories" into which one organizes experiences (Palmquist, 1993). Dewey contended that knowing and learning is a function of sensory and intuitive capabilities: biological and cognitive talents that interact and interconnect through experiences (Dobbert & Kurth-Schai, 1992). Piaget's theory of genetic epistemology describes how individuals move through cognitive stages as they constantly interact with their environments; environmental input is filtered through existing cognitive structures, a process which finally leads to assimilation: the restructuring of existing cognitive structures to accommodate new data (Piaget, 1964; Piaget & Inhelder, 1969). Vygotsky's zone of proximal development also indicates that experiences are perceived through one's existing mental apparatus (Vygotsky, 1978; 1981), and Kelly summarized this same idea in his writings. In his Experience Corollary, Kelly states, "A person's construction system varies as he successively construes the replication of events" (Kelly, 1955; 1969; 1970; 1977). I will return to this corollary for a more detailed discussion at a more pertinent point later in this chapter.

It is my contention that, during the laboratory experiences, the teacher participants developed a true understanding of the NOS; they were engaged in the cognitive and social patterns inherent in the practice of science, as opposed to following pre-defined steps in a scientific method. These cognitive and social patterns have been described as consisting of three perpetual processes: (1) establishing the existence of interesting phenomena, (2) utilizing appropriate research materials to gather data related to the phenomena, (3) and, most importantly, successively defining the limits of one's knowledge in ways that make evident the next logical question to be asked—what Merton identified as "specified ignorance" (1987, p. 2227).

All of the participants in the TSP field experience engaged in these perpetual processes related to scientific discovery throughout the summer. Although the experiments and scientific findings were not on the cutting edge of today's science, they were on the edge of each individual's knowledge. As science was practiced in the field, participants engaged in discourses and interactions that were reflections of the discourses and interactions of the scientists who made the original discoveries; the ways that these historical figures are reported to have interacted are identical to the ways that scientists interact with one another in modern scientific practice. In addition, data and questions that were not previously anticipated added elements of originality to each of the research projects. Each of the teachers completed complex lines of investigation, and Paul described them individually in terms that are associated with science and its practice: Diane as "enthusiastic and curious", Julia as "persistent and inquisitive", Martha and Sherry as "critically intelligent." Piaget wrote, "practical activity precedes and shapes the intellectualized consciousness that grows out of it" (Youniss & Damon, 1992, p. 278), and Kelly ties activity to cognition by describing the process of "sense-making" as a scientific one. "He sees us seeking, as scientists, for ever more complex and comprehensive theories (collections of constructs) which correspond increasingly well with the changing flux of experience" (Kenny, 1984, ¶ 52). Therefore, behaviors consistent with the NOS as well as verbalizations indicating teachers' understanding of the NOS support my argument that these teachers understood the NOS. The counter, of course, is to ask, "Could they really understand the NOS and act in ways that refute their understanding?" This is apparently the case, as this phenomenon (teachers understanding the NOS and behaving in ways that seem to contradict that understanding) is evident in other research as well as in the current study (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & Lederman, 1998; Brickhouse, 1990; Lederman, 1992; 1999; Lederman & Zeidler, 1987). I turn to the Lederman (1999) study to compare and contrast with the findings of my current research, and to increase my understanding of the underlying reasons for this phenomenon.

Lederman engaged in a study specifically to determine whether teachers' understandings of the NOS influence classroom practice and, if so, to identify factors that enhance or interfere with that influence. Case studies of five high school biology teachers were conducted simultaneously. Purposive sampling of these specific teachers was based on the a priori perception by Lederman that these teachers all had sound understandings of the NOS, although all five teachers differed in teaching experience and backgrounds. In addition to his previous interactions with each of them, Lederman relied upon the analysis of data collected via an open-ended questionnaire followed by semi-structured interviews. Interview data collected at the beginning of the study supported his selection of these specific teachers, and another interview at the conclusion of the study reaffirmed his prior assessment related to their understandings of the NOS. Data were collected through interviews, classroom observations, open-ended questionnaires, and instructional plans and materials for a full year to examine influential factors. Using analytical induction, Lederman analyzed each of the data sources independently and then collectively as a single body to construct teacher profiles, scrutinize developing assertions, and triangulate data.

Lederman reported differences in how beginning teachers, Barry and Lisa (< 5 years of experience), and the most experienced teachers, Mary and John (14 years and 16 years), exhibited behaviors congruent with sound NOS understandings. While "the two most experienced teachers...exhibited classroom practices consistent with their professed views about the NOS...the two beginning teachers...were still struggling to develop an overall organizational plan for their biology courses and were each a bit frustrated by the discrepancy between what they wanted to accomplish versus what they were capable of accomplishing with their students" (p. 924). The fifth teacher, with 9 years of teaching experience and "perhaps the most subject matter knowledge among the five teachers" (p. 924) did not teach in a manner consistent with her professed views of the NOS. This teacher, Alice, appears to be a negative case that challenges the findings of research related to the Systemic Initiatives (SI), which indicated an increasing use of standards-based teaching practices (synonymous with practices that reflect the NOS) among teachers who have increased content knowledge (Kahle, 1999).

The finding from the current study that Diane, with only five years of teaching experience, did not change teaching practices to reflect her understanding of the NOS, seems to add support to Lederman's tentative postulation that experience is necessary to "mediate the relationship between a teacher's view of the NOS and classroom practice" (p. 925). My hypothesis, supported by previous research (Brickhouse, 1990; Duschl & Wright, 1989; Lederman & Zeidler, 1987), is that Diane's obstacles focused on content restrictions related to her teaching assignment. Lederman's observations led him to hypothesize that the obstacles for the beginning teachers in his study were mainly course organizational issues; such issues could include a content component. While it seems reasonable that experience could be a contributing factor to translating the NOS into classroom practices, specific findings from both studies contribute to my skepticism regarding the degree of influence that experience contributes. Alice, from Lederman's study, and Sherry, from the current study, were both experienced teachers, with 9 years and 15 years respectively, and yet did not teach in ways that reflected their understandings of the NOS. It may be that experience must be coupled with other factors before a noticeable impact is achieved.

The current study indicates that the autonomy afforded a teacher in a rural setting may enhance the translation of the NOS into classroom practices, while Lederman's study points out that Barry was unable to do so, even though he taught in a rural school and also had a mentor (John) who was "recognized as an excellent teacher of projects-based science and scientific inquiry" (p. 919). Considering these discrepancies, one might be led to propose that both experience and the conditions of autonomy provided in rural settings are necessary to facilitate teachers' translation of the NOS into classroom practices. However, Lederman reminds us that the teachers in his study had freedom regarding curriculum emphasis, and Sherry, from the current investigation, declared that she did not feel institutional constraints but cognitive ones. The problem then becomes focused on learning more about cognitive constraints and cognitive spurs to action. It is here that I return to the work of George A. Kelly, noted not only for his pioneering work in psychology but also for his knowledge and degrees in physics, mathematics, educational sociology, and education as well as to cognitive science. I also draw from the work and insights of Vincent Kenny, Director of the Institute of Constructivist Psychology in Dublin, Ireland, who has extensively reviewed Kelly's work.

George Kelly's theory is that of the Personal Construct: a constructivist theory that he formulated from synthesizing his personal experiences, his interactions with clients in his therapeutic practice, and his studies of Dewey (who was, of course, heavily influenced by C.S. Peirce). At the very core of Kelly's theory lies the idea that a construct system is an anticipatory system; it is used to help an individual form predictions and inferences as he imagines and anticipates outcomes of future events. In order to fully comprehend Kelly's theory and its application to the current study, we must consider both a working definition of a "construct," and the organization of constructs.

In Kelly's anticipatory system, constructs can be defined scientifically and experimentally. "In scientific terms a construct was described as a prediction or anticipation of future events. In experimental terms we may see a construct as a hypothesis that we put forward to see how it is 'treated by reality;' is it smashed to pieces, invalidated by a reality it failed to measure up to, or is it found to be useful?" (Kenny, 1984, ¶ 86). The system is explained through a five-phase "cycle of experience," (See figure 4, page 132), but one must take care in remembering that the phases are separated to help our understanding and

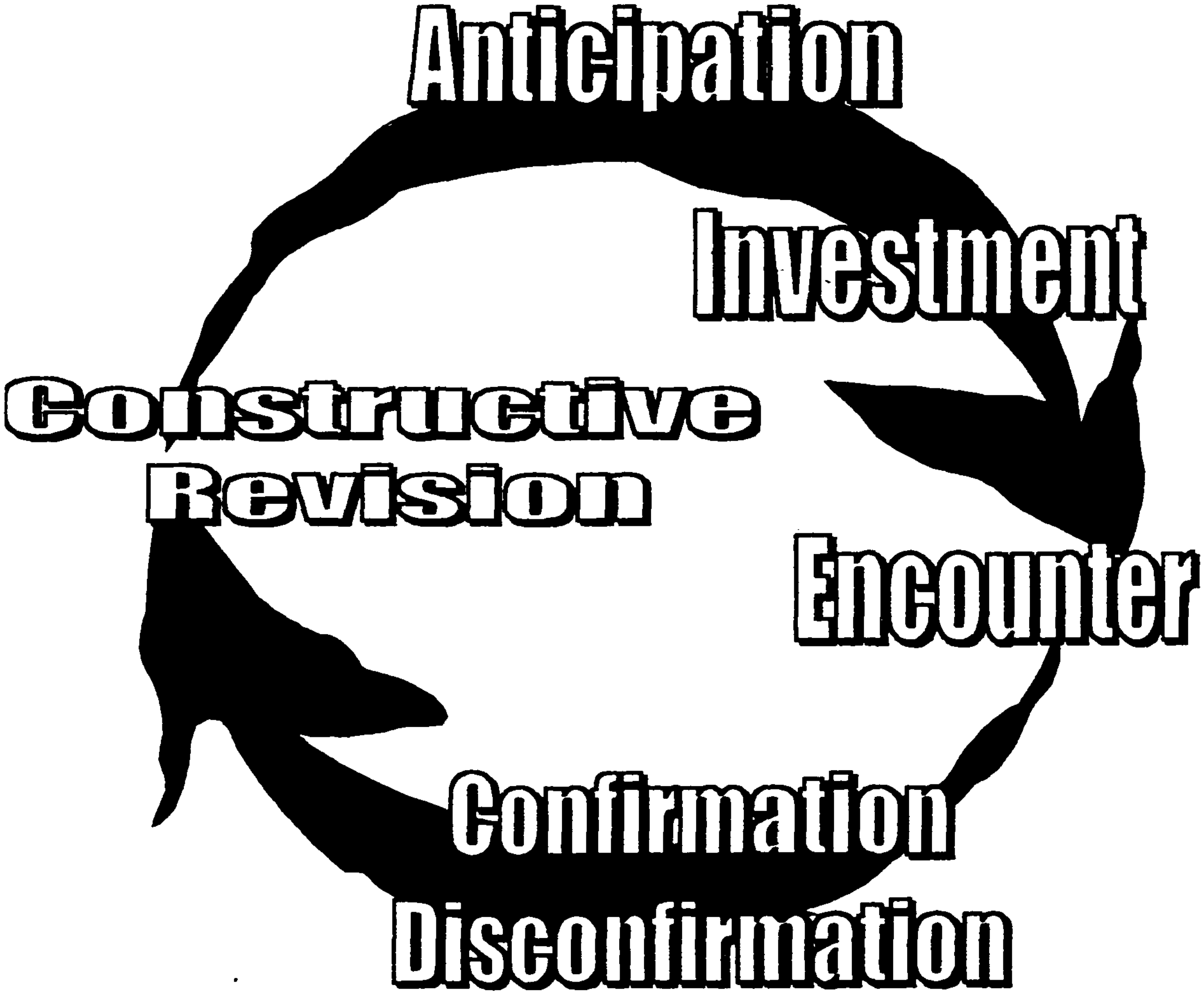


Figure 4: Five-phase Cycle of Experience

discussion of them, and that the cycle can be broken prematurely at any point. This cycle of experience is not a "step-by-step" procedure any more than science is "the scientific method" as outlined by steps in a textbook.

The initial phase in the cycle of experience is Anticipation. Here, as an individual begins to imagine oncoming events, he projects himself forward into them, perhaps even mentally writing dialogs that he feels are likely to occur. Anticipation is followed by an Investment phase, where the individual prepares to meet the event. I believe that it is during this phase that anticipations of actions are cognitively moved into a variety of contexts, for comparison purposes. However, the way that constructs are organized, resulting from past experiences in those specific contexts, always dictate some aspects of these comparisons. This process is a type of internal validation test of anticipations, a dress rehearsal of sorts where one might attempt to overlay constructs from one context onto another—deciding whether what "works" in one context could be useful in another. Assuming that one's anticipations pass this internal analysis, a more compelling investment is warranted, and one proceeds to the next phase: the Encounter. This phase is where the anticipated event becomes a reality or, more correctly, a perception of reality. Anticipated behaviors are acted upon in what Kelly calls "experiential experiments," and data are collected about the perceptions of the event so that it can be compared with the anticipated outcomes. The process of making this comparison is the Confirmation/Disconfirmation phase; predictions (constructs/anticipations) regarding the perceived outcomes of events are either supported or refuted. Whether the predictions are supported or refuted, the Constructive Revision phase ensues and existing constructs are either shored up, or they are re-constructed so that the next round of predictions/anticipations are more likely to be supported. That is, the entire construing system is revised in such a way that it becomes more efficient in anticipating future events. Because we are interested in teachers' decisions regarding how to act and interact in classroom contexts, and actions are governed by constructs, we must examine the organization of those constructs.

Constructs, as mental structures, both describe events as we experience them and are the criteria for determining how we rectify newly formed constructs with existing ones. That is, perception dictates organization. Constructs are categorized into proper hierarchical orders and connections are established among these orders; connections are determined as constructs related to events are cleaved according to similarities and differences among them. In this way, we simultaneously protect and expose our mental structures: exposing the most subordinate ones to external events, thus inviting changes to them, and protecting more super-ordinate structures from external influences. These super-ordinate structures are only revised through internal forces, and the change is related to the level of exposure the individual allows—what Kelly called "permeability."

As mentioned earlier, the cycle of experimentation is not always completed. Kenny (1987) identifies reasons why people become "stuck" at various parts of the cycle, usually unable to engage, or to reach and proceed through the Encounter phase. Among these reasons, he lists (1) ambiguous anticipations that cannot be specified into action, (2) being too afraid to risk themselves, or (3) fearing to encounter so much that when the event arrives they feel too threatened to "indwell" it. Apparent in Kelly's theory is the idea that everyone is involved in seeking to maintain some measure of control over the flow of events in which they are involved—this is the reason behind building cognitive structures that are efficient prediction-making equipment. If acting a certain way endangers that measure of control, the individual may determine that it is better to re-Anticipate than to Encounter. "A person hesitates to experiment...he may fear that the conclusion of the experiment will place him in a position where he will no longer be able to predict and control.... He doesn't want to be caught with his constructs down" (Kelly, 1955, p. 13). Research on teachers' thinking and decision making is congruent with Kelly's theory; the experiences gathered in classroom contexts may affect teachers' beliefs about students, teaching, learning, and the NOS. Therefore paying attention to contexts of learning is extremely important, as many researchers and educators are proclaiming (Rogers & Dunn, 1997; Roth, 1994; Roth & Bowen, 1995; Tobin & LaMaster, 1995). A scientifically minded individual may fail to act in a way that demonstrates the NOS if prior experience in the classroom context conflicts with such behavior. "Scientific spirit requires a man to be at all time ready to dump his whole cartload of beliefs, the moment experience is against them" (Peirce, 1955, p. 47).

Kelly's theory could certainly offer one explanation for teacher behaviors that do not align with sound understandings of the NOS. In his Fragmentation Corollary, Kelly states, " A person may successively employ a variety of construction subsystems which are inferentially incompatible with each other" (1955; 1969; 1970; 1977). In other words, individuals commonly engage in experiential experiments (behaviors) that appear to be in conflict. All four of the teachers who participated in this study exhibited behaviors that indicated a clear understanding of the NOS while in the TSP laboratory setting, but moving those experiential experiments into the contexts of their classrooms resulted in some behaviors that appeared incongruent with their understandings. I reiterate the clear evidence of the anticipatory systems found among the interactions and discourses of each of these teachers. (1) Diane anticipated few, if any, connections between her own learning in the TSP laboratory context and her past teaching/learning experiences in her classroom context. She therefore engaged in responding to the anticipations of the other teacher participants while in the laboratory, but made no anticipations of behaviors related to her own classroom—she internally invalidated any such anticipatory attempts as soon as they were conceived. (2) Julia anticipated connections between her TSP experiences and her classroom experiences, but strictly confined her anticipations so that they dealt only with repeating the specific activities and protocols that she had learned. The freedom to explore and question, the most essential element of the NOS, was omitted from Julia's anticipations of future classroom events and therefore from any possibility of experiential experiments. (3) As Martha enhanced her own learning in the TSP laboratory environment, she rehearsed very specific anticipations of classroom events. She further examined her anticipations by asking questions related to using experimental examples to enhance her existing repertoire of lesson plans, behavior that I see as seeking a type of external validation. Even after her summer experiences were completed, Martha sought additional external validation through continuing discourse with me immediately prior to enacting her anticipations regarding the use of experiments and strategies with her students. She sought my opinion related to lines of reasoning that she anticipated using to assist her students in developing their own constructions of science, as well as the protocols and processes that she thought were appropriate. Her cycles of experience came to fruition as she interacted with her students. (4) Sherry voiced anticipations of action that related her learning in the TSP laboratory setting to classroom contexts, but as she came nearer to making the Encounter a reality, her skeptical, critical intelligence caused her not to act. She became stuck in her cycle of experience as her prior experiences weighed toward the negative, and she failed internally to validate her anticipations. This led Sherry to continually abort her cycles of experience, instead developing a cycle that led her to perpetually re-Anticipate rather than Encounter. (A comparison between TSP context attributes and each teacher's classroom context attributes along with connections, as she perceived them, between her perspective classroom context attributes and the TSP context attributes is provided in Appendix C.)

Anticipations Toward Action

The iterative processes of reasoning and literature review allowed me to develop theory; theory that turns out to be remarkably congruent with Kelly's Personal Construct Theory. These processes have also moved my line of specified ignorance to a point where anticipations of future actions can be made: predictions to be tested through future experiential experiments. Using this line as a springboard for action, I must ask, "Now that I know, what do I do?" In my quest to answer this question I have redefined my role in terms of a new metaphor; I see myself—a science teacher educator (STE)—as Kelly sees the personal construct therapist. In this metaphor, the STE must accept the crucial fact that changes in education are dependent upon the abilities of teachers to transform themselves (Caine & Caine, 1997). Therefore, the STE as therapist should define the purpose for interactions as "not to produce a state of mind but to produce a mobility of mind that will permit one to pursue a course through the future" (Kelly, 1955, p. 208). My goal should be to help move teachers forward through cycles of experimentation, and to influence the direction of drift (Kenny, 1987). This movement is similar to the “scaffolding” in Vygotsky’s metaphor (except that it connotes a cyclic flow rather than a linear climb); that is, a social device for producing “movement along construct channels which will commit the client [teacher] to constructive action” (Kenny, 1987, ¶ 63). The secret of producing that movement is to continue the discourses. For, if there is one TRUTH salient from the current research it is this: Discourse was not only the way that I could visualize the lines that people drew, it was the instrument through which they learned to draw them.

Kelly recommended that the language used in therapeutic discourses should help an individual consider upcoming events propositionally. Asking “What do you think would happen if you tried this and so?” and continuing to ask such questions with modified anticipated actions until a positive outcome can be predicted, would enhance the probability that internal invalidations would be overcome. Once these internal validation tests are passed, behavioral experiments can be conducted; some will be externally validated while others may be refuted. But, no matter how the concluding outcomes of the behavioral experiments are weighed, the individual overcomes the fear of Encounter and can then modify anticipated behaviors appropriately so that anticipations are increasingly successful. The act of seeking external validation through experiments moves the individual into the Cognitive Reconstruction phase, and each succeeding Encounter becomes less difficult. Martha’s anticipations and verbal tests for external validation, followed by detailed rehearsals preceding her classroom actions, illustrate this point. It is my contention, however, that the discourse community—formed as individuals developed partnerships during the TSP summer experiences—must be extended to reach into classroom contexts. I have chosen to review an interpretive study by Tobin and LaMaster (1995), representative of recent literature in science education that presents classroom case studies, to illustrate the necessity for professional development to move across contexts.

Tobin and LaMaster (1995) presented a picture of a first-time teacher of middle- and high-school science as she struggled with remodeling her concept of the various roles a teacher plays. Although Sarah was the focus of the study, the researchers were very much aware of the need to consider the social setting and the interactions of all participants. This need to "listen to the voices of Sarah and the other participants" (Tobin and LaMaster, 1995, p. 227) supported the authors' claims that focus questions, methods, and interpretations constructed from the data agreed with a social constructivist philosophy, the tenets of which assume that knowledge is indivisible with the knower.

Participants included four of Sarah's colleagues who were also science teachers (all male), the school principal, and students in two science classes taught by Sarah. Sarah, through reflection and self examination, identified three problem areas that she felt were obstacles to establishing a constructivist classroom as she had intended. In previous research, relationships between metaphors used by science teachers to think about their roles and the teaching of science were identified (Tobin, 1990; Tobin, Tippins, & Hook, 1994, cited in Tobin & LaMaster, 1995). As "Sarah was aware that she conceptualized her teaching roles mainly in terms of metaphors...metaphors and associated images and language were referents for Sarah's actions" (Tobin & LaMaster, 1995, p. 226). The goal of the study was to build on this previous research to see if teachers could use metaphors as a basis for reconceptualizing their teaching roles, using Sarah's personal experiences and reflections.

Data included field notes, video recordings, and direct input from Sarah through transcripts of interviews as well as a journal begun the previous semester and kept throughout the study that continued for an additional semester. Data relating to students' descriptions of the interactions and classroom environment were archived. Discussion at early meetings centered on behavioral data but became more probing as the study went on. The researchers believed that if Sarah could understand why certain things were happening in her classroom, she could develop strategies for change.

Findings indicated that Sarah's teaching did change as she used metaphors and reflection to guide a plan of action. "Sarah changed her beliefs as she reflected on what happened in her classes and pondered ways to improve the learning of students…these changes in belief mirrored what was observed in the classroom" (Tobin and LaMaster, 1995, p. 239).

This study required the collection of a massive amount of data and an extraordinary time commitment. While demanding, this type of longitudinal study decreases the chances of affected behavior by the participants for the benefit of the research. Input and support from colleagues, school administrators, and science educators were essential for Sarah's change in beliefs and classroom practices. Characteristics displayed by administrators and colleagues as well as attitudes toward Sarah held by these individuals were mentioned briefly, but not delineated as essential components for systemic change. If teacher change (as depicted by Sarah in this study) cannot occur separately from changes in attitudes on the part of other school personnel, these attitudes should also be examined in detail. Further, these changes could not have taken place outside the classroom setting. This points out a weakness in professional development strategies that isolate teachers from the social learning situations occurring in classrooms. The discourses reported in this study through mini-vignettes clearly illustrated the subtle changes in mindset that occurred as Sarah adopted new metaphors for a multiplicity of teaching roles, and illustrates the metaphor of the STE as personal construct therapist that I have identified for my personal role. In terms of Kelly's theory, however, I would rephrase the major finding of Tobin and LaMaster in the following manner.

Sarah's discourse community allowed her to develop successive, increasingly successful anticipations of future classroom events; completed cycles of experience that took her from a teacher who clings to the security of antiquated teaching practices and beliefs about learning to a teacher who is comfortable with the chaos of complex, rich, and sometimes messy environments that stimulate students to transform their learning experiences.

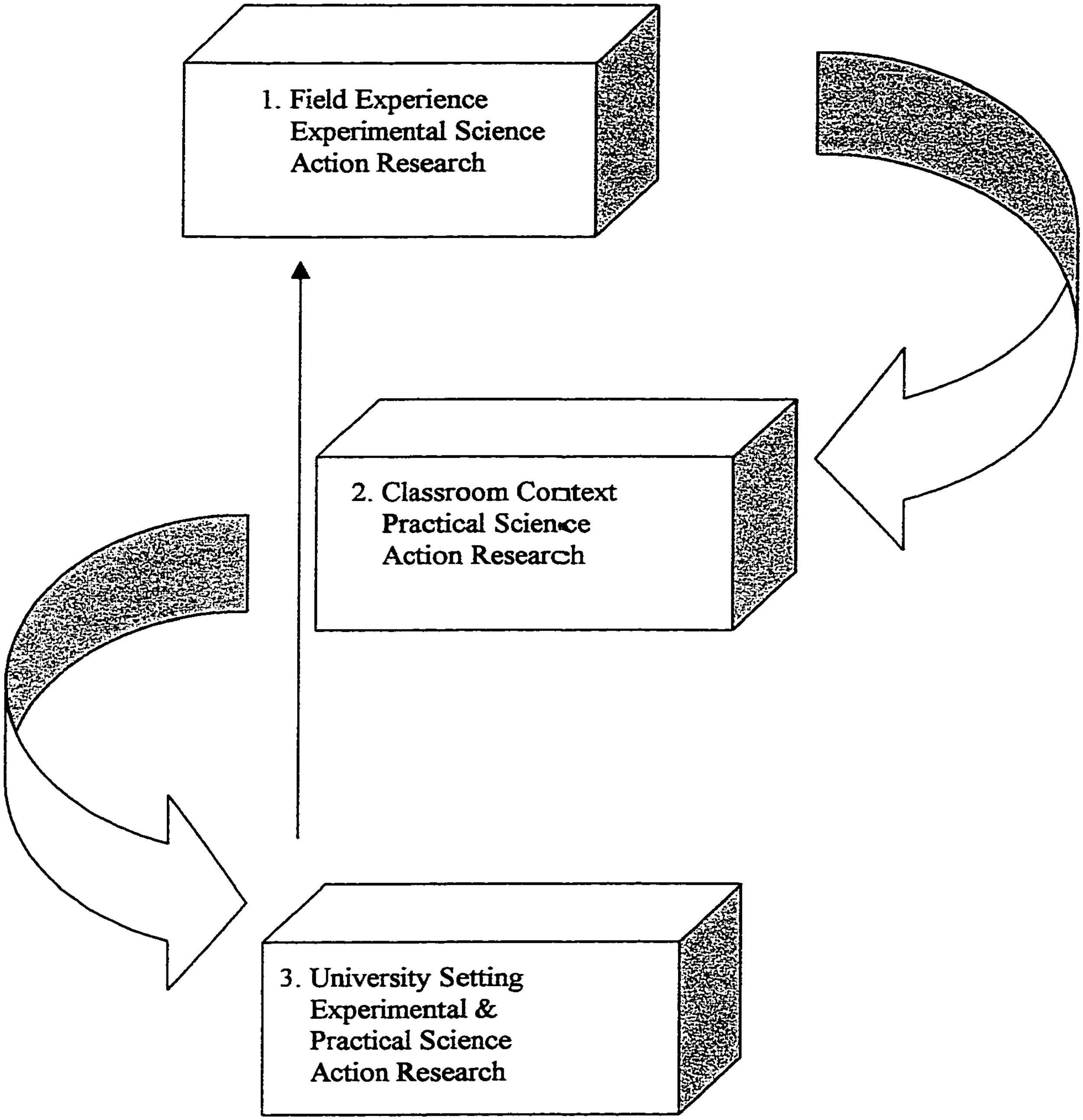
<u>The Experiential Experiment: A Model for Professional Development</u>

The summer laboratory experiences have proven to be catalysts for the transformation of teachers' thinking about science, especially in regard to the ways that they learned and practiced science in this context. Catalysts initiate a process or affect the speed at which that process occurs, but do not <u>support</u> the process to its completion. If the TSP is to effectively meet its goals related to classroom impact, I believe that it must become more than a catalyst; it must become a program of research where the discourse community established during this catalytic phase is supported through continuing discourse across contexts. I further believe that science educators at all levels of the science education hierarchy must practice science –continuously identifying phenomena, utilizing strategic research settings and materials (that is, conducting the research in the setting where the most accurate and pertinent data can be gathered—sometimes muticontextual), and defining the known from the unknown by drawing that line of specified ignorance that Merton (1987) identified as the "useful" type of ignorance. Furthermore the role of personal construct therapist may be shifted among the individuals of the discourse community according to context. While the STE can assume the therapeutic role in the context of the laboratory and K-12 classrooms, scientists and experienced K-12 classroom teachers can assume the role of therapist as they observe interactions among a STE and her students (preservice teachers) in the university context. This role shifting can only be done in multiple contexts if the partnerships initially formed are strong, non-threatening relationships.

The final outcome of my research is the development of a three-phase model for the continued metamorphosis of the TSP. As a way to contribute to the improvement of science education by extending the discourse community across contexts is now clear, a model of the TSP as a program of research has emerged. (For a graphic representation of this model, see figure 5, p. 143). Phase 1: As field experiences proceed, relationships are developed and a discourse community is formed. Teachers are engaged in genuine scientific inquiry where they develop an understanding of the nature and processes of science; scientist and STE become receptive to perceived needs and utilize insight to begin playing social roles as they understand teachers' anticipations (as these individuals are going through their own cycles, of course). Phase 2: Classroom research (also known as participatory or action research) perpetuates the types of interactions and activities of the field experience; teachers examine their classroom practices and reflect upon factors that enhance or stand in the way of scientific practices; the inquiry team is provided with opportunities for assisting teachers in moving through cycles of experience that lead them to incorporate more of the essence of science into their classroom in practical ways.

Phase 3: Learning from the field setting and the high school science classroom context is applied to the development of lessons and activities for preservice teachers in university settings; these lessons capture the nature and processes of science, and the praxis of classroom science. Ideally, preservice teachers would then engage in the field experiences of Phase 1, and a virtuous cycle of scientific practice that penetrates all levels of the educational hierarchy would result.

Figure 5: Model for Professional Development:
A Program of Research



References

Abd-El-Khalick, F., Bell, R.L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. Science Education, 82(4), 417-436.

Abd-El-Khalick, F. & Lederman, N. G. (1998). Improving science teachers' conceptions of the nature of science: A critical review. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Abraham, M.R. (1982). A descriptive instrument for use in investigating science laboratories. Journal of Research in Science Teaching, 19(2), 155-165.

Adler, P.A., & Adler, P. (1994). Observational techniques. In N.K. Denzin & Y.S. Lincoln (Eds.), Handbook of qualitative research (p. 377-392). Thousand Oaks, CA: Sage.

Aikenhead, G. (1973). The measurement of high school students' knowledge about science and scientists. Science Education, 57(4), 539-549.

Aikenhead, G. (1987). High school graduates' beliefs about science-technology-society: Characteristics and limitations of science knowledge. Science Education, 71(4), 459-487.

Alexander, P.A., Schallert, D.L., & Hare, V.C. (1991). Coming to terms: How researchers in learning and literacy talk about knowledge. Review of Educational Research, 61(3), 315-343.

Allen, L.R. (1967). An examination of the classification ability of children who have been exposed to one of the 'new'elementary science programs. Dissertation Abstracts, 28(7), 2591A.

Allen. L.R. (1971). An examination of the ability of first graders from the science curriculum study program to describe an object by its properties. Science Education 55(1), 61-67.

Allen, L.R. (1972). An evaluation of children's performance on certain cognitive, affective, and motivational aspects of the Interaction unit of the Science Curriculum Improvement Study. Journal of Research in Science Teaching, 9(2), 167-173.

Allen, L.R. (1973). An examination of the ability of third-grade children from the Science Curriculum Improvement Study elementary science program to identify experimental variables and to recognize change. Science Education, 57(2), 135-151.

Alper, J. (1994). Scientists return to the elementary-school classroom. Science, 264, 768-69.

Association for the Advancement of Science. (1989). Science for all Americans. New York, N.Y.: Oxford University Press, Inc.

Association for the Advancement of Science. (1993). Benchmarks for scientific literacy. New York, N.Y.: Oxford University Press, Inc.

Association for the Advancement of Science. (1997). National science education standards. New York, N.Y.: Oxford University Press, Inc.

Association for the Advancement of Science. (1999). Blueprints for reform. New York, N.Y.: Oxford University Press, Inc.

Ausubel, D.P. (1963). The psychology of meaningful verbal learning. New York, NY: Grune and Stratton.

Ausubel, D.P. (1968). Educational psychology. New York, NY: Holt, Rinhart & Winston.

Bates, G.R. (1978). The role of laboratory in secondary school science programs. In M.B. Row (Ed.), What research says to the science teacher. Washington, DC: National Science Teachers' Association.

Becker, H.S. (1998). Tricks of the trade: How to think about your research while you're doing it. Chicago & London: The University of Chicago Press.

Bogdan, R. C. & Biklen, S. K. (1992). Qualitative research for education: An introduction to theory and methods. Needham Heights, MA: Simon & Schuster, Inc.

Brickhouse, N.W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. Journal of Teacher Education, 41(3), 53-62.

Brockmeyer, M.A. (1998). The impact of an extended inquiry-based inservice program on the beliefs and practices of beginning secondary science teachers. Unpublished dissertation, University of Iowa.

Bybee, R.W. & Sund, R.B. (1990). Piaget for educators. Prospect Heights, Illinois: Waveland Press, Inc.

Caine, R.N. & Caine, G. (1994). Making connections: Teaching and the human brain. Menlo Park, CA: Addison-Wesley.

Caine, R.N. & Caine, G. (1995). Reinventing schools through brain-based learning. Educational Leadership, 52 (7), 43-47.

Caine, R.N. & Caine, G. (1997). Education on the edge of possibility. Alexandria, VA: Association for Supervision and Curriculum Development.

Carraher, T.N., Carraher, D.W. & Schliemann, A.D. (1985). Mathematics in the streets and in schools. British Journal of Developmental Psychology, 3(1), 21-29

Chen, K. T. (1990). Reversing sagging precollege skills in mathematics and science. Institute of Electrical and Electronics Engineers Spectrum, 44-48.

Claxton, G. (1991). Educating the inquiring mind: The challenge for school science. London: Harvester Wheatsheaf.

Cobern, W. (1991). World view theory and science education research Monograph of the National Association for Research in Science Teaching, 3. Manhattan: Kansas State University.

Connor, J.V. (1990). Naive conceptions and the school science curriculum. In M.B. Rowe (Ed.), What research says to the science teacher: Volume 6. The process of knowing. Washington, DC: National Science Teachers Association.

Costello, R.B. (Ed.). (1997). American heritage college dictionary, (3rd ed.), Boston & New York: Houghton Mifflin Company.

Dewey, J. (1916). Democracy and education. New York, NY: Macmillan

Dhondt, A.A., Telsch, K, & Tucker, D. (2000). Three perspectives: The scientist, the student, and the teacher. National Academy of Sciences Conference, [10/16/96]. Available: http://www.terc.edu/ssp/conf_rep/ncssp_6/threeper.htm.

DiRocco, M.D. (1999). How an alternating-day schedule empowers teachers. Educational Leadership, 56 (4), 82-84.

Dobbert, M.L. & Kurth-Schai, R. (1992). Systematic ethnography: Toward an evolutionary science of education and culture. In LeCompte, Millroy, & Preissle's (Eds.), The handbook of qualitative research in education. San Diego, CA: Academic Press.

Doyle, W. (1983). Academic work. Review of Educational Research, 53(2), 159-199.

Driver, R. (1998). Attitudes toward science: Issues and concerns. School Science Review, 79(288), 27-33.

Driver , R. & Bell, B (1986). Students' thinking and the learning of science: A constructivist view. School Science Review, 67(240), 443-456.

Duschl, R.A. & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. Journal of Research in Science Teaching, 26, 467-501.

Ebenezer, J.V. & Haggerty, S.M. (1999). Becoming a secondary school science teacher. Upper Saddle River, NJ: Prentice Hall.

Edwards, D.J.A. (1998). Types of case study work: a conceptual framework for case-based research. The Journal of Humanistic Psychology, 38(3), 36-60.

Eineder, D. V. & Bishop, H.L. (1997). Block scheduling the high school: The effects on achievement, behavior, and student-teacher relationships. NASSP Bulletin, 81(589), 45-54.

Eisner, E.W. (1998). The enlightened eye: Qualitative inquiry and the enhancement of educational practice. Upper Saddle River, NJ: Prentice Hall.

Epstein, R. & Skinner, B.F. (1982). Skinner for the classroom. Champaign, IL: Research Press.

Erickson, F. (1992). Ethnographic miroanalysis of interaction. In M.D. LeCompte, W.L. Millroy, & J. Preissle (Eds.), The handbook of qualitative research in education. (pp. 201-225). San Diego, CA: Academic Press.

Fitzpatrick, J. E. & Mowers, M. (1997). Success and the four block schedule: Stakeholders buy in! NASSP Bulletin, 81(588), 51-56.

Friedler, Y., & Tamir, P. (1984, April). Triangulation approach to research on science learning in the school laboratory. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Friedler, Y. & Tamir, P. (1986). Teaching basic concepts of scientific research to high school students. Journal of Biological Education, 24(4), 263-269.

Gall, M.D., Borg, W.R., & Gall, J.P. (1996). Educational research an introduction. White Plains, N.Y.: Longman Publishers USA.

Gallagher, J.J., & Tobin, K.G. (1991). Reporting interpretive research. In J.J. Gallagher (Ed.), Interpretive research in science education [Monograph, 4], 83-95. Manhattan, KS: National Association for Research in Science Teaching, Kansas State University.

Gardner, H. (1983). Frames of mind. New York, NY: Basic Books.

Gardner, H. (1993). Multiple intelligences: The theory in practice. New York, NY: Basic Books

Glaser, B., & Strauss, A. (1967). The discovery of grounded theory: Strategies for qualitative research. Chicago: Aldine.

Glasser, W. (1998). Choice theory: a new psychology of human freedom. New York, NY: Harper-Perennial.

Gunstone, R. F. & Champagne, A. B. (1990). Promoting conceptual change in the laboratory. In E. Hegarty-Hazel (Ed.), The student and the curriculum (159-182). London: Rutledge.

Hashweh, M.Z. (1996). Effects of science teachers' epistemological beliefs in teaching. Journal of Research in Science Teaching, 33 (1), 47-63.

Hofstein, A. & Lunetta, V.N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. Review of Educational Research, 52, 201-217.

Hurd, P.D.(1995). Reinventing the science curriculum: Historical reflections and new directions. In Bybee, R. W. & McInerney, J.D. (Eds.), Redesigning the science curriculum. Colorado Springs, CO: BSCS.

Igelsrud, D. & Leonard, W. (1988). Labs: What research says about biology laboratory instruction. American Biology Teacher, 50, 303-306.

Ivins, J.E. (1986). A comparison of the effects of two instructional sequences involving science laboratory activities. Dissertation Abstracts, 46(8), 2254A.

Jensen, E. (1998). Teaching with the brain in mind. Alexandria, VA: Association for Supervision and Curriculum Development.

Jenson, A.R. (1969). How much can we boost IQ and scholastic achievement? Harvard Education Review, 39, 1-124.

Jorgenson, D.L. (1989). Participant observation: A methodology for human studies. Newbury park, CA: Sage.

Judson, H.F. (1996). The eighth day of creation: Makers of the revolution in biology. Cold Spring Harbor, NY: Cold Spring Harbor Press.

Kahle, J.B. (1997). Teacher professional development: Does it make a difference in student learning? Testimony to the U.S. House of Representatives committee on Science [10/23/97]. Available: http://www.house.gov/science/kahle_061099.htm.

Kelly, G.A. (1955). The psychology of personal constructs. Volume 1. New York: Norton.

Kelly, G.A. (1969). Man's constructions of his alternatives. In: B Maher (Ed.) Clinical psychology and personality: The selected papers of George Kelly. New York: Wiley.

Kelly, G.A. (1970). A brief introduction to personal construct psychology: In: D. Bannister (Ed.) Perspectives in personal construct theory. London: Academic Press.

Kelly, G.A. (1977). The psychology of the unknown. In: D. Bannister (Ed.) New perspectives in personal construct theory. London: Academic Press.

Kemperman, G., Kuhn, H.G., & Gage, F. (1997). More hippocampal neurons in adult mice lining in an enriched environment. Nature, 386(6624), 493-495.

Kenny, V. (1984). An introduction to the personal construct psychology of George A. Kelly. Irish Journal of Psychotherapy, 3. Available: http://www.oikos.org/vincpcp.htm.

Kenny, V. (1987). Anticipating Autopoiesis: Personal construct psychology and self-organizing systems. Paper presented at Psychotherapie En Autonome Systemen, De Senaatszaai Van Het Academiegebouw Der Rijksuniversiteit, Domplein 2, Utrecht, Holland. Available: http://www.oikos.org/vincautopo.htm.

Kotulak, R. (1993). Inside the brain. Kansas City, MO: Andrews & McMeel.

Kriegel & Brandt. (1996). Sacred cows make the best burgers: Paradigm-busting strategies for developing change-ready people and organizations. New York, NY.: Warner Books, Inc.

Kyle, W.C. & Bonnstetter, R.J. (1992). Science curriculum improvement study: Profile of excellence. Hudson, JH: Delta Education.

Langenbach, M., Vaughn, C. & Aagaard, L. (1994). An introduction to educational research. Needham Heights, MA: Simon & Schuster, Inc.

Laszlo, E. (1996). The whispering pond: A personal guide to the emerging vision of science. Rockport, MA: Element Books, Inc.

Lather, P. (1991). Getting smart. New York, NY: Routledge, Chapman and Hall, Inc.

Lawson, A. E. (1975). Developing formal thought through biology teaching. American Biology Teacher, 37(7), 411-419,429.

Lawson, A. (1999, March). Is there a scientific method: The neurological basis and pattern of scientific thought. Paper presented at the annual convention of the National Association for Research in Science Teaching, Boston, MA.

Lawson, A.E., Abraham, M.R. & Renner, (1989). A theory of instruction: Using the learning cycle to teach science concepts and thinking skills. NARST Monograph, 1.

Lawson, A.E. & Renner, J. W. (1975). Piagetian theory and biology teaching. American Biology Teacher, 37(6), 336-343.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29(4), 331-359.

Lederman, N.G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. Journal of Research in Science Teaching, 36(8), 916-929.

Lederman, N.D. & O'Malley, M. (1990). Students' perceptions of the tentativeness in science: Development, use, and sources of change. Science Education, 74(2), 225-239.

Lederman, N.G., Wade, P. & Bell, R.L. (1998). Assessing understanding of the nature of science: A historical perspective. The nature of science in science education, (331-350). Netherlands: Kluwer Academic Publishers.

Lederman, N.G. & Zeidler, D.L. (1987). Science teachers' conceptions of the nature of science: Do they really influence teaching behavior? Science Education, 71(5), 721-734.

Lichtman, M. (1990). The best for our kids: Exemplary elementary guidance & counseling programs. American Association for Counseling and Development: Alexandria, VA.

Lazarowitz, R. & Tamir, P. (1994). Research on using laboratory instruction in science. In D.L. Gabel (Ed.), Handbook of research on science teaching and learning (45-93). New York, NY: NSTA

Maor, D. & Taylor, P.C. (1995). Teacher epistemology and scientific inquiry in computerized classroom environments. Journal of Research in Science Teaching, 32(8), 839-854.

Marek, E.A. & Cavallo, A.M.L., (1995). Passkeys to learning science in the elementary schools: The data and language of science. Journal of Elementary Science Education, 7(1), 1-15.

Marek, E.A. & Cavallo, A.M.L. (1997). The learning cycle: Elementary school science and beyond. Portsmouth, NH: Heinemann.

Marek, E.A., Eubanks, C. & Gallaher, T.H. (1990). Teachers' understanding and the use of the learning cycle. Journal of Research in Science Teaching, 27(9), 821-834.

Marek, Haack & McWhorter (1994). Long-term use of learning cycles following inservice institutes. Journal of Science Teacher Education, 5(2), 48-55.

Marek, E.A. & Renner, J.W. (1979). Intellectual development, IQ, achievement, and teaching methodology. The American Biology Teacher, 41(3), 145-150.

Marek, E.A., & Westbrook, S.L. (1990). The development and evaluation of a model inservice program for secondary school science teachers. Washington, DC: National Science Foundation.

McNally, D.W. (1974). Piaget education and teaching. Sydney: Argus & Robertson.

Merton, R.K. (1987). Three fragments from a sociologist's notebooks: Establishing the phenomenon, specified ignorance, and strategic research materials. Annual Review of Sociology, 13, 1-28.

Miller, J.D. (1989) Scientific literacy. Paper presented at the annual meeting of the American Association for the Advancement of Science. San Francisco, CA.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Research Council. (1996). The role of scientists in the professional development of science teachers. Washington, DC: National Academy Press.

Palmquist, S.R. (1993). Kant's system of perspectives: An architectonic interpretation of the critical philosophy. New York, NY: University Press of America.

Peirce, C.S. (1955). The scientific attitude and fallibilism. In: Buchier (Ed.) Philosophical writings of Peirce. New York: Dover.

Pert, C. (1997). Molecules of emotion. New York, NY: Charles Scribner's Sons.

Phillips, I.D. (1997). On the block: A hot trend in class scheduling is giving high school educators a whole new way to manage time. (pros and cons of block scheduling). Techniques, 72(6), 32-38.

Piaget, J. (1964a). Cognitive development in children. Journal of Research in Science Teaching, 2(3), 176-186.

Piaget, J. & Inhelder, B. (1969). The psychology of the child. New York, N.Y.: Basic Books.

Pope, M. & Gilbert, J. (1983). Personal experience and the construction of knowledge in science. Science Education, 67(2), 193-203.

Posner, G., Strike, K., Hewson, P. & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Renner, J.W. & Marek, E.A. (1990). An educational theory base for science teaching. Journal of Research in Science Teaching, 27(3), 241-246.

Renner, J.W., Stafford, D.G., Coffia, W.J., Kellogg, D.H. & Weber, M.C. (1973). An evaluation of the Science Curriculum Improvement Study. School Science and Mathematics, 73(4), 291-318.

Roberts, D.A. (1982). The place of qualitative research in science education. Journal of Research in Science Teaching, 19 (4), 277-292.

Rodgers, D.B. & Dunn, M. (1997). And never the twain shall meet: One student's practical theory encounters constructivist teacher ed practices. Journal of Teacher Education, 18(3), 10-25.

Rogers, S. & Renard, L. (1999). Relationship-driven teaching. Educational Leadership, 57(1), 34-39.

Roth, W-M. (1994). Experimenting in a constructivist high school physics laboratory. Journal of Research in Science Teaching, 31(2), 197-223.

Roth, W-M & Bowen, G.M. (1995). Knowing and Interacting: A study of culture, practices, and resources in a grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. Cognition and Instruction, 13(1), 73-128.

Roth, W-M. & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. Journal of Research in Science Teaching, 30(2), 127-152.

Saunders, W.L. & Shepardson, D. (1987). A comparison of concrete and formal science instruction upon science achievement and reasoning ability of sixth-grade students. Journal of Research in Science Teaching, 24(1), 39-51.

Schneider, L.S. & Renner, J.W. (1980). Concrete and formal teaching. Journal of Research in Science Teaching, 17(6), 503-517.

Shortt, T.L. & Thayer, Y.V. (1999). Block scheduling can enhance school climate. Educational Leadership, 56 (4) 76-81.

Shymansky, J.A., & Kyle, W.C., Jr. (1992). Establishing a research agenda: Critical issues of science curriculum reform. Journal of Research in Science Teaching, 29(8) 749-778.

Snyder, S. & Frechtling, J. (1997). The need for better evaluations of professional development programs. In The Fifth National Evaluation Institute: Synthesis and Reflections. [2/15/97].

Solomon, J. (1987). Can pupils use analogies for electric current? School Science Review, 69 (247), 249-54.

Solomon, J. (1991). Group discussions in the classroom. School Science Review, 72 (261), 29-34.

Stake, R. E. & Easley, J. (1978). Case studies in science education. Urbana-Champaign. University of Illinois, Center for Instructional and Curriculum Evaluation.

Strauss, A.L. & Corbin, J.M. (1990). Basics of qualitative research. Newberry Park, CA: Sage Publications, Inc.

Suckow, W. W. (1990). Physical science workshops for teachers using interactive science exhibits. School Science and Mathematics, 90 (1), 42-47.

Sutman, F.X., Hiilosky, A., Priestley, W.J. & Priestley, H. (1999, March). Implications for the use of the inquiry matrix in professional enhancement experiences. Paper presented at the annual convention of the National Association for Research in Science Teaching, Boston, MA.

Svolopoulos, V.C. (1995). A study of science teachers' experiences in a science research internship. Unpublished dissertation, New York University, Syracuse.

Sutton, J. T. (1989). Mathematical tasks and the NCTM curriculum and evaluation standards. Mid-continent Regional Education Lab: Aurora, CO.

Tobin, K. (1990). Research on laboratory activities: In pursuit of better questions and answers to improve learning. School Science and Mathematics, 90(5), 403-418.

Tobin, K. & Gallagher, J.J. (1987). What happens in high school science classrooms? Journal of Curriculum Studies, 19(6), 549-560.

Tobin, K. & Gallagher, J.J. (1987). The role of target students in the classroom. Journal of Research in Science Teaching, 24(1), 61-75.

Tobin, K & LaMaster, S.U. (1995). Relationships between metaphors, beliefs, and actions in a context of science curriculum change. Journal of Research in Science Teaching, 32(3), 225-242.

Tobin, K., Tippins, D.J. & Gallard, A.J. (1994). Research on instructional strategies for teaching science. In D.L. Gabel (Ed.), Handbook of research on science teaching and learning (45-93). New York, NY: NSTA.

Toothacker, W. S. (1983). A critical look at introductory laboratory instruction. American Journal of Physics, 51, 516-520.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Vygotsky, L.S. (1981). The genesis of higher mental functions. In J.V. Wertsch (Ed.), The concept of activity in Soviet psychology. Armonk, NY: Sharpe.

Ward, C.R. & Herron, J.D. (1980). Helping students understand formal chemical concepts. Journal of Research in Science Teaching, 17(5), 387-400.

Wandersee, J. H. Mintzes, J.J & Novak, (1994). Biology from the learners' viewpoint: A content analysis of the research literature. School Science and Mathematics, 89(8), 654-668.

Welch, W.W., Klopfer, L.E., Aikenhead, G.S., & Robinson, J.T. (1981). The role of inquiry in science education: Analysis and recommendation. Science Education, 65(1), 33-50.

Wells, G. (1999). Dialogic inquiry in education: Building on the legacy of Vygotsky. Available: http://www.oise.utoronto.ca/~gwells/NCTE.html.

Westbrook, S.L. & Marek, E.A. (1991). A cross-age study of student understanding of the concept of diffusion. Journal of Research in Science Teaching, 28 (8), 649-660.

Wheatley, G. H. (1991). Constructivist perspectives on science and mathematics learning. Science Education, 75(1), 9-21.

Wheeler, G. (1998). Science, 279, 1611.

Wier, E.A. (1991). Scientists and elementary teachers: Partners in science teaching. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, Lake Geneva, WI, April.

Wier, E.A. (1993). Scientist and teacher partnerships in elementary schools. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA., April.

Yager, R.E. & Zehr, E. (1985). Science education in U.S. graduate institutions during two decades. Science Education, 69(2), 163-169.

Youniss, J. & Damon, W. (1992). Social construction in Piaget's theory. In H. Beilin & P. Pufall (Eds.) Piaget's theory: Prospects and possibilities, p. 267-286.

Zucker, A.A., Young, V.M., & Luczak, J.M. (1996). Evaluation of the American association of rate advancement of science's Project 2061: Executive summary. Menlo Park, CA: SRI International.

APPENDIX A

IRB APPROVAL

The University of Oklahoma

OFFICE OF RESEARCH ADMINISTRATION

July 6, 1999

Ms. Robbie V. McCarty
3001 Pheasant Run Road #219
Norman OK 73072

Dear Ms. McCarty:

Your research application, "Scientist-teacher Interaction: Moving Toward Partnership?," has been reviewed according to the policies of the Institutional Review Board chaired by Dr. E. Laurette Taylor and found to be exempt from the requirements for full board review. Your project is approved under the regulations of the University of Oklahoma - Norman Campus Policies and Procedures for the Protection of Human Subjects in Research Activities.

Should you wish to deviate from the described protocol, you must notify me and obtain prior approval from the Board for the changes. If the research is to extend beyond 12 months, you must contact this office, in writing, noting any changes or revisions in the protocol and/or informed consent forms, and request an extension of this ruling.

If you have any questions, please contact me.

Sincerely yours,

Susan Wyatt Sedwick

Susan Wyatt Sedwick, Ph.D.
Administrative Officer
Institutional Review Board

SWS:pw
FY99-258

cc: Dr. E. Laurette Taylor, Chair, Institutional Review Board
Dr. Edmund A. Marek, Instructional Leadership & Academic Curriculum

1000 Asp Avenue, Suite 314, Norman, Oklahoma 73019-0430 PHONE: (405) 325-4757 FAX: (405) 325-6029

APPENDIX B

INFORMED CONSENT FORM

APPENDIX B

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH

This research is being conducted under the auspices of the University of Oklahoma-Norman Campus. This document serves as the participant's consent to participate.

INTRODUCTION

The study, "Scientist-teacher interaction: Moving Toward Partnership?" is being conducted by Robbie Von McCarty and is sponsored by Dr. Edmund A. Marek.

DESCRIPTION OF THE STUDY

The purposes of the study are (1) to examine the dynamics of a research scientist-science teacher group interaction, (2) identify the components of partnership that assist a scientist in accepting the role of science educator and science teachers in seeing themselves as scientists, and (3) to generate theory regarding the design of interaction that can serve as a working model for building future partnerships.

POTENTIAL BENEFITS AND RISKS OF PARTICIPATION

The results of this study should encourage you to consider yourself part of the scientific community. Further, it should offer suggestions for building interactions with your students as co-researchers, just as you are co-researchers in the summer project. The study will also provide you with support if you wish to approach school administrators with plans for implementing scientific inquiry techniques into lesson plans.

While generalizations made from qualitative studies with small samples are not transferable directly to populations, insight gained from the study could contribute to curriculum mapping for the development of courses with high probabilities of stimulating conceptual change in students.

PARTICIPANT'S ASSURANCES

Participation in this study is purely voluntary and you may withdraw at any time without penalty. If you choose not to participate in this project your standing in the project and receipt of stipend will not be affected. The stipend remains $5,000 for the completion of the entire program as stated in the original information that was sent with your application. The field portion of the study will be conducted for a period of six weeks, beginning July 1, 1999 and continuing through August 15, 1999. During that time, video and audio recordings will be made and used to examine the dynamics of interaction. These recordings will be transcribed and analyzed, with authentication verified by you at the request of the researcher. In addition, some existing documents will also be obtained to add to the data. These documents will include the applications submitted by you when you applied to the program as well as documents presented to funding agencies, which describe the summer program. Additional documents may include lesson plans or assessment instruments that you use in your classroom, if you choose to share them with the other teachers participating in the summer project. Follow-up interviews and authentication could extend into the following school year, but the study will proceed for a period not to exceed twelve months.

Your confidentiality will be protected at all times. When not in the possession of the researcher, all video, audio and transcript records will be kept in a locked cabinet. At the completion of the study, all recordings will be destroyed through incineration. Neither your name, title nor specific identifying information will appear in papers or published reports. If you have any questions about the research project you may contact me, Robbie Von McCarty, at 405.366.1332. If you have questions regarding your rights as a research participant please call the Office of Research Administration at 405.325.4757.

I agree to participate in the study described above.

______________________________	______________________________
Participant's Signature	Date
______________________________	______________________________
Researcher's Signature	Date

APPENDIX C

CONTEXT ATTRIBUTE COMPARISON

APPENDIX C

Each set of contextual constructs that contributes to an individual's overall personal construct theory (PCT) has multiple dimensions. Because interest for this study lies in the conceptual system labeled epistemology, or the nature of learning, the dimensions of each context, along with some of its attributes or properties (the list is selective and not meant to be construed as all-inclusive) can be defined as answers to the following questions.

- Who is the learner? This dimension includes the attributes of maturity, developmental level, motivation, potential, and former learning experiences.
- What type of environment is provided for the learner? The attributes within this dimension include class size (or the learner to teacher ratio), availability of appropriate artifacts and supplies, and whether the learner must function independently or is given opportunities for interactions and discourses with both mentors and peers.
- What is to be learned? This dimension includes attributes concerning the setting of priorities. Major foci may be content, technical processes, problem-solving processes, and language appropriate to the subject matter.
- What strategies utilized by the teacher/mentor contributed to the learning? Attributes or properties of this dimension would include the use of lecture, printed materials or "readings", analogy, study notes, story telling, and questioning.
- When is learning expected to occur? Attributes of this dimension deal with real time aspects.

Attributes of these five dimensions of contextual constructs that teachers built during the TSP laboratory experiences, validated through participant verification, were described as follows.

TSP CONTEXT

- Learners: Mature individuals who were highly motivated and capable of functioning at an abstract level of reasoning made up the learner group.
- Environment: A 5:1 mentor to learner ratio (including the researcher as a learner), a rich supply of resources (artifacts, supplies, and technology), and on-going opportunities for collaboration provided an enriched environment.
- Learning: Problem-solving processes were of the utmost priority, with technical processes included only as necessary for the development of content knowledge, with language acquisition as a natural outcome of these processes.
- Strategies: Daily interactions included critical questioning, analogies, discussion of "readings" as individuals became interested in and saw the need for printed information, study notes in the form of laboratory notebooks and personal journals, and story-telling as a way of bringing the history of scientists and their discoveries into the experiments and learning processes.
- Time: The only deadline that participants had to meet was the eight-week end-of-project timeline for scholarly presentations.

DIANE'S CLASSROOM CONTEXT

Diane did not use any of the activities from the field experiences the following school year, and she did not significantly change any of her teaching practices. Although she reported using more inquiry, further examination revealed that her definition of inquiry was limited to using more questioning techniques during class discussions. This finding is consistent with that of Marek et al (1994), who found that even teachers in the "low use" learning cycle category reported using questioning procedures. This is also congruent with the claim that Rogers & Dunn make regarding students [preservice teachers]: that "they may only be adopting some practices which can be easily assimilated into their exiting practical theories" (1997, p.10). Diane's lack of change in classroom practices resulted largely from the lack of similarity between contextual constructs.

- Learners: Students were junior and senior level, with cognitive abilities that varied from concrete to abstract. Learners in Diane's Anatomy and Physiology course were somewhat more motivated than average students because the course was an elective, and they chose to be involved. Diane saw her students as similar to herself only in that she believed them to be visual learners and that they needed "hands-on" experiences such as dissection in order to learn the anatomical placement of organs. She did not see her students as being highly motivated like herself.
- Environment: Student to teacher ratio in this course averaged 20:1. Artifacts other than printed materials for student use were limited to cats and dissection instruments. Detailed instructions were provided for student explorations involving the anatomy of the cats, and interactions occurred almost exclusively between lab partners, or between individual students and Diane.
- Learning: Priority in Diane's Anatomy and Physiology course was given to content knowledge and language acquisition, with the memorization of

anatomical structures and functions being the most important knowledge for students to gain. Diane's course was no exception.

- Strategies: In order to accomplish the content and language goals for the course, Diane made use of lecture and study notes. However, she did see that she could modify this dimension of her previously held classroom PCT by adding the attribute of questioning during class discussions and pre-examination reviews.
- Time: Diane's class met for 80 minutes each day for one semester. This time frame allowed students to perform dissections, work on reports, and present their work to the class at times. Diane did have to provide structure in order to accommodate the activities during this time frame however.

JULIA'S CLASSROOM CONTEXT

Julia focused more on the inclusion of activities and experiments for her students than on developing the habits of mind and manner that promote genuine inquiry. She did improve her classroom climate: she devoted more time for students to interact with scientific equipment and materials, and to work in teams, but the main reason for the "teamwork" was to complete the experiment rather than to challenge team members' thinking. Julia was tenacious in her efforts to procure additional equipment and supplies, even to the extent of approaching industries in her area for funding.

- Learners: Students were multi-grade, but each grade level was grouped into a specific course with the exceptions of the physics and chemistry classes, which contained both junior and senior students. Cognitive abilities varied from concrete to abstract, with abstract thinkers almost exclusively in the chemistry and physics classes. As a general rule, students' former learning experiences in science have been in environments provided by Julia, unless they are 8th grade students who are entering her classes for the first time. Julia saw her students as being less motivated and curious than her.

- Environment: Student to teacher ratio averaged 10:1. Scientific artifacts had been in short supply prior to Julia's involvement in the TSP. Supplying more equipment and materials for student manipulation was the major way that Julia saw of creating a classroom environment that would be more similar to her learning environment in the TSP. Julia's previously held PCT (that students must do their own work) was modified to allow for teams of students to work together to accomplish a task.
- Learning: In her previously held beliefs, Julia's number one priority was content knowledge accompanied by language acquisition. Julia's anticipations and behavior was modified by the addition of technical processes as necessary to complete the experiments that she introduced, and problem-solving processes were occasionally emphasized.
- Strategies: Julia's previously held belief dictated that she provided lectures and study notes if she expected learning to occur. In order to share the experiments that she found personally rewarding for herself with her students, Julia modified her pre-existing belief. The modifications were made in a manner that was "true" to her previous belief, however, by designing highly structured lessons and instructions that she felt students could follow, and sometimes did the experiments as demonstrations. Julia also added questioning strategies to her repertoire, although she continued to feel "unnatural" doing so at times.

- Time: Julia's classes met for 45-minute class periods—they had previously med for 80 minutes on a block schedule. This time frame reinforced Julia's belief that she must provide highly structured lessons; she had to be sure activities and experiments could be completed in such a short time.

MARTHA'S CLASSROOM CONTEXT

Martha connected her own learning to her students' learning from the beginning of the project, as in evident in the accounts of her discourses. She perpetually engaged in role playing: asking questions and making comments from a secondary school science student's point of view. She believed that if she were curious or excited about an experiment or result that her students would be too. Although modifications had to be made so that activities could be used within the time frames and levels of cognitive development of her students, Martha kept the essence of discovery as she developed lessons and activities for her students by guiding student research through questioning tactics very similar to those Paul used during her TSP laboratory experiences. This finding is consistent with a substantive body of research that shows that learners imitate the behavior of role models that they hold in high esteem (Bandura & Walters, 1963, cited in Rogers and Dunn, 1997).

- Learners: Martha's students were in grades eight through twelve and ranged in potential cognitive levels from concrete to abstract. However, students in similar age groups and cognitive levels were grouped together, which facilitate the preparation of lessons. Martha's social nature contributed to her learning, and she believed that her students learned in ways similar to her own. She held this belief before her participation in the TSP summer experience, which allowed her to engage in role playing and rehearse conversations that she anticipated having with her students.

- Environment: Student to teacher ratio in most of Martha's courses averaged 10:1, although the two courses that she was free to redesign had a student to teacher ratio of 7:1. Martha had received grants that allowed her to purchase equipment and supplies and her TSP experiences guided her decisions when ordering. Martha's social nature impacted classroom environment as well, and she had always encouraged group interaction and discussion. Her participation in the TSP reinforced her belief that students learn through challenging interaction, and she incorporated even more group activities.
- Learning: Priority in Martha's classes was previously given to "real world" applications. She doggedly connected each learning experience with areas of students' lives and attempted to help them see that science is a fact of daily life. She continued to set this priority, and in addition Martha promoted learning technical processes as needed, expected that appropriate language would be accumulated naturally through the learning experiences, and contributed more time to problem-solving activities.
- Strategies: Martha used lecture and study notes as methods of facilitating learning, but depended more on discussion and interactive review sessions and responses to her questions as formative assessments of student learning. She modified her pre-TSP belief in this dimension by incorporating analogies and story telling (regarding the scientists she had learned about) as well as expanding

the use of questioning to guide student learning rather than using questions as assessment tools only.

- Time: Martha had only 45-minute class period in which to engage her students in active learning. She had always structured activities so that they could be completed. She modified this dimension of her belief to develop a long-term, project-approach course in order to provide students with opportunities to design their own experiments rather than performing "canned" laboratory exercises. Prior to her TSP experiences she had not visualized a way to accomplish this with the time constraints that existed.

SHERRY'S CLASSROOM CONTEXT

Sherry did not use the experiments from the TSP, and did not significantly change her teaching practices. Although she expressed a deep desire to make changes, Sherry found herself in a mental struggle. She truly wanted to create a learning environment that was rich and fun, as she had experienced during the summer; but she could not make it work for her classroom—there were just too many differences between the classroom and the laboratory. As we spoke, however, Sherry declared that the differences exist more in her mind than in reality. The descriptions of the dimensions of Sherry's classroom beliefs identify factors that were obstacles standing in the way of Sherry's desire to implement change.

- Learners: Sherry's students were in 10^{th} grade, and ranged in potential cognitive levels from concrete to abstract even though they were all similar in age. They also differed in cultural background and travel experiences, as many of them were military dependents. Sherry saw herself as very different from the majority of her students, and did not modify her classroom PCT in this dimension. She was highly motivated, curious, loved science, and had a skeptical nature. She felt that her students were just the opposite—apathetic about school in general and science in particular.

- Environment: Student to teacher ratio in Sherry's classes averaged 25:1. Sherry had accumulated adequate supplies and equipment over her 15 years of teaching, but found that she and the other science teachers did not use all of the equipment that they had. Sherry's skeptical nature and sense of humor contributed to an interactive atmosphere in her classes, but the interaction was mostly between her and students. She found that when students had too much time to interact they usually squandered their time and did not complete tasks.
- Learning: Priority in Sherry's classes was given to introductory biology content with knowledge of the appropriate terms as an indicator of learning. The reasons for prioritizing content lay mainly with the importance that Sherry placed on her students being adequately prepared to function in college, although Sherry also attempts to connect science to the daily lives of her students during class discussions. She also felt that it was important for students to gain familiarity with the laboratory apparatuses used in science, so prepared lessons that included experiments.
- Strategies: Sherry found lecture and study notes to be the tools that she used most frequently. She had used class discussions, but saw them as somewhat limited to question-and-answer reviews after her TSP experiences. She had made a habit of added at least one additional laboratory activity per semester to her repertoire of

teaching tools, but described these experiences as "cookbook", or highly structured verification-type laboratories. After her participation in the TSP Sherry saw a need, and developed a strong desire, to change the design of these experiences. However, her practices remained the same.

- Time: Sherry had 80-minute class periods with which to interact with her students, but found that she had difficulty holding their attention for an entire class. The implementation of the 4 X 4 block had allowed her to implement more laboratory experiences, but these remained very structured with directions written in a way that emphasized what students should do to make sure they remained "on task", rather than questions designed to stimulate discourse and debate.