PERCEPTIONS OF PHYSICS TEACHERS WHO HAVE PARTICIPATED IN A CONSTRUCTIVIST IN-SERVICE EXPERIENCE

by

WALTER ROSS SNOW

under the direction of Dr. David F. Jackson

ABSTRACT

This dissertation study was conducted to examine the perceptions held by physics teachers who have participated in a constructivist in-service experience. Six participants were each observed in their classrooms and interviewed twice. They were asked to share their perceptions of what constitutes effective science teaching, effective student science learning and how they perceived the influence of their participation in the in-service training program on their views of effective science teaching and effective student science learning. The findings of this study indicated that the most common perception held by these teachers is that effective science teaching and effective student science learning both involve a shift in the control of the learning process from teacher to student. The teachers perceived that there needs to be a reduction in the visible role of the teacher as compared to the traditional, lecture-centered approach and that there needs to be an increase in student-student interaction. In regard to the influence of the in-service experience, several of the teachers expressed the perception that their understanding of some of the fundamental concepts of physics had meaningfully increased as a result of their participation in the program. Although the teaching style of all of the participants can be described as social constructivist, the findings suggest that the more experienced teachers give less credit to their in-service experience and seemed to have already adopted a distinctly social constructivist approach on their own. One possible implication of this study may be that designers of in-service programs for science teachers might need to take more into account both the subject matter background and the level of teaching experience of the participants for whom a program is intended.

INDEX WORDS: Alternative conceptions, Conceptual change, Constructivism, In-service programs, Modeling, Physics education, Physics in-service, Social constructivism, Teacher perceptions.

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This dissertation is dedicated to my loving wife, Dr. Sue Ellen Snow,
my children, David and Brian Snow, and Cassie and Jonathan Cain,
for always being there to listen, encourage, comfort, support and love.
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INTRODUCTION

In the summer of 1988, I was a veteran chemistry teacher who suddenly found myself out of a job due to the mysteries of school finance and taxpayer rebellion. Confident that there were jobs available in more economically stable school districts nearby, I reactivated several of my job applications from the previous year and went knocking on doors. The best teaching assignment I was able to find was a position teaching college preparatory and Advanced Placement <u>physics</u> at a large, local suburban high school. Needing to argue that some of my physical chemistry credits should also count as physics credits just to survive an accreditation audit, I knew I would need to find a way to strengthen my content-area knowledge in physics. A serious illness in the summer of 1989 forced me to drop out of a physics class at Arizona State University and I spent the following school year looking for another good opportunity.

That opportunity appeared in the form of a physics teacher workshop at Arizona State University entitled the "Modeling Physics Workshop," hereinafter referred to as the Modeling Program, whose purpose was to pilot an innovative approach to teaching the mechanics portion of introductory high school physics. This program was based on research in physics education which indicated that the most effective physics teaching involved teaching for conceptual change using constructivist techniques while formally acknowledging and addressing student preconceptions. The Modeling Program was co-created by Dr. Malcolm Wells, veteran high school physics teacher in Tempe, Arizona, and Dr. David Hestenes, professor of physics at Arizona State University (ASU). Wells earned his doctorate at Arizona State with Hestenes heading his doctoral committee. Together they applied for an NSF grant to create a physics teacher education program based upon their research and Wells' attempts to use the Modeling methodology in his own classroom.

My experience with the program encompassed the summers of 1990 and 1991 and a follow-up week in 1992. The program has continued in a one-summer format ever since, expanding every year both in number of participants involved and in number of locations across the country. The scope of the program has also increased to include topics traditionally reserved for the second semester of introductory physics, such as waves, light and sound, optics, and electricity and magnetism. I consider myself fortunate to have been a part of that pilot group and I feel that my participation in the program has changed me profoundly.

Rationale

The National Science Education Standards state that "Professional development for a teacher of science is a continuous, lifelong process." (National Research Council, 1996, p. 57) Yet, in spite of what they termed "the widely-acknowledged importance of in-service professional development activities," Neuschatz and McFarling (1999) reported, in a large-scale survey of physics teachers commissioned by the American Institute of Physics, that only half of all physics teachers had participated in as much as a single day-long workshop, meeting, or course during the year prior to the survey. They also reported that only one-third of those physics teachers surveyed have degrees in either physics or physics education.

One way for teachers to improve their content knowledge, such as when they are assigned to teach more advanced level courses or are assigned to teach courses outside their certificated area of expertise, is to take university-level science content courses. Unfortunately, most of these courses are not specifically designed for teachers. In the sixties and early seventies, the National Science Foundation sponsored a number of summer programs for science teachers that consisted almost entirely of science content but those programs were later eliminated in favor of more pedagogically-oriented ones. I earned my own Master’s degree in Chemistry through one of those content-oriented programs. It can be argued that those programs were an early attempt at teaching “pedagogical content knowledge” even before Shulman created a name for it in 1987, but my personal recollection is that the program in which I participated was not significantly different from the chemistry courses I had taken as an undergraduate.

Another way for teachers to maintain and improve their teaching is to attend in-service training programs. The majority of in-service programs I have encountered have generally involved new technology such as data collection with CBL's (calculator-based labs) and have been of short duration, usually one day. Programs this short appear to operate under the assumption that the teacher has picked up his or her content knowledge elsewhere and is looking for newer and more effective ways of delivering that content to students. There is a considerable body of recent research (Garet, Porter, Desimone, Birman, & Yoon, 2001; Kahle & Boone, 2000; Supovitz & Turner, 2000; van Driel, Beijaard, & Verloop, 2001) that shows the relative ineffectiveness of programs of such short duration.

I feel very fortunate to have encountered the opportunity to participate in the Modeling Program. The essence of the program is that physics can be taught more effectively if student misconceptions about physics are explicitly addressed in advance and more scientifically acceptable conceptions are developed to replace them using a wide variety of different models. In order to participate in this program, candidates had to have both a strong content background in physics and substantial physics teaching experience. The purpose of the pilot program was to develop a set of laboratory experiments and follow-up activities and to train teachers in the modeling pedagogy.

One thing we were not expecting was to be learning physics. After all, we were well-educated veterans who were attending the program to improve our pedagogy, not our content knowledge. As the program progressed, it was almost embarrassing to me to realize how many of the classic physics preconceptions I still shared and had managed to talk my way around over my many years of teaching. The problem was much deeper than I had realized, and successfully applying this new pedagogy was going to be more difficult than I had anticipated. Informal conversations with other members of the pilot group revealed to me that many of them were sharing the same experience. Ideas as elementary as Newton’s Third Law had taken on a whole new meaning for us and we were anxious to start a new school year to try out these new conceptions on our students.

My search of the professional literature has turned up only a modest number of studies on the influence of in-service professional development programs, such as the Modeling Program, on veteran physics teachers. Roberts & Chastko (1990) state that “There simply is very little research on which to base an understanding of teacher thinking that is specific to secondary school science (p. 198).” In an article describing a refresher training program for experienced physics teachers in Hong Kong, Chung, Mak & Sze (1995) observed that

> most of these studies have based their investigation within the primary or junior secondary settings and focused on the training of beginning teachers. The retraining of experienced teachers with a focus on reflection in the teaching of a specific subject at the senior secondary level has never gained the deserved attention. (p. 152)

The greater attention paid to beginning teachers might imply that researchers feel that a practicing veteran teacher is essentially a finished product or that the attitudes and teaching styles of veterans are difficult to change and possibly not worth the effort. It might also imply that veteran teachers are logistically more difficult to study than preservice teachers or simply that there are substantially fewer in-service programs to study. Regardless of what this research focus implies, I feel that the study of the influence of professional development on veteran science teachers is important. It is my hope that, by studying the perceptions of teachers who have participated in constructivist in-service training of significant duration, it might be possible to design professional development programs that are more appropriate for and better meet the needs of veteran science teachers.

Purpose of the Study

The purpose of this study is to understand the perceptions of what constitutes a) effective student science learning and b) effective science teaching held by physics teachers who have participated in a constructivist in-service training program. The purpose is also to understand how these teachers perceive the influence of their participation in the in-service training program on their views of effective student science learning and effective science teaching. This will be accomplished by a qualitative study of six physics teachers who have participated in the Modeling Program and who have been identified by the directors of the program as exemplary modelers. The results of this study could give designers of such in-service programs better insight into their ability to have a lasting impact on the perceptions of the participants.

Research Questions

My research questions are: 1. What are the perceptions of what constitutes effective student science learning held by physics teachers who have participated in a constructivist in-service program? 2. What are the perceptions of what constitutes effective science teaching held by physics teachers who have participated in a constructivist in-service program? 3. What do these teachers perceive to be the influence of their participation in the in-service training program on their views of effective student science learning and effective science teaching?

History of the Modeling Program

In order to examine the perceptions of these teachers, it would be useful to take a closer look at the program which they all have experienced.

The Modeling Program was created in the summer of 1990 out of the work of Dr. Malcolm Wells, physics teacher in Tempe, Arizona, and Dr. David Hestenes, professor of physics at Arizona State University. Wells wrote his doctoral dissertation, entitled “Modeling Instruction in High School Physics (Arizona State University, 1987),” on an innovative approach to physics teaching based on Hestenes’ modeling philosophy. This philosophy resulted from research (Richtmyer, 1933; Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b) which showed that traditional, didactic, teacher-centered physics instruction was ineffective in preparing high school students for the rigors of university physics. The study by Halloun & Hestenes (1985a) determined that conventional physics instruction does little to change pre-existing common sense beliefs held by students prior to formal instruction in physics. In the follow-up article (1985b), they studied the nature of these common sense, pre-Newtonian beliefs and developed a taxonomy for use during instruction.

Shortly thereafter, Hestenes (1987) proposed a new methodology of physics teaching centered around the mathematical modeling approach. Halloun & Hestenes (1987) then applied this modeling approach to the teaching of introductory mechanics and conducted a controlled study of university students with and without modeling. The researchers claimed positive results for their innovative approach based on pre- and post-testing of these students.

As described by Hestenes (Hestenes, 1987; Halloun & Hestenes, 1987), modeling is a more constructivist, hands-on, student-centered approach which both Wells and Hestenes were convinced could be made into a workable teaching method. They approached the National Science Foundation for funding for a two-summer pilot program involving twenty teachers to create and test curricular materials and laboratory experiments and flesh out a complete program to teach the mechanics portion of college preparatory high school physics. The NSF approved funding for the project and included, for the first time in their history, money for participants to purchase classroom sets of computers, software, and computer-interfaced data-gathering equipment such as photogates, force probes, and sonic motion detectors. The computers were to be used to help students gather accurate data quickly and to allow them to use graphing programs to help them extract the important mathematical relationships (“mathematical models”) from the laboratory data.

After collaborating on the creation of the Modeling Program for high school teachers, Hestenes & Wells (1992) reported on their earlier development of the Mechanics Baseline Test for use as a pre- and post-test in evaluating the effectiveness of physics instruction in mechanics. Hestenes, Wells & Swackhamer (1992) further reported on the development of a second instrument, the Force Concept Inventory (FCI), to assess students’ preconceptions on force. These tests were used by Wells during his doctoral research, by my pilot group in the Modeling Program in 1990 and 1991, and by all subsequent teachers who have participated in the program. The validity of the FCI has been questioned (Heller & Huffman, 1995; Huffman & Heller, 1995) and vigorously defended (Hestenes & Halloun, 1995) but the test itself has gained widespread attention and popularity (Griffiths, 1997) and has become known as the “Hestenes Test.”

Hestenes (1992) independently wrote an article strengthening the epistemological, historical, and pedagogical underpinnings of modeling theory by treating it as an elaborate game with its own set of rules. In 1995, Wells, Hestenes, and Swackhamer collaborated on a landmark article giving the complete background to Wells’ development of the Modeling Program and a detailed description of its implementation and effectiveness. This article summarized the success of the first four years of the program and was intended as a blueprint for change in high school physics teacher preparation. Halloun (1996) then reported on his own study of Lebanese high school and college students using the modeling approach and claimed significant improvements in problem-solving performance in both groups.

The Modeling Methodology

The modeling methodology introduces each new concept through the demonstration of some simple phenomenon, such as a ball rolling down a sloped track, with little or no comment by the teacher. The students share their observations and brainstorm how the demonstration could be turned into a laboratory experiment. This process brings forward any preconceptions the students may have about the phenomenon being investigated and helps them identify the relevant, quantifiable variables. The students then develop and agree on a laboratory procedure and data is collected, graphed, and analyzed by groups of three students. Each group then completes and submits a single group lab report and a post-lab discussion session is held in which each group summarizes their conclusions on a portable whiteboard, a process hereinafter referred to as “whiteboarding.” The students display the boards in front of the entire class and, after group discussion, the class reaches consensus as to the most valid conclusions justified by the data. The teacher introduces the appropriate, generally accepted vocabulary in context and almost as an afterthought (“By the way, does anyone know the word we commonly use to refer to the slope of this graph? Right, it is known as acceleration.”).

During the sessions that follow, the concept is “deployed” by applying it to other related and familiar phenomena and reinforced through quantitative problem-solving. Whiteboarding sessions are used for students to display their solutions for public comment, including justifying their choices of mathematical models. This process is repeated through the familiar topics of motion, force, momentum, and energy, emphasizing the use of the select few mathematical models developed from the experiments rather than long lists of isolated formulas and defined vocabulary words.

Emphasis is always placed on the ability of each student to verbally justify his or her choice of mathematical model during the problem-solving process. At some point the teacher demonstrates a new phenomenon which differs in some key fashion from the previous ones and the cycle repeats.

The biggest drawback to the modeling method is that it is extremely time-consuming. I have discovered through my own experience and through informal conversations with colleagues, including the six participants in this study, that it is extremely difficult to do justice to Newtonian mechanics and still have adequate time to teach those topics normally reserved for the second semester of physics such as waves, sound, light, electricity, magnetism, and “modern” physics. This is, however, a trade most of us are willing to make in order to achieve any reasonable degree of depth of understanding. In the struggle between breadth and depth, the modeling methodology and those teachers I have talked with who have been trained in its use find in favor of depth. This attitude agrees with the criticisms in the Third International Mathematics and Science Study (TIMSS) which labeled our curriculum “a mile wide and an inch deep (National Center for Educational Statistics, 1996).” It also agrees with the comments of the National Science Education Standards in emphasizing “active science learning” over “presenting information and covering science topics (National Research Council, p. 20).”

The Modeling Philosophy

There are three essential characteristics of the modeling philosophy, at least insofar as it is employed in the Modeling Program. First, it attempts to inspire conceptual change in students, specifically in moving them from a traditional, naïve, Aristotelian paradigm to a more sophisticated, experimentally-driven, Newtonian paradigm. Second, it uses much of a student’s pre-existing knowledge, frequently referred to as preconceptions, misconceptions, or alternative conceptions, as the starting point for creating conceptual change. Third, and most important to this study, it relies on a constructivist teaching and learning approach containing elements of both radical and social constructivism. A summary of the relevant literature on conceptual change, alternative conceptions, and constructivism in teaching is included in Chapter 2 of this study.

Perceptions, Conceptions, and the Reflective Process

This is the study of the perceptions of effective physics teaching and effective student science learning held by six physics teachers who have participated in a constructivist in-service training program. It would be instructive at this point to define the meaning of the term “perception” and differentiate it from the term “conception.” For the purposes of this study, the term “perception” shall mean a mental image comprised of an assemblage of impressions of events derived from past experience and serving as the basis for future actions (Eisner, 1985; Hamilton, 1998). For example, the perceptions these six teachers hold of effective science teaching have been assembled from their own past teaching experiences and the mental images they have created, which I have attempted to have them describe in Chapter 4 of this study, are now the basis for their continued and future teaching. The term “conception,” in contrast, refers to ideas or abstractions formed not necessarily from personal experience or impressions but being of a more intellectual or universal nature. In comparison with conceptions, perceptions are more concrete, personal, and less universal in nature.

It is possible for perceptions to gradually become conceptions in certain cases but only with the intervention of the reflective process. Reflection on individual perceptions can result in them becoming generalized into larger abstractions that we would then label as conceptions. Without adequate testing, there is always the danger of these conceptions disagreeing with generally held scientific ideas and becoming labeled as alternative conceptions or misconceptions. This is very possibly the origin of many of the Aristotelian ideas in physics that were later challenged by Galileo and Newton. These intuitive, common-sense concepts are frequently the same ones that are held by physics students because they originate from individual perceptions.

Epistemological Theoretical Framework

The dominant theoretical framework that undergirds my study, the Modeling Program, and my science teaching is constructivism. Constructivism is, however, a difficult term to pin down because it has taken on a significant number of different forms. My concern here is to differentiate between some of the various strands of constructivism and the related notion of social constructionism in order to clarify which of these strands best informs my teaching, my research, and this study.

Guba (1990) defines a paradigm as “a basic set of beliefs that guides action, whether of the everyday garden variety or action taken in connection with a disciplined inquiry (p. 17).” He then summarizes what he admits are his own constructions (p. 27) of the four prevailing paradigms “that guide disciplined inquiry (p. 18).” These paradigms are traditional positivism, postpositivism, critical theory, and constructivism, and he openly confesses a preference for constructivism (p. 17). He summarizes constructivism as being characterized by a relativist ontology consisting of multiple “socially and experientially based" mental constructions, a subjectivist epistemology as the only way to access these individual constructs, and a hermeneutic/dialectic methodology whose purpose is to attain or at least approach consensus (pp. 25-27).

Guba's purpose in summarizing the four paradigms is not to select a "winner" but to initiate a dialogue whose purpose is to

> take us to another level at which *all* of these paradigms will be replaced by yet another paradigm whose outlines we can see now but dimly, if at all. That new paradigm will not be a closer approximation to the truth; it will simply be more informed and sophisticated than those we are now entertaining. (1990, p. 27)

As a result, his brief summaries serve his purpose. Fortunately, he also serves mine. In that one short phrase, "socially and experientially based," Guba succinctly captures the essence of the spectrum that separates the competing strands within constructivism and separates social constructionism from them (although, in light of the quotation above, I am certain he would not approve of the term "competing strands").

The fundamental, but not the only, difference between these strands is the role played by personal experiences versus the role played by social interactions in the formation of an individual's mental constructs. Phillips (1995) labeled this axis or dimension "individual psychology versus public discipline (p. 7)." This will be the dominant theme of this analysis.

Ernest (1995), in his chapter entitled "The One and the Many," differentiates between four forms of constructivism/constructionism: trivial constructivism, radical constructivism, social constructivism, and social constructionism. Unfortunately, he also muddies the waters by stating that "there are almost as many varieties of constructivism as there are researchers (p. 459)" and then warns "there is a risk of wasting time by worrying over the minutiae of differences (p. 459)." Still, there are many researchers for whom these differences are crucial and worth discussing.

Radical Constructivism

von Glasersfeld is the generally accepted champion of the version of constructivism known as radical constructivism. Ernest (1995) states that radical constructivism

> is based on both the first and second of von Glasersfeld's principles. The second profoundly effects the *world* metaphor, as well as that of the *mind*: "The function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality (von Glasersfeld, 1989, p. 182)." (Ernest, 1995, p. 473)

In 1991, von Glasersfeld reiterates:

> Radical Constructivism, I want to emphasize, is a theory of *active knowing*, rather than a traditional theory of knowledge or epistemology. From this standpoint, as Piaget maintained fifty years ago, *knowledge serves to organize experience*, not to depict or represent an experiencer-independent reality. (p. xix)

Smith (1995) elaborates on von Glasersfeld's distinction between knowing and knowledge:

> The predominate use of the word *knowledge* refers to socially accepted linguistic and symbolic forms. Likewise, the term *individual knowing* typically refers to individual meanings. . . . . . *Knowing* seems to capture more a sense of a dynamic process rather than of static entities and has more in common with constructivist views of the continuity of the processes of assimilation and accommodation. However, constructivists could also be uncomfortable with the implications for the word *knowledge*. With this usage, one can accept the idea of "knowledge in books," "knowledge in representations," and "shared knowledge." (p. 24)

The roots of von Glasersfeld's ideas go back not only to Piaget but also to notions analogous to Darwinian evolution. In 1984, he stated:

> In phylogenesis, as in the history of ideas, "natural selection" does not in any positive sense select the fittest, the sturdiest, the best, or the truest, but it functions negatively, in that it simply lets die whatever does not pass the test . . . . The relation between viable biological structures and their environment is, indeed, the

> same as the relation between viable cognitive structures and the experiential world of the thinking subject. Both structures *fit* – the first because natural accident has shaped them that way, and the second because human intention has formed them to attain the ends they happen to attain, ends that are the explanation, prediction, or control of specific experiences . . . . Quite generally, our knowledge is useful, relevant, viable, or however we want to call the positive end of the scale of evaluation, if it stands up to experience and enables us to make predictions and bring about or avoid, as the case may be, certain phenomena (i.e., appearances, events, experiences). If knowledge does not serve that purpose, it becomes questionable, unreliable, useless, and is eventually devaluated as superstition. That is to say, from the pragmatic point of view, we consider ideas, theories, and "laws of nature" as structures that are constantly exposed to our experiential world (from which we derived them), and either they hold up or they do not. (pp. 22-24)

He continues:

> Radical constructivism, thus, is *radical* because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all and finds himself in full agreement with Piaget, who says, "Intelligence organizes the world by organizing itself (Piaget, 1937, p. 311)". (p. 24)

Critics of von Glasersfeld's ideas such as Gergen (1995) and Philips (1995, 1996) use quotations such as these to label radical constructivism as solipsistic (believing in no reality except the self). Phillips (1995) states:

> My own view is that any defensible epistemology must recognize – and not just pay lip service to – the fact that nature exerts considerable constraint over our knowledge-constructing activities, and allows us to detect (and eject) our errors about it. (p. 12)

In Gergen's words: "Yet to escape Scylla of dualism in this way confronts the theory with an equally perilous Charybdis – that of a self-defeating solipsism (p. 28)." Gergen, a social constructionist, is most concerned with issues of language, communication, and social interaction, and he questions von Glasersfeld's theory on the grounds of the difficulties associated with trying to communicate with others who are (according to von

Glasersfeld) merely viable constructs in the mind of the cognizing subject (p. 29). In his own defense, von Glasersfeld (1995b) states that charges of solipsism are

> a basic misunderstanding of constructivism, and it springs from the resistance or refusal to change the concept of knowing. I have never denied an absolute reality, I only claim, as the skeptics do, that we have no way of knowing it. As a constructivist, I go one step further: I claim that we can define the meaning of *to exist* only within the realm of our experiential world and not ontologically. When the word *existence* is applied to the world that is supposed to be independent of our experiencing (i.e. an *ontological* world), it loses its meaning and cannot make any sense. (P. 7)

This emphasis on the active knowing of the individual and constant reference to Piagetian psychology tends to place radical constructivism also at the individual end of the individual – social dichotomy. Von Glasersfeld (1989) reminds us:

> To make the Piagetian definition of knowledge plausible, one must immediately take into account (which so many interpreters of Piaget seem to omit) that a human subject's experience always includes the social interaction with other cognizing subjects. (p. 126)

He continues his defense (1995b):

> If one reads Piaget's original works with the necessary attention – by no means an easy task because his explanations are not always immediately transparent – one finds that somewhere in almost every book he reiterates that the most important occasions for accommodation arise in social interaction. (p. 11)

In 1991, he states:

> As Piaget reiterated many times, after infancy the most frequent cause of *accommodation* (change in a way of operating or acting) arises in social interaction when the individual's ways and means turn out to be in some sense insufficient in comparison to the ways and means of others (Piaget, 1967). (p. xviii)

It is von Glasersfeld himself who is now doing the accommodating by absorbing elements of socioculturalism into his theory and moving closer to social constructivism (Ernest, 1995).

Social Constructivism

Ernest (1995) locates social constructivism more toward the social end of the individual – social continuum by stating that it

> regards individual subjects and the realm of the social as interconnected. Human subjects are formed through their interactions with each other, as well as by their individual processes. Thus, there is no underlying metaphor for the wholly isolated individual mind. Instead, the underlying metaphor is that of *persons in conversation*. (pp. 479-80)

Emphasizing the sociocultural foundations of scientific knowledge, Driver, Asoko, Leach, Mortimer & Scott (1994) state:

> These ontological entities, organizing concepts, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world. Scientific knowledge as public knowledge is constructed and communicated through the culture and social institutions of science. . . . Whereas the individual construction of knowledge perspective places primacy on physical experiences and their role in learning science, a social constructivist perspective recognizes that learning involves being introduced to a symbolic world. . . . . . . From this perspective knowledge and understandings, including scientific understandings, are constructed when individuals *engage* socially in talk and activity about shared problems or tasks. Making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members. (pp. 6-7)

Conversation requires language. According to Ernest (1995), the use of the persons in conversation metaphor "gives pride of place to human beings and their language in its account of knowing (p. 480)." He continues:

> It is increasingly recognized that much instruction and learning takes place directly through the medium of language. Even manipulative or enactive learning, emphasized by Piaget and Bruner, takes place in a social context of meaning and is mediated by language and the associated socially negotiated understandings. (p. 480)

Ernest refers to the ontology of the social constructivists as "sophisticated realist," by which he means "there is a world out there supporting the appearances we have shared access to, but we have no certain knowledge of it (p. 480)." This term is very much in line with Guba's "critical realist" terminology. Driver et al. (1994) tend to agree:

> But a view of scientific knowledge as socially constructed does not logically imply relativism. In proposing a realist ontology, Harre (1986) suggests that scientific knowledge is constrained by how the world is and that scientific progress has an empirical basis, even though it is socially constructed and validated (a position that we find convincing). (p. 6)

The epistemology of social constructivism is described by Ernest (1995) as "a fallibilist epistemology that regards conventional knowledge as that which is lived and socially accepted (p. 480)." He uses the absolutist-fallibilist distinction to separate those epistemologies which allow for the possibility of achieving absolute knowledge from those which hold that all knowledge is temporary and subject to falsification at any moment (p. 483). I personally support the fallibilist position.

Ernest does not cite any researchers who clearly label themselves as social constructivists but he does suggest that "the distinction between these two paradigms is becoming less clear cut as the social dimension is more fully accommodated by radical constructivism (p. 480)." This is consistent with his earlier warning about the "minutiae of differences." Recently, Marin, Benarroch, and Gomez (2000) attempted to show how social constructivism and Piagetian constructivism both enrich and depend on each other. I welcome efforts like this to emphasize the similarities and downplay the differences.

Social Constructionism

Ernest (1995) begins his discussion of social constructionism with the statement that "social constructionism resembles social constructivism, but prioritizes the social above the individual (p. 481)." This positions social constructionism clearly at the extreme <u>social</u> end of the individual – social dichotomy. Gergen (1985) summarizes what he perceives as the social constructivist's agenda:

> Social constructivist inquiry is principally concerned with explicating the processes by which people come to describe, explain, or otherwise account for the world (including themselves) in which they live. (p. 266)

This quotation reveals the concern of social constructivists on language and communication. This focus on language is made even clearer a decade later (Gergen, 1995):

> In my view, social constructionism represents a radical break with both the exogenic and endogenic orientations to knowledge, and thereby suggests a substantially altered agenda both in terms of scholarly inquiry and educational practice. In its radical form, social constructionism does not commence with the external world as its fundamental concern (as in the exogenic case) or with the individual mind (as endogenecists would have it), but with language. (p. 23)

Gergen (1995) continues by comparing social constructionism with "traditional conceptions of knowledge with a communal concern (p. 24)":

> In certain respects, constructionism finds a close ally in Vygotskian formulations. Both standpoints place community prior to the individual; both look at individual rationality largely as a by-product of the social sphere; and both hold cooperative or dialogic processes as central to the process of education. However, there is also an essential difference between the two orientations. Social constructionism places the human relationship in the foreground, that is, the patterns of interdependent action at the microsocial level. There is little attempt to explain these patterns by recourse to psychological processes within persons. (p. 24)

For Gergen and the social constructionists, the things we consider knowledge are "temporary locations in dialogic space" which are "in continuous production as dialogue ensues (p. 30)." How one achieves a position of authority within this space is also crucial to Gergen. As opposed to the endogenic tradition (where he places constructivism) which grants authority by "natural endowment or by refining the internal capacities for thought (p. 31)," social constructionism holds that

> authority is socially accorded, and within most academic spheres it is typically given to those occupying a given discursive position. Thus, anyone may be an authority who occupies the position, if permitted to do so by a relevant social group. (p. 31)

Taken to the extreme, this viewpoint leads to semi-humorous, tongue-in-cheek comments such as Amdahl's (1991) observation that "most education is based on the premise that speaking the language is more important than having something to say (p. 4)." This quotation is humorous in the context of Amdahl's writing but is more than slightly uncomfortable for a career educator when I take note of how much emphasis I have seen on the teaching of vocabulary, usually out of context, in high school classrooms.

Gergen (1995) reveals his sociocultural orientation with the following comment:

> When knowledge is viewed as a form of mental representation, as traditionalists would have it, it is typically endowed with a transcendent character. . . . . . . Truth, as it were, knows no context. Yet as we shift the locus of knowledge from mind to language, the traditional assumptions are no longer viable. Rather, our agreements regarding the relationship of language to referents are always located within particular sociohistorical circumstances. (p. 25)

Gergen continues by attempting to differentiate his view of social constructionism from constructivism (pp. 27-29) but focuses almost entirely on von Glasersfeld and the radical version as cited above.

I consider myself a social <u>constructivist</u> because that orientation strikes me as the optimal compromise position between extremes. I can be swayed one minute by the arguments of Piaget, Richards, and von Glasersfeld as I focus on my own individual mental operations and those of my students and then be swayed the next by the arguments of Driver, Gergen, Vygotsky, Wittgenstein, and the socioculturalists as I focus on the social aspects of teaching and learning and the influence of language. After all, much and probably most of what I hold as knowledge has arrived through language and discourse in a sociocultural context but much of what I know about the “laws” or patterns of operation of the physical world were learned in infancy, before I had a language, so I see merit in both approaches and don’t really see how they can be separated. I find it not at all surprising that there is inevitable drift of both extremes toward the center, leading to Ernest’s comment about the “minutiae of differences.”

The methodology of the Modeling Program contains elements of both radical and social constructivism. Students are encouraged, through exposure to a series of carefully selected experiments, to confront their pre-existing knowledge and reorganize their “experiential world” as a set of coherent mathematical models. These models are not represented as objective truths but merely as the most viable and widely accepted current models of the behavior of the physical world. The purpose of developing multiple models is to enable each student to assemble a unique, personal mental representation that makes the most sense to and works best for that individual. The process of developing these models encourages students to pay close attention to their <u>individual</u> observations and senses as well as engaging in the <u>social</u> development of these models through discussion and argument.

Since reality, for the social constructivist, is socially constructed, no attempt should be made to model a single reality. Rather, the researcher’s task is to nonjudgmentally record all of the multiple participant perspectives as much as possible in their own words, constantly striving for the emic viewpoint. The goal is understanding, not explanation, so preliminary hypotheses are to be avoided but tentative and limited working hypotheses may be allowed to emerge during the data analysis process. Adequacy of the research is judged by feedback to the participants themselves, generalization is rejected out of hand, and transferability of findings to any other situation is left to the reader (Firestone, 1990). This is very much the plan for my study.

Researcher Biases

Like most teachers who pay any attention at all to feedback in the form of standardized test scores, I spent the substantial part of my twenty-eight year teaching career wondering what I was doing wrong, why my students just didn't seem to "get it," and whether or not there was a better way. I pride myself on the fact that I feel I am a good listener and I have spent many evenings, weekends, and vacations reflecting on my own practice in light of what I have seen and heard in the classroom. In some subtle and insidious way, it began to occur to me that maybe I was working too hard at perfecting my own performances (for that is truly what they were) and not hard enough at engaging the students. Once I began to pay more attention to student learning rather than my teaching, things began to change. I found myself becoming much more Socratic and much more adept at using "wait time" as an instructional tool. But these were just techniques. What I lacked was a theoretical foundation.

Enter the Modeling Program. As I have already stated in the introduction, I believe that my participation in those two summers has changed me profoundly as a teacher, but initially I was a skeptic. It was too radical an approach and seemed to throw too much of the responsibility for learning back on the students for my taste. But I gave it a chance. As we progressed through the curriculum, beginning each new concept with a lab experiment and role-playing as students during post-lab discussions, I began to have more and more faith in the validity of the approach. Oddly enough, I began to experience a considerable amount of conceptual change as well. I was learning physics.

I am now a strong supporter, even a cheerleader, for the Modeling Program. I hope to become a group instructor in the near future and help others experience the kind of professional growth and excitement that I was fortunate to experience. It is the most effective professional development program for veteran physics teachers that I have yet discovered. Everything I have read in the process of preparing this study has only strengthened my belief in the solidity of its foundation.

This study is not specifically about the Modeling Program. Rather, it is about the perceptions of veteran physics teachers who have been exposed to a constructivist in-service experience. I just feel that the participants in this study were fortunate enough to have been exposed to the best.

CHAPTER 2

REVIEW OF THE LITERATURE

The purpose of this review is to survey the body of literature that informed my study. The literature relevant to my study falls primarily into five categories: in-service science teacher education, science teacher reflective thinking, conceptual change, alternative conceptions, and constructivism in education. The distinctions between the last three are, at times, quite small and some of the literature under one heading might just as easily be placed under one of the other two headings. It was the recognition of the complementary nature of the three that made them the three pillars of the Modeling philosophy.

In-Service Science Teacher Education

Acknowledging that there is a scarcity of research on the subject, Keys & Bryan (2001) reviewed the existing literature and proposed an aggressive research agenda on the role of teachers in the process of inquiry-based science education reform. They specifically focus on the need for research into teacher beliefs, the teacher knowledge base, teacher practices, and student science learning.

The preparation of preservice science teachers has received a moderate amount of attention in the professional literature. Two early studies identified the crucial need for the preparation of more new physics teachers. In 1968, Green reported on the short supply of physics teachers and made a series of recommendations for improvements in preservice physics teacher preparation. Lambert (1975) reported on the rather dire physics teacher shortage in Great Britain and identified the sharp discrepancy between physics teacher preparation courses taught in physics departments and those taught in education departments, in effect alluding to pedagogical content knowledge twelve years before that phrase was created. He also proposed the elimination of what he perceived as the somewhat demeaning term “in-service training” and replacing it with the more respectful concept of “post-certificate study (p. 516).”

Some of the research on preservice science teacher training has focused on the teachers themselves. An article by Kagan (1992) reviewed forty qualitative studies of preservice and novice physical science teacher preparation and identified three specific stages through which these teachers move. She observed that most preservice training programs do not specifically address these transitions. Mellado (1997) studied the relationship between the conceptions of preservice science teachers on the nature of science and their classroom practice and found that there is virtually no correspondence.

Some of the research on preservice science teacher training has focused more on promising techniques and specific programs that promote these techniques. McDermott (1975) proposed a detailed preservice physics teacher training program involving use of the laboratory, inquiry teaching, and an historical approach to physics. Saunders, Eastmond & Camperell (1994) reported on two projects at Utah State University that they claim improve secondary science teacher preparation by focusing on conceptual change teaching and cognitive psychology. Treagust, Harrison & Venville (1998) described an organized approach to the use of analogies in preservice and in-service teacher training that holds promise for being effective in enhancing student understanding of science concepts. Crawford (1999) reported on a case study of a preservice teacher who successfully constructed an inquiry-based teaching environment. Aiello-Nicosia & Sperandio-Mineo (2000) reported on a qualitative study of preservice teachers who had participated in an innovative teacher education program which used the physics modeling approach. They reported that the stimulation of metalearning and metareflection in these teachers was effective in generating change in their teaching approach.

In-service science teacher education for experienced teachers has also received only a moderate amount attention in the professional literature but there has recently been an upswing in research on the topic. Some of the earlier studies concentrated on identifying the need for physics in-service education. Oines (1971) reported on the 1970 International Congress on the Education of physics teachers in Secondary Schools, which recommended annual in-service training, characterized by a balance between subject matter and relevant pedagogy. A study by Rubba (1982) indicated that physics teachers have especially strong needs for in-service training to help make their teaching more humanistic and responsive to student needs. Jones (1985) reported on an in-service physics teacher preparation program for teachers who were teaching out-of-field and found that their greatest need was specific training in the use of laboratory experiments and classroom demonstrations.

Some of the more recent research has dealt with the influence of the duration of professional development on its effectiveness. Supovitz & Turner (2000) examined survey data from the NSF Teacher Enhancement program and concluded that both individual teacher content preparation and the quantity of professional development experienced by the teachers were major factors in influencing inquiry teaching practice and changing classroom culture. A study by van Driel, Beijaard & Verloop (2001) investigated the role of teacher practical knowledge and concluded that long-term professional development experiences are essential for development of this crucial form of teacher knowledge. Kahle & Boone (2000) reported the results of a survey of over 500 Ohio science teachers and principals which found that the two most important factors in improving science teacher professional development are availability of support materials and the duration of the professional development experience itself. Reporting the results of a survey of over a thousand math and science teachers, Garet, Porter, Desimone, Birman & Yoon (2001) found that professional development of long duration, focused on content, containing opportunities for hands-on work, and integrated into daily school life were most likely to enhance teacher knowledge and skills.

As I stated earlier, only a relatively few studies have concentrated on assessing the influence of the professional development on the teachers themselves. In a study with many parallels to my own, Hand & Treagust (1994) investigated the changes in junior secondary science teacher thinking as a result of participation in an extended constructivist in-service program and reported changes which included a change in control of the teaching process from teacher to student, increased valuing of student knowledge, and increased involvement of students in the learning process. Chung et al. (1995) described a refresher training program in Hong Kong for experienced physics teachers which "provided impetus for reflection (p. 160)" and enabled them to "rethink their current practice in terms of a more constructivist view of science teaching (p. 151)." In a recent study of twelve teachers who had filled out questionnaires before and after taking part in an in-service program for veteran physics teachers, Flores, Lopez, Gallegos & Barojas (2000) found that the participating teachers perceived a steady transformation from empiricism to cognitivism but that the continued transformation to constructivism was much more difficult and much less evident. Luft (1999) described the results of a study of teachers who had participated in a demonstration classroom in-service program and suggested that this type of program might be a worthwhile alternative to traditional yearlong programs. Borghi, DeAmbrosis, Lunati, & Mascheretti (2001) tested an innovative approach to physics teacher in-service training based on reconsideration of disciplinary knowledge and the opportunity to work with other teachers to make it suitable for teaching. Teachers' reactions to a trial unit on friction were reported.

Science Teacher Reflective Thinking

As recently as 1990, Roberts & Chastko, in a study cited earlier, expressed the view that "research in science education has not shown much attention to science teacher thinking (pp. 197-98)." They cited major reviews of teacher thinking research (Clark & Peterson, 1986; White & Tisher, 1986) which contained no entries at all on science teacher thinking. Their own study revealed that reflection in student teachers seemed to require both an appropriate knowledge base and an appropriate attitude. They speculated on the possibility of the existence of a predisposition to reflect or not reflect in student teachers and described three evasive styles used to avoid reflection.

This concern with reflection and the concept of "reflection-in-action" can be traced back to Schon's (1983) landmark work that described reflection as a purposeful, problem-solving effort. In an in-depth case study of a third-year preservice science teacher, MacKinnon (1987) tested criteria for detecting reflection during clinical supervision and suggested that the development of professional competence may be related to the habit of reflecting on practice. MacKinnon also emphasized the use of reflection from pupil-centered perspectives. Russell (1995), in a rather unusual self-study, reported on his own reflective experiences as he returned to the high school physics teacher role from his position as teacher educator. One of his findings was that preservice teachers need the opportunity to observe one teacher and one class over time rather than jumping around and observing superficial differences between teachers, thus allowing for more reflection. He also reaffirmed the value of experience for beginning teachers over merely being told how to teach. In a case study of an expert middle school science teacher, Moallem (1997) discussed the view that professional development should promote reflection-in-action to link reflection to teaching performance. He also promoted the process of self-analysis as leading to conceptual change in teachers. Finally, he discussed the importance of social context and school culture in providing time and opportunities for reflection. Even more recently, a study by Abell, Bryan & Anderson (1998) investigated the personal theories of preservice elementary teachers and compared their development with the process of conceptual change in the personal theories of students on science. This comparison with conceptual change is in general agreement with the findings of Moallem.

Conceptual Change

Conceptual change is a major theme that runs through much of science teaching research. Two of the most important and pivotal works defining conceptual change are the articles by Posner, Strike, Hewson & Gertzog (1982) and Strike & Posner (1985) which claim that conceptual change occurs when there is dissatisfaction with a current concept and when the new concept is intelligible, plausible, and fruitful. The two fundamental concepts of their model are the status of ideas and how they fit into an individual's conceptual ecology. Strike & Posner (1992) later expanded their definition of conceptual ecology to include such factors as goals and motivation. Pintrich, Marx & Boyle (1993) continued this line of research by studying the importance of various motivational factors in mediating conceptual change

One recurring theme in the literature is that conceptual change teaching should involve conceptual conflict and conceptual dissonance. Hewson & Hewson (1984) cite two studies which demonstrate how conceptual conflict between scientific conceptions and previously-held alternative conceptions can be used in the classroom to promote conceptual change. More recently, Rea-Ramirez & Clement (1998) defended the use of the term dissonance for the same purpose and enumerated a number of possible sources of dissonance in science teaching.

Some of the literature on conceptual change has focused on proposals for how to implement it in the classroom. Duschl & Gitomer (1991) proposed a conceptual change learning model which promotes the creation of a "portfolio culture" in which teachers and students are encouraged to jointly confront student conceptions and help the students organize the restructuring of their knowledge. Dykstra, Boyle & Monarch (1992) developed a taxonomy of types of conceptual change, including differentiation, class extension, and reconceptualization, and proposed strategies for dealing with each, including the use of concept maps.

Many articles have been written promoting the use of conceptual change teaching and reporting on classroom research showing its effectiveness. Hewson & Beeth (1993) studied a fifth-grade science classroom and developed some practical guidelines for the implementation of conceptual change teaching. Palmer & Flanagan (1997) studied the effect of age on a student’s willingness to undergo conceptual change and found that age had no effect on the process. Adams & Chiappetta (1998) studied a group of introductory physics students and concluded that a high degree of conceptual change is associated with a consistent and logical world view, even though physics is not perceived as connected to real-world activities. Guzzetti, Williams, Skeels & Wu (1997) reported that refutational texts can be effective at encouraging conceptual change by creating cognitive conflict, although some individuals require follow-up discussion. In an extensive study of three different grade levels, Weaver (1998) found that hands-on laboratory experiences in conjunction with post-lab discussion and reflection are effective in promoting conceptual change but that teachers must have access to laboratory research opportunities as well. Fellows (1994) reported the results of a study that showed the value of student writing in both assessing and promoting conceptual change.

Several studies have been done on the value of conceptual change in the education and training of science teacher candidates and novice teachers. Stofflett & Stoddart (1994) reported on a study of elementary teacher candidates which concluded that, in order to effectively incorporate conceptual change teaching pedagogy into their own teaching, these candidates need to have learned their own science content in classes using conceptual change pedagogy. Gunstone, Gray & Searle (1992) reported on a study of Australian science graduates involved in a teacher training course which found that the best results occur when the conceptual change process is made explicitly metacognitive. Sequeira & Leite (1991) compared the conceptual change process to the historical development of scientific ideas and concluded that teachers’ knowledge of the history of science supports conceptual change teaching.

Not all researchers investigating conceptual change agree on its definition or its mode of implementation. Rowlands, Graham & Berry (1999) summarized some of the competing trends in physics education and proposed a schema theory to resolve some of the conflicts.

Alternative Conceptions

The term “alternative conceptions” (or schemes or frameworks) refers to ideas formed by an individual which appeal to that individual as being based on common sense. The individual is frequently not aware of the origin of these notions and whether they were created within the individual based on personal experience or whether they were assembled from his or her collective interactions with others. They are referred to by a variety of names, including preconceptions, naïve conceptions, misconceptions, and misunderstandings.

The use of the term “alternative conceptions” implies that these ideas are alternatives to and do not formally agree with the generally-accepted scientific view on a particular subject and “have the potential to interfere with future learning (Klammer, 1998, p. 3).” The term “preconception” emphasizes that the specific idea in question was formed prior to formal instruction and subtly implies that it is in need of refinement and sophistication. The term “naïve conception” more overtly emphasizes the lack of maturity or sophistication of the particular concept under discussion. The term “misconception” (or misunderstanding) frequently refers to ideas formed after instruction (Treagust & Smith, 1989, p. 380) which disagree with generally-accepted scientific views. It is probably the most judgmental of the labels, implying from the onset that the notion being referred to is completely mistaken and should be rejected and replaced. The term “misconception” was quite popular in the literature of the 1980’s and early 1990’s but seems to have been gradually replaced by the term “alternative conception,” with its greater respect for the inherent value of a student’s conceptions as something to build on and modify.

There have been a significant number of studies establishing the fact that alternative conceptions about physical science are widespread and persistent from early childhood all the way to adulthood. Helm (1980) administered a twenty-question physics test (included in the article) to a large number of South African high school and university students as well as science teachers and found that there was little difference between the student groups. He identified a significant number of deep-seated misconceptions and even the teachers, who scored considerably better than the students, seemed to harbor some of these same misconceptions. Ivowi (1984) conducted a similar study on a smaller group of Nigerian students using a modification of Helms’ test and found that the same misconceptions were present in his students. He suggested increased teacher preparation as a way of addressing this problem. Saxena (1991) tested nearly 200 Indian high school and college students on their understanding of the behavior of light and identified four distinct misconceptions. He also suggested that a contributing cause might be the lack of opportunities within the physics curriculum to apply basic concepts. Noce, Torosantucci & Vicentini (1988) cited the results of a previous study (Ruggiero, Cartelli, Dupre & Vicentini, 1985) on Italian middle school children which identified three misconceptions concerning gravity, air, and freefall and then administered the same pencil-and-paper test to over four hundred Italian secondary students, university students and adults. They found that most of the misconceptions held by the children in the earlier study are still present at all levels through adulthood and they cite the contributing influence of the mass media. Galili & Kaplan (1996) found that alternative conceptions regarding weight and gravity were very resistant to change even in Advanced Placement high school physics students.

Some researchers have identified alternative conceptions and suggested strategies for attempting to deal with them. Champagne & Klopfer (1983) observed middle school students during physical science activities and found that the students had already formed some elaborate and persistent naïve conceptions. They described a process of ideational confrontation designed to facilitate the process of schema change in the students. Osborne (1984) spoke out in favor of formal instruction on Newtonian dynamics in the primary grades as a way of heading off the formation of alternative conceptions. Clough & Driver (1986) interviewed 84 students ranging in age from 12 to 16 on a variety of physics and biology topics in order to assess the consistency of the use of student alternative frameworks. They discovered that, although there appear to be some very clearly identifiable alternative frameworks, "a model of learning as a process of conceptual change from a single identifiable naïve view to the accepted view may be too simplistic (p. 489)." Dupin & Johsua (1987) administered a questionnaire on electricity to 920 French students ranging from sixth grade to college and identified a series of very fundamental and stubborn misconceptions including some created by the same well-intentioned teaching that was trying to address more basic misconceptions. Teacher awareness of the existence of these misconceptions is cited as an important step in rooting them out. Piburn, Baker & Treagust (1988) tested a group of forty college students on their views concerning gravity and discovered that those students with limited conditional reasoning skills held the greatest number of misconceptions. They also suggested that it is probably necessary to address these misconceptions explicitly in attempting to teach physics to this type of student. Gauld (1988) studied the conceptions of a group of fourteen-year-old boys on the topic of electric current and found that they were willing to abandon their misconceptions if compelling experimental evidence can be presented. Treagust & Smith (1989) interviewed and tested over 100 Australian tenth-grade students on their understanding of astronomy and uncovered some fundamental misconceptions about the role and function of gravity in astronomy. They also suggested that awareness of these misconceptions and dealing with them in some formal way is crucial to achieving a more scientifically acceptable level of understanding. Roach (1992) proposed the use of an historical teaching approach to show students that their concepts are not so much wrong as they are immature. Thomaz, Malaquias, Valente & Antunes (1995) promoted the use of constructivist teaching techniques and an explicit awareness of the nature of the alternative conceptions on the part of the teacher. Gang (1995) proposed the use of the Learning Cycle to help students rethink their alternative conceptions. Klammer (1998) proposed the use of bridging analogies and strongly supported the use of modeling.

Several articles attempted to link the existence of alternative conceptions to Piagetian stage theory of development. Eckstein & Shemesh (1993) administered a questionnaire on motion to over 600 students ranging from elementary through high school and identified several levels of sophistication in the student conceptions which they compared to the Piagetian stage theory. They conclude that teaching strategies must be designed to be appropriate to the particular stage of alternative concept development.

A progressive development of alternative concepts was observed by Bar, Zinn & Goldmuntz (1994) in a large-scale study of children of ages four to thirteen concerning their understanding of weight. Oliva (1999) found that student alternative conceptions about mechanics do have elements of a Piagetian structure and recommended a re-examination of our thinking regarding conceptual change.

The presence and persistence of misconceptions or alternative conceptions in teachers have been studied as well. Lawrenz (1986) demonstrated the critical need for better physical science in-service training by testing a group of over 300 elementary teachers and identifying several serious misconceptions relating to matter, motion, and electrical phenomena. Crawley & Arditzoglou (1988) studied the science misconceptions of nearly 50 preservice elementary teachers using the pilot versions of two new multiple-choice tests for life science and physical science. They found that these prospective teachers held many of the historical science misconceptions and they suggested several strategies for confronting them during their science methods courses. In a study of elementary school teachers, Barnes & Barnes (1989) identified a significant number of physical science misconceptions and attempted to deal with them by promoting question-asking behavior. Berg & Brouwer (1991) studied a group of high school physics teachers and discovered that these teachers had a difficult time identifying student alternative conceptions in the area of gravity and circular motion, that the teachers themselves harbored some of these conceptions, and that their typical strategies for dealing with them were, for the most part, ineffective.

Heller & Finley (1992) studied a group of elementary and middle school teachers participating in a physics in-service program on electricity and found that these teachers had formed a series of contradictory concepts about current flow which had certain propositions in common. An awareness of both the commonalties and the variances in these teachers' prior understandings was cited as crucial to teaching for conceptual change. Ginns & Watters (1995) reported finding a high proportion of scientific misunderstandings in a large-scale study of preservice elementary teachers but that those with strong high school physics and chemistry backgrounds seemed to fare much better. In a study with very disturbing implications for physics education, Trumper & Gorsky (1996) questioned a group of Israeli physics students preparing to become high school physics teachers and found that a very large percentage of them revealed serious misconceptions about concepts of force and many of them still held to the Aristotelian "impetus" concept. They suggested the adoption of a constructivist or generative learning model in preservice teacher education programs. In 1998, Trumper reported on the results of a longitudinal study of a similar group of Israeli preservice physics teachers on their conceptions of energy and found that most of them hold a number of different alternative conceptions, including the confusion of energy and force and the belief that energy is a concrete entity.

Constructivism in Education

The generative learning model (Wittrock, 1974; Osborne & Wittrock, 1983) is a precursor to the current constructivist framework in use in science education. These authors viewed the brain as an active agent that constructs interpretations and draws inferences rather than just passively receiving information. They also suggested that the restructuring of knowledge is a major factor favoring its transfer to long-term memory. Franke, Carpenter, Fennema, Ansell & Behrend (1998) proposed a model for teacher education which is both self-sustaining and generative. The term generative, as they used it, refers to the necessity of adapting teaching methodology by being aware of how students think as they are forming concepts. This approach is implicitly if not explicitly constructivist.

Researchers have proposed specific techniques for promoting constructivist learning in science students. In a case study on the teaching of waves, Geddis (1991) proposed that science teachers should be less concerned about correcting student misconceptions and more concerned about using constructivist teaching methods to promote critical scientific thinking. Etchberger & Shaw (1992) identified cooperative education as an ideal vehicle for promoting constructivist learning. Colburn (2000) discussed constructivism as both a philosophy and a learning theory and recommended a series of specific activities that promote constructivist teaching in the classroom.

Several studies have been conducted which claim to show purported benefits of the use of constructivist techniques in science classroom teaching. Linn & Songer (1991) found that middle school student understanding significantly increased when the students were motivated to predict outcomes, construct their own understanding, and develop models for their results. Windschitl & Andre (1998) compared the effects of constructivist versus objectivist teaching techniques in a college physiology class and found that the constructivist learning environment produced significantly greater conceptual change, primarily in those students with more advanced epistemological beliefs. Naylor & Keogh (1999) proposed the use of concept cartoons as a way of effectively implementing constructivism in elementary science teaching. They originally proposed it as a teaching tool for use in in-service teacher training but describe a study of its use by student teachers with elementary school students.

A number of studies have shown the influence of constructivist techniques in teacher training as well. In a case study of a mathematics teacher undergoing a constructivist transition, Etchberger & Shaw (1992) found that reflection can have a powerful influence on the way a teacher perceives of effective student learning. Mosenthal & Ball (1992) studied the role that subject matter knowledge plays in constructivist in-service teacher training. In a study of a constructivist alternative teacher education program, Condon, Clyde, Kyle & Hovda (1993) found that teachers prepared with a constructivist orientation experienced a growth in efficacy and a distinct role redefinition. Keiny (1994) investigated the effects of individual and group reflection during a constructivist “teacher thinking” seminar and found that they led to a greater awareness of their own “theories-of-teaching.” Hashweh (1996) surveyed a large group of science teachers and found a strong connection between a constructivist orientation, an ability to detect alternative conceptions, and effective conceptual change teaching techniques. Kinnucan-Welsch & Jenlink (1998) studied three cadres of teachers engaged in constructivist professional development and found that the intense social interaction facilitated the transition to a more constructivist orientation. A group of teachers in a constructivist graduate science methods course were studied by Jones, Rua & Carter (1998) and found to have significantly developed their content and pedagogical knowledge within Vygotsky’s zone of proximal development. Beck, Czerniak, & Lumpe (2000) studied teacher beliefs insofar as they relate to implementation of constructivist teaching in the classroom. They found that developing positive attitudes toward constructivism is essential for effective implementation and that attitude varied greatly by gender, education, and experience.

In fairness, I must acknowledge that there is some notable disagreement about the value or desirability of constructivism in science education. Phillips (1995) cautioned against the indiscriminate use of constructivist techniques by educators with only a limited understanding of the issues involved. Oxford (1997) warned of the "fragmentation" and "shape-shifting" within constructivism that dilute its effectiveness. Phillips (1996) and von Glasersfeld (1996) engaged in a short but lively philosophical exchange on the ontologies that undergird their positions. In another equally lively debate, Baines & Stanley (2000) attacked constructivism as denying students the opportunity to take advantage of teacher expertise while Chrenka (2001) defended constructivism as requiring and using that very same expertise. Jenkins (2000) took somewhat of a neutral stance, citing opposing perspectives and summarizing the current situation as "one of confusion and often uncritical espousal of a fashionable research paradigm." Matthews (1998, 2002) extensively summarized his interpretation of the thoughts of many of the proponents of constructivism, mostly of the more radical end of the spectrum, and strongly cautioned science educators not to use their position of authority in the classroom for purposes of indoctrination. He clearly betrayed his own opinion of the constructivist movement by quoting Devitt (1991): "Constructivism attacks the immune system that saves us from silliness (p. ix)." Kragh (1998) was less charitable. She recounted a similar history of the constructivist movement and then stated:

> If the received view of science may cause anti-science sentiments, constructivism is a frontal attack on the entire edifice of science and as such is far more damaging. (p. 242)

A quotation such as this makes it clear that there is less than universal agreement on the value of a constructivist approach to science education.

Other Relevant Literature

I found several other articles useful and informative during my search of the relevant literature but they do not fit comfortably into any of the above categories. I have chosen to reference them here in a separate section. They have been grouped by subtopic wherever possible.

The use of the modeling approach in science education has received some recent attention in the literature. Harrison & Treagust (2000) presented a conceptual typology of models currently in use in science education, recommended the use of multiple models in science lessons, and promoted the social negotiation of their meanings. I was pleased to note the close correspondence between the listed types of models and the various models used in the Modeling Program as well as the emphasis on the social aspects of their use. In a similar vein, Greca & Moreira (2000) reviewed the current understandings of mental models, conceptual models, and the modeling process. They also emphasized the positive impact these understandings can have on science education. Passmore & Stewart (2002) described in detail the development of a nine-week course in evolutionary biology based on the modeling approach to science teaching. Justi & Gilbert (2002) reported on a large-scale interview study of science teachers on the use of modeling as a teaching methodology. They found that the teachers perceived widely varying purposes for modeling and that they felt that prior experience with a phenomenon was an essential prerequisite for successful modeling. They created a “model of modeling” framework for better understanding the teachers’ perceptions of the modeling process.

Another strand within the realm of science teacher thinking is thought regarding the nature of science and science literacy. In an oft-cited and somewhat disturbing study of science teachers’ conceptions of the nature of science, Lederman & Zeidler (1987) reported that programs designed to improve science teachers’ conceptions of the nature of science did not appear to influence their teaching behaviors. They suggested several changes in the then-current teacher education programs to address this issue. On the other hand, Brickhouse (1989) conducted a study of the philosophies of science held by three science teachers and found that their views of science were indeed consistent with their classroom instruction. Their philosophies greatly influenced their use of demonstrations, laboratory time, vocabulary, and their choice of instructional goals. Five years after his previously cited article, Lederman (1992) published an extensive review of research on both teacher and student conceptions of the nature of science and drew attention to the complexity of the factors influencing the teaching of this topic. He used the opportunity to issue an appeal for more research into the development of pedagogical content knowledge in teachers. Koballa, Kemp & Evans (1997) quoted the National Science Education Standards in promoting the necessity for science teachers to strive to improve their understanding of science literacy. Arguing that an understanding of science literacy is a lifelong pursuit, they presented a description of science literacy along a three-dimensional spectrum involving multiple levels of understanding, multiple domains, and multiple levels of value.

Several studies have implications in regard to the preservice training of science student teachers. Czerniak & Schriver (1994) conducted a study of self-efficacy in preservice teachers and found that student teachers classified as “highly efficacious” tended to focus on the students, tended to use educational theories and instructional practices learned in class, and judged success or failure as results of their own skill. The researchers felt that their study showed that self-efficacy is a viable construct for examining student teacher thinking and behaviors. Shapiro (1996) reported on an assignment she used with her elementary science methods students involving an open-ended, authentic investigation into a question of their choosing. In a case study of one of her students, she described the changes in the student’s personal constructs regarding the nature of scientific investigation and evaluated the effectiveness of the assignment. Levin & Ammon (1996) reported on an eight-year longitudinal study of a fifth grade teacher as he progressed to the level of an “integrated constructivist.” They found that working with student teachers forces more experienced teachers to rethink and articulate their teaching philosophies. They also found that younger cooperating teachers seem to be better able to articulate their thinking to student teachers than more experienced teachers, whose thinking had become “automatic.”

Several articles highlighted differences in the methodologies used to study science teacher thinking. Tobin, Espinet, Byrd & Adams (1988) conducted a case study of an expert tenth grade science teacher and evaluated his thinking and teaching against the views of the team of professional teacher educators observing him. The teacher was quoted as stating that he did not see “eye to eye” with the researchers on many issues. Cornett (1990), on the other hand, conducted a naturalistic case study of a first-year, seventh grade science teacher and was able to identify seven distinct personal theories held by the subject. He suggested the need for a longitudinal study and vigorously defended his choice of a naturalistic study for research into teacher thinking because of its ability to see things through the eyes of the subject, comparing it to the study by Tobin et al. A study by Bradford & Dana (1996) explored the use of metaphorical thinking as a research tool for investigating science teacher thinking. They found a close relationship between the teaching practices of the subject of the study and the metaphors she chose to describe herself. They also related metaphorical thinking to the process of reflection. Hewson, Kerby & Cook (1995) described an analytical process for determining the science teaching conceptions of experienced teachers by using an interview grid technique. Several teachers were interviewed using the Conceptions of Teaching Science Interview and the use of the analysis grid was demonstrated. Hewson & Kerby (1993) had previously written an article on the effect of teacher thinking on teacher practice and had introduced the use of the CTS Interview as a tool for investigating teacher conceptions.

Several other studies have focused on more specific teaching methodologies or strategies. Oakes (1997) defended the use of graphing as a teaching and conceptualizing tool and found its primary strength to be the ability to make the discovery process quantitative. Greenwald (2000) focused on the use of problem-based learning (PBL) as a teaching tool. She found that, through the use of ill-defined problems, there is a dramatic shift in the roles of teacher and student, with students taking more responsibility for their learning and teachers assuming the role of challenging questioner.

Summary

The lack of emphasis on research into the in-service professional development needs of experienced physics teachers is at once understandable and lamentable. It is understandable because of the attention that must be paid to the development of new physics teachers in a time of teacher shortage and because physics is still a subject that is taken by only 28% of high school students (Neuschatz & McFarling, 1999). It is, at the same time, lamentable because our evolving understanding of how students learn cannot filter down on its own to overworked veteran teachers. Some teachers are insightful enough to observe, reflect, and modify their teaching on their own without benefit of exposure to professional literature and current theories. These are the teachers von Glasersfeld (1995b) was talking about when he said:

> In summary, the best teachers have always known and used all this information, but they have known and used it more or less intuitively and often against the official theory of instruction. Constructivism does not claim to have made earth-shaking inventions in the area of education; it merely claims to provide a solid conceptual basis for some of the things that, until now, inspired teachers had to do without theoretical foundation. (p. 15)

Unfortunately, in my experience, it seems that most veteran teachers continue to do what they have always done and, when it fails to give adequate results, look for factors to blame such as the students, the parents, changing demographics, or the social climate. These are the teachers most in need of effective professional development and how to make it more effective is in need of considerably more study.

The much more abundant literature on conceptual change, alternative conceptions, and constructivism in teaching shows that student learning is receiving substantial attention. The fact that the literature on these topics is constantly cross-referring tends to support the idea that they are three aspects of one larger whole. It is this larger whole that the Modeling Program is attempting to address. The program is designed to bring to the surface student alternative conceptions and use constructivist techniques to stimulate conceptual change, at least bringing the students from the naïve, Aristotelian paradigm to the more experimentally-based Newtonian paradigm. More important, the goal of the program is to stimulate the passive constructivist in each student and help that student understand that he or she has the ability to be an active, lifelong learner. Whether the Modeling Program is the most effective way to accomplish these ends remains to be seen but I remain convinced that it's a good start.

CHAPTER 3

METHODOLOGY

This chapter contains (a) an overview of the study, (b) a discussion of my general methodology, (c) a discussion of my methodological theoretical perspective, (d) a description of my research design, (e) a description of my participants and participant selection criteria, (f) a description of my data collection methods, (g) a description of my data analysis procedure, and (h) a discussion of the issues of reliability and validity.

Overview

The purpose of this study is to understand the perceptions of what constitutes effective science teaching and effective student science learning held by physics teachers who have participated in a constructivist in-service training program. The purpose is further to understand how these teachers perceive the influence of their participation in the in-service training program on their views effective science teaching and effective student science learning.

General Methodology

I have chosen a qualitative design for this study because it is conducive to rich description and because it leads to an understanding of the research questions from the insider's point of view (the emic perspective). Bogdan & Biklen (1998) outline the goal of qualitative research:

> The qualitative researcher's goal is to better understand human behavior and experience. They seek to grasp the processes by which people construct meaning and to describe what those meanings are. They use empirical observation because

> it is with concrete incidents of human behavior that investigators can think more clearly and deeply about the human condition. (p. 38)

Guba (1978) describes qualitative research in education as naturalistic because the researcher is visiting the locations where the events under study naturally occur. The data gathered by this method include talking, listening, teaching, and working. Erickson (1986) stated that interpretive, participant observation fieldwork

> involves being unusually thorough and reflective in noticing and describing everyday events in the field setting, and in attempting to identify the significance of actions in the events from the various points of view of the actors themselves. (p. 121)

By entering the worlds of the participants, it becomes possible to gain a better appreciation of how they have come to the understandings that they have.

Methodological Theoretical Perspective

Crotty (1998) defines the term theoretical perspective as "the philosophical stance lying behind a methodolgy (p. 66)." Elaborating on this definition, he says:

> Another way to put it is to say that, whenever one examines a particular methodology, one discovers a complexus of assumptions buried within it. It is these assumptions that constitute one's theoretical perspective and they largely have to do with the world that the methodology envisages. Different ways of viewing the world shape different ways of researching the world. (p. 66)

My theoretical perspective is interpretivist and the methodology it supports in this study is qualitative analysis, specifically narrative inquiry. According to Schwandt (1994):

> The constructivist or interpretivist believes that to understand this world of meaning one must interpret it. The inquirer must elucidate the process of meaning construction and clarify what and how meanings are embodied in the language and actions of social actors. To prepare an interpretation is itself to construct a reading of these meanings; it is to offer the inquirer's construction of the constructions of the actors one studies. (p. 118)

This statement makes interpretivism, the search for understanding through interpretation, and narrative inquiry, the study of "first-person accounts of experience (Riessman, 1993,

p. 17)” appear to me to be compatible and mutually supportive concepts. Schwandt (1994) continues:

> I read this union of the interpretive turn and the tradition of practical philosophy, with its defense of the Socratic virtues and its emphasis on our fundamental character as dialogic, conversational, questioning beings, to be a most promising and hopeful development. The interpretivists’ profound respect for and interest in socially constructed meaning and practice is consonant with the turn toward the moral-practical (phronesis) and away from *theoria*. (P. 132)

This “respect” for socially constructed meaning supports the compatibility of interpretivism as a methodological theoretical perspective and social constructivism as an epistemological theoretical perspective.

In describing the importance and function of interpretation in social science, Carr & Kemmis (1986) state that

> all descriptions of actions must contain an interpretive element. To describe somebody as teaching, for example, is not simply to describe their observable behavior. What is observed may be somebody baking a cake, standing on his head, reading a book, playing the piano or talking to a child. What allows any of these behaviors to be interpreted as teaching is an identification of the particular ‘subjective meanings’, according to which those performing these actions understand what they are doing. Actions, unlike the behavior of most objects, always embody the interpretations of the actor, and for this reason can only be understood by grasping the meanings that the actor assigns to them. A task of ‘interpretive’ social science is to discover these meanings and so make action intelligible. (p. 88)

According to Kvale (1996), the role of interpretation in qualitative research is the search for

> more extensive and deeper interpretations of meaning, inspired by hermeneutical philosophy. The researcher has a perspective on what is investigated and interprets the interviews from this perspective. The interpreter goes beyond what is directly said to work out structures and relations of meaning not immediately apparent in the text. (p. 201).

Interpretivism is a broad perspective linked historically to the German intellectual tradition of hermeneutics (Schwandt, 1994, p. 119) and Max Weber and the verstehen tradition in German sociology, which focuses on understanding (verstehen) as opposed to explaining (erklaren) (Crotty, p. 67). Merriam cites the distinction made by Carr & Kemmis (1986) among the three basic forms of educational research – positivist, interpretive, and critical (Merriam, 1998, p. 4). She then elaborates:

> In *interpretive* research, education is considered to be a process and school is a lived experience. Understanding the meaning of the process or experience constitutes the knowledge to be gained from an inductive, hypothesis- or theory-generating (rather than a deductive or testing) mode of inquiry. Multiple realities are constructed socially by individuals. (p. 4)

It is this understanding of the experience (participation in the Modeling Program) and subsequent perceptions developed in the participants that is the focus of this study.

Research Design

My study involves six high school physics teachers who have participated in an intensive, constructivist, physics in-service program.

The research methodology for this study is narrative inquiry. Polkinghorne (1988) defines narrative as “the primary way through which humans organize their experiences into temporally meaningful episodes (p. 1).” Riessman (1993) defines it as “first-person accounts of experience (p. 17).” According to Kramp (in press), “The object of narrative inquiry is understanding – the outcome of interpretation – rather than explanation (p. 1).” She continues:

> What distinguishes narrative as a mode of inquiry is that it is both the process – a narrator/participant *telling* or *narrating* – and the product – the *story* or *narrative* told. Thus it is both the means by which you, as researcher, gather data, and the discourse or form of the data gathered. (p. 1)

According to Richardson (1995):

> Narrative is both a mode of reasoning and a mode of representation. People can ‘apprehend’ the world narratively and people can ‘tell’ about the world narratively. (p. 200)

Richardson describes Bruner's theory on human cognition:

> According to psychologist Jerome Bruner (1986), narrative reasoning is one of two basic and universal human cognition modes. The other mode is logico-scientific. The two modes are irreducible to each other and complementary. Each mode provides a distinctive way of ordering experience and constructing reality, has its own operating principles and criteria of 'well-formedness,' and has radically different procedures for verification (p. 11). (pp. 200-201).

The final lines of Richardson's article provide the essential justification for my choice of narrative inquiry:

> How should we write? If we wish to understand the deepest and most universal of human experiences, if we wish our work to be faithful to the lived experiences of people, if we wish for a union between poetics and science, or if we wish to use our privileges and skills to empower the people we study, then we *should* value the narrative. (pp. 218-9)

It is my intention to be as faithful to the lived experiences of my participants as possible.

I used a semistructured approach to interviewing my study participants in order to encourage the production of narrative, as defined above. My interview protocol is included as "Appendix A" of this study. Kramp (in press) describes the process and the goal:

> In response to the invitation you, as researcher, extend to the participant to 'Tell me about,' active subjects construct a narrative that is particular, personal, and contextualized in time and place. Having heard the narrative or having been told the story, you as researcher use any one of a variety of frameworks to analyze and interpret its meaning and understand the phenomenon you are researching. Through narrative inquiry you gain access to the personal experiences of the storyteller who frames, articulates and reveals life as experienced in a narrative structure we call story. In narrative inquiry this story is the basic unit of analysis. (p. 1).

The stories these six teachers have to tell are forthcoming.

Participant Selection

The participants in this study consist of a purposeful sample of six veteran high school physics teachers, three males and three females, who have participated in at least one summer of the Modeling Program and have been identified by the directors of the program as exemplary modelers.

Although there are exemplary modelers from locations across the country, four of the subjects live in reasonable proximity to each other near where the Modeling Program was held during the first few years. Therefore, the selection of that cluster is, in a sense, a convenience sample as well since it made my travel arrangements more manageable and limited my air travel. The other two are located within a reasonable driving distance of my current location.

Of the six participants, five have master's degrees and one is currently pursuing it. Only one of the six has an undergraduate degree in physics. Two have degrees in chemistry, one in zoology, one in biology, and one in microbiology. Four of them are teaching complete physics schedules and two are split between chemistry and physics. All are using the Modeling methodology on a daily basis in their physics classes. A brief table of information containing details about each of the six is included below.

	Gender	Age	Years Teaching	Undergraduate Major	Teaching Schedule
1	Male	35	10	Physics	Physics (9th grade)
2	Female	50	29	Chemistry	Physics, Chemistry
3	Female	35	13	Biology	Freshman Science, Physics, A.P. Physics
4	Male	48	17	Zoology	Freshman Science, Physics, Honors Physics

5	Male	48	14	Chemistry	Physics, A.P. Physics, A.P. Chemistry
6	Female	50	15	Microbiology	Physics, A.P. Physics

Data Collection Methods

Schwandt (1994) warns that

> not only are methods the most unremarkable aspect of interpretive work, but a focus on methods (techniques for gathering and analyzing data) often masks a full understanding of the relationship between method and inquiry purpose. The aim of attending carefully to the details, complexity, and situated meanings of the everyday life world can be achieved through a variety of methods. Although we may feel professionally compelled to use a special language for these procedures (e.g., participant observation, informant interviewing, archival research), at base, all interpretive inquirers watch, listen, ask, record, and examine. (p. 119)

With Schwandt's words in mind, I chose to use data consisting of an initial round of semistructured interviews, a follow-up round of semistructured interviews, fieldnotes taken during classroom observations, and limited amounts of supplementary archival data such as lesson plans, sample tests, student lab notebooks, and webpages. Follow-up phone calls and e-mail messages were used as needed.

Interviews

Bogdan & Biklen (1998) define an interview as "a purposeful conversation, usually between two people but sometimes involving more, that is directed by one in order to get information from the other (p. 93)." Patton (1987) states that an interview allows us

> to enter the other's perspective. We also interview to learn about things we cannot directly observe. We cannot observe everything. We cannot observe feelings, thoughts, and intentions. We cannot observe behaviors that took place at some previous point in time. We cannot observe situations that preclude the presence of an observer. We cannot observe how people have organized the world and the meanings they attach to what goes on in the world. We have to ask people questions about those things. (p. 109)

Since it is my purpose to probe into the feelings, thoughts, perceptions, and meanings held by the participants, interviewing was the primary strategy I chose to use for data collection in this study.

Patton (1987) identifies three distinct types of interviews: the informal conversational interview, the general interview guide approach, and the standardized open-ended interview. The specific type of interview approach chosen for a study should be based on the research goal (Bogdan & Biklen, 1998).

The informal conversational interview involves questions that arise spontaneously in the course of the interview. Since the specific questions are not predetermined, the participant plays a major role in determining the content and flow of the interview. This approach involves a great deal of time for data collection and makes data analysis more difficult due to the individual nature of the information gathered.

The interview guide approach, also known as the semistructured interview (Kvale, 1996, p. 124), is characterized by a list of prepared questions or issues, the wording or order of which may vary from interview to interview. Kvale (1996) summarizes the semistructured interview as follows:

> It has a sequence of themes to be covered, as well as suggested questions. Yet at the same time there is an openness to changes of sequence and forms of questions in order to follow up the answers given and the stories told by the subjects. (p. 124)

By providing a focus for the conversation, the interviewer can make relatively efficient use of interview time. On the positive side, this type of interview allows for a comprehensive and systematic approach across all participants. On the negative side, this style of interview can result in the inadvertent omission of crucial topics.

Probes, an interview technique used to go deeper into the responses (Merriam, 1988), add to the richness of the data and give cues to the interviewee about the desired level of response. Probes can be used to elaborate, clarify, or provide additional details in a conversational style.

The standardized, open-ended interview requires each participant to respond to the same carefully worded questions in the same order. Interview questions are prepared in advance in exactly the form they will be asked. This approach to interviewing maximizes the use of time and minimizes any effects created by the interviewer. On the positive side, standardized, open-ended interviews greatly simplify the process of data analysis, especially cross-case analysis. On the negative side, this approach greatly limits the flexibility of the interviewer to pursue particular questions or to deal with any issues that may spontaneously emerge during the interview.

Bogdan & Biklen (1998) remind us that it is important to focus on the research goal when selecting the specific type of interview for a study. For my study, I chose to use the semistructured, interview guide approach during the first interview with each participant in order to most effectively address my research questions. The interview guide approach allows for comparable data across subjects and is frequently used in multiple-participant studies (Patton, 1987). It also encourages the creation of stories and narrative, which makes it compatible with and supportive of a narrative inquiry methodology. After a preliminary analysis of the data, a follow-up interview was held with each participant. Since this interview was intended to fill in gaps in the first interview and expand on issues raised in the first interview, I used more of an informal conversational interview approach with specific questions prepared in advance, tailored to each participant. Both rounds of interviews were mechanically recorded with the permission of all participants in order to allow me to concentrate on the conversations themselves and create probes at the appropriate moments.

Observation

According to Patton (1987), the participant observation procedure has several distinct advantages as a data collection technique. This procedure allows for direct experience with the events under study and a greater understanding of the context in which those events occur. It also can make information available that might otherwise have been unavailable or taken for granted by participants. Finally, it can present a more complete view of the phenomenon and allow the researcher to form impressions that will be important during data analysis and interpretation.

Difficulties with participant observation, according to Merriam (1998), include the fact that

> Participant observation is a schizophrenic activity in that the researcher usually participates but not to the extent of becoming totally absorbed in the activity. While participating, the researcher tries to stay sufficiently detached to observe and analyze. It is a marginal position and personally difficult to sustain. (p. 103)

Merriam also warns that “Another concern is the extent to which the observer investigator affects what is being observed (p. 103).” Since qualitative research assumes subjectivity and interaction, the question should not be “whether the process of observing affects what is observed but how the researcher can identify those effects and account for them in interpreting the data (p. 103).” She concludes by saying that “the researcher must be sensitive to the effects one might be having on the situation and account for those effects (P. 104).” For this reason, I took the role of non-participant observer as much as possible so as to have as little affect on the classroom dynamics as possible.

The combination of observation and in-depth interviewing is essential so that we can both observe the behaviors of the participants and interpret the meanings that they assign to them as Carr & Kemmis (1986) described earlier.

I spent one full day (same day as the first interview) observing each of these teachers in their classrooms. In the course of an entire day watching each of these teachers teach several different classes, I was able to observe each individual's interaction with students, approach to instruction, questioning style, and comfort level with the Modeling methodology. More time would possibly have allowed me to fill in some finer detail, but it is my experience in working with and observing other teachers that it is possible to develop a reasonably clear picture of a teacher's style in a very short period of time. Experienced teachers especially are prone to very unique and idiosyncratic mannerisms and are usually unflustered by the presence of an observer, especially one with no supervisory role to exercise. Fieldnotes taken during these observations yielded some additional insights into each teacher's perceptions of what constitutes effective science teaching and effective student science learning.

Archival Data

Finding significant amounts of supplementary archival data was problematic. Teachers who have adopted the Modeling methodology tend to have extremely sketchy lesson plans if, in fact, they have any written plans at all. The student-centered nature of modeling and the Socratic questioning it encourages make it difficult to know how each class period will evolve. In more than one conversation with teachers who use modeling I have heard the comment that they know where they want to be by the end of a class period but they cannot predict with any assurance how they are going to get there. That has also been my own personal experience with using the Modeling methodology.

Obtaining sample tests was also problematic since the Modeling Program is so complete that all practicing teachers have multiple assessments available on compact disk already prepared by the developers of the program. When in full modeling mode, these teachers seldom write their own tests or quizzes. Likewise, the format and expectations for written student lab reports is also clearly dictated by the program materials. Therefore, I learned relatively little about the individual teachers by sampling these materials.

Webpages can potentially reveal information about a teacher's approach to teaching. Most teachers, however, lack the time or skills to truly customize a webpage and most of us merely have links from a school website to a list of assignments or possibly a course syllabus. Still, the text of a syllabus is a potential source of insight into a teacher's approach to teaching. Two of the participants had personalized webpages and one of them yielded some insights into that participant's approach to inquiry teaching.

Data Analysis Method

The purpose of qualitative research is to gain a better understanding of human behavior and experience. The most important part of the process is not data collection but data analysis, which is where the process of interpretation actually takes place (Patton, 1990). This is the point at which the researcher makes sense of the data (Merriam, 1988). Bogdan & Biklen (1998) give an overview of the process:

> Data analysis is the process of systematically searching and arranging the interview transcripts, fieldnotes, and other materials that you accumulate to increase your own understanding of them and to enable you to present what you have discovered to others. Analysis involves working with data, organizing them,

> breaking them into manageable units, synthesizing them, searching for patterns, discovering what is important and what is to be learned, and deciding what you will tell others. (p. 157)

According to both Patton (1987) and Merriam (1988), one of the most distinctive aspects of qualitative research is that the processes of data collection and data analysis take place simultaneously. Insights gained during the early rounds of data collection redirect succeeding rounds as well as refining the questions to be asked. This interplay of collection and analysis inevitably improves the quality of the final product.

The analysis process began with the interview data. Each of the interviews was transcribed in preparation for analysis. Fieldnotes from the classroom observations were typed in as much detail as possible. The limited amount of supplementary archival data was grouped by participant

My data analysis method is analysis of narrative. The structure of this analysis follows the Bogdan and Biklen (1998) model found in their chapter on data analysis (pp. 171-7). In this section, they suggest a series of coding categories including, but not limited to, setting/context, definition of situation, perceptions held by subjects, subjects' ways of thinking, process, activity, event, strategy, relationship and social structure, and methods.

The development of coding categories is a critical part of the analysis process. According to Coffey & Atkinson (1996), coding consists of condensing down the bulk of the data into analyzable units by creating categories that arise from an initial analysis of the data. The goal of the process is to make the data analysis manageable and to retrieve the most important bits of data. This occurs when the coding categories lead to linkages within the data. Again, according to Coffey & Atkinson (1996), "The important analytic work lies in establishing and thinking about such linkages, not the mundane processes of coding (p. 27)."

After continuous rereading of the interview data, I concluded that the most useful coding category for my analysis and the one most closely linked to the purpose of my study was perceptions held by the subjects. I created three subcategories, one specifically for each research question: perceptions related to effective science teaching, perceptions related to effective student learning, and perceptions related to the influence of the Modeling Program.

In order to facilitate the coding and linkage process, the transcripts were reread many times and then relevant sections were highlighted in the left margin using a different color highlighter for each code. Similarly coded data was then grouped together for each participant using the "cut and paste" function on the word-processing software and reprinted as a separate document. This data was then repeatedly reread by subcategory and a key word or words from each line was written in the right margin next to that line. The key words were then reread repeatedly and those that occurred frequently were listed on separate paper. The subcategory documents were then reread again with each of the frequently occurring words or phrases in mind until themes began to emerge. After each theme was identified, the relevant passages containing the key words that led to that theme were grouped together and organized in the most coherent order possible to support the theme.

When the time came to complete the cross-case analysis, the relevant themes that emerged from each participant were summarized by research question and then the data on each question from all six participants was reread several times. Common themes across participants within each research question were identified and listed in order of decreasing commonality. These became the sources of the broader themes discussed in Chapter 5.

Reliability and Validity

According to Goetz & LeCompte (1984), reliability, or the extent to which ones findings can be replicated, is quite problematic in qualitative research. Merriam (1998), states the case quite emphatically:

> Because what is being studied in education is assumed to be in flux, multifaceted, and highly contextual, because information gathered is a function of who gives it and how skilled the researcher is at getting it, and because the emergent design of a qualitative case study precludes a priori controls, achieving reliability in the traditional sense is not only fanciful but impossible. (p. 206)

Since reliability, at least in the traditional sense, is not possible, Merriam (1998) suggests substituting Lincoln & Guba's (1985) notion of dependability. She further suggests several techniques for increasing dependability, including an explanation of the investigator's position, triangulation of data, and the creation of an audit trail (pp. 206-7). Goetz & LeCompte (1984) add to that list verbatim accounts of participant conversations, peer examination, and the mechanical recording of data.

"Internal validity deals with the question of how research findings match reality (Merriam, 1998, p. 201)." Maximizing internal validity can be accomplished by the use of certain qualitative data collection and analysis techniques such as informant interviews, participant observation, and researcher self-monitoring (Goetz & LeCompte, 1984; Merriam, 1998). I used several additional strategies during this study, including triangulation, member checking, and a statement of the researcher's biases.

Triangulation is the use of “multiple investigators, multiple sources of data, or multiple methods to confirm the emerging findings (Merriam, 1998, p. 204).” Although I was the sole investigator in this study, I triangulated the interview data, the observation fieldnotes, and the archival data to maximize internal validity. Member checking involves “taking data and tentative interpretations back to the people from whom they were derived and asking them if the results are plausible (Merriam, 1998, p. 204).” I sent drafts of what I had written about each of the participants back to them and requested their comments on the accuracy and plausibility of what I have written. Two of the participants never responded, two of them said that everything looked fine to them as it stood, and two approved of my writing and expressed surprise at how they sounded in the quotations. I assured them that verbatim transcripts of informal conversations always sound less than flattering when scrutinized but that that is the nature of informal conversation and nothing to be upset about. As for researcher biases, a statement of these biases is presented at the end of Chapter 1 and was referred back to at key points during the analysis process.

Merriam (1998) states that “external validity is concerned with the extent to which the findings of one study can be applied to other situations. That is, how generalizable are the results of a research study (p. 207)?” She then cites Guba & Lincoln (1981) in saying that there is no point in trying to judge the external validity of a study that is not first judged to be internally valid. Beyond that, generalizability is very problematic in qualitative research. I make no claims for generalizability for this study. The sample size (six) is small, the participants have already demonstrated their belief in and support of the Modeling Program as attested to by being judged exemplary by the directors of the program, and the participants are all veteran high school physics teachers from suburban schools in two metropolitan areas. Therefore, it would be <u>at most</u> possible to consider them as representative of purposefully-selected veteran suburban high school physics teachers, a very specific and narrow group indeed.

Merriam (1988) suggests that generalizability or external validity is related to what the reader wants to learn. I hope that I have provided an adequate description of my participants and leave it up to the reader to decide on the applicability of my findings to other situations and other populations.

CHAPTER 4

SUMMARY OF FINDINGS

Yin (1989, pp. 134-5) proposes several methods for writing up multiple-case study reports, two of which could apply to my study. The first possibility he offers is to present each case separately and then include a separate section dealing with the cross-case analysis. The second possibility is not to present each case separately but rather to do only cross-case analysis, with a separate section devoted to each issue or research question.

My plan for the chapter summarizing my results is to tell the story of each of my participants in a separate sub-section of the chapter and then unite them in the cross-case analysis in the seventh sub-section followed by a summary table of themes. This will allow for a more detailed description of each. Within each participant sub-section, I will give a brief professional history of the participant, a description of the demographics and socioeconomics of his or her school (as reported by the participant), a description of the participant's teaching schedule and teaching environment, and a brief summary of my observations of the participant in action in the classroom. Then I will formally address each of the three research questions with extensive interview quotations supplemented by supporting observations and any relevant archival data. In the seventh sub-section, I will perform a separate cross-case analysis for each of the three research questions.

The names used for all participants are pseudonyms, consistent with university research policies and the promise I made to each to safeguard their identity.

Robert -- the Natural Philosopher

Robert is a thirty-eight year old physics teacher at a private college-preparatory academy in a large, southeastern metropolitan area. The high school division of this academy has an enrollment of approximately 800 students, 88% white, 12% minority, and socioeconomically upper-middle class to upper class.

Robert graduated from a prestigious southeastern technical university in 1987 with a B.S. degree in physics. He immediately joined the Peace Corps where he spent two years teaching science in Gabon, Africa. His teacher training consisted of a twelve week training program in French, a language with which he had had no previous experience. He returned to the United States in 1989 and supported himself by waiting tables while he pursued teaching certification in a provisional teaching certification program jointly sponsored by the Peace Corps, a local university, and a local urban public school system. After receiving full certification in 1991, he began teaching high school physics in that urban school system. He taught at one high school for four years, another school in the same system for two more years, and then, in 1997, he moved to the school where he is currently teaching. He completed his M.Ed. in physics in 1996 at the same university that sponsored his certification program. He is currently married and is the proud father of two young daughters.

Robert participated in a two-summer version of the Modeling Program in the summers of 1999 and 2000 and has been a strong proponent of the modeling methodology ever since. His school has chosen the “physics first” structure for the high school science curriculum and, as a result, Robert’s teaching schedule consists of four ninth grade physics classes that meet six hours per week each.

Robert’s classroom is very large and brightly lit with high ceilings, wall-to-wall carpeting, and four very large windows, two each on the long back wall and the shorter wall to its right. Across the long back of the room are located five large, rolling, free-standing lab tables which are flat and bare except for electrical outlets at each end. In the middle of the room are located five clusters of four individual student tables and chairs arranged in squares with students facing each other. Robert uses this arrangement to facilitate small group work and the whiteboarding process. The front of the room is the remaining long wall with a long, wall-mounted horizontal sliding whiteboard at its center and a large, hanging television monitor just to its left. The remaining three walls have continuous lab counters with sinks in four locations, closed cabinets beneath, and small glass-fronted cabinets above the counters on the two narrow walls. The long back wall has two large, closed, six-foot tall storage cabinets between the windows. A large, open cabinet with two dozen cubbies is located next to the door entering the room and students deposit their bookbags there and bring only their physics materials to their individual desks.

At Robert’s request, there is no demonstration bench at the front of the room. His small teacher desk sits well off to the side to the left of the television monitor and is used primarily for his computer. There is no barrier at all between the students and the front board and two of the student desk clusters are located within four feet of the whiteboard. Students move easily from their desks to the front whiteboard and Robert is always in motion from side to side when working at the board so as not to consistently block anyone’s view. When it is necessary to do some sort of a demonstration, Robert invites the whole class to gather around one of the back lab tables.

Lined up along the floor below the marker tray of the front whiteboard are over two dozen portable student whiteboards, most of which still contain work from previous classes to be shown in class the next day. When students display their boards, they lift them up onto the marker tray and stand on either side. The boards remain on the marker tray until all students have had their opportunity to present to the class.

Almost all available wall space and most of the lab counter space is occupied with display boards from student science fair projects. He rotates the display boards frequently so that all students see their work featured at some point during the year.

Robert began each of the classes that I observed with an exercise he calls “science questions.” Students are encouraged to submit in writing and then orally, in front of the class, any question they can think of that relates to science. Some of the questions seemed directly related to the physics they were studying in class but most of them were more random, often related to some current topic in the news. Robert went to great lengths to compliment each student question with statements like “Gee, that’s a great question,” or “Wow, I never thought about that before.” He would then ask if anyone in the class thought they knew the answer to each question and would attempt to answer it himself if no satisfactory answer came from the other students. He frequently apologized for his lack of background in chemistry or biology but attempted to answer questions in those fields anyway. Students received extra credit if they were willing to stand and ask their questions in class and all questions ended up being posted on his personal school webpage within the school website.

The formal part of each lesson began with a student being called upon to summarize the previous day’s lesson. Two classes then went directly to a continuation of the previous day's whiteboarding session with students finding their individual whiteboards in the pile under the marker tray of the front whiteboard. Robert retreated to the back of the room and fired question after question at each group as they presented to the class. He also fired questions at other students, encouraging them to bring knowledge acquired in previous classes to bear as they attempted to clarify what the students in the front of the room were presenting. He constantly encouraged students to question each other, always complimenting each question with exclamations like "Wow, great question!" The students spontaneously applauded each presentation.

In two classes, he invited the students to gather around a back lab table and demonstrated collisions of lab carts of different masses. He asked if they saw any relationships or patterns among the various collisions and then acknowledged each response in a very neutral manner, not giving any hint as to whether they were correct or not. He then had students brainstorm how to organize an experiment to systematically investigate the behavior of objects during collisions. He responded to each suggestion with questions designed to make them think through the variables they intended to investigate. The students then went back to their desks and worked for the remainder of the period with their lab partners writing a purpose, hypothesis, procedure, and apparatus list for the experiment they would all do the next day. Robert drifted around the room, eavesdropping on each group and answering questions with questions. One girl started to ask him a question and then backed off, saying with a twinge of sarcasm, "Never mind, you won't answer me anyway." Robert just smiled and walked away.

One of his classes had completed the data collection portion of a lab experiment the previous day and Robert escorted them down the hallway to a computer lab where the students graphed and analyzed their data. The printouts of these analyzed graphs are then pasted into student lab books as an essential part of the data analysis section of each lab report. The students seemed very comfortable with the computer software and only asked Robert questions related to some minor technical bugs involving sending the computer output to some networked printers.

Perceptions of Effective Science Teaching

Robert expressed a wide variety of perceptions about effective science teaching, dealing with issues of teacher and student roles, the organization of the teaching process, sensitivity to students, and the nature of science itself. His passion for what he does and his philosophical views on science and science teaching were evident throughout both interviews.

Robert felt that an effective science teacher must work to transfer much of the control of the learning process from the teacher to the students. He described his own high school physics teacher as “very lecture-based and didactic,” something that he personally found “very appealing” at the time because he anticipated that “that was what college was going to be like,” but has since come to feel is “not the right way or not a very effective way to teach most science, and probably math, too.” Since his participation in a Foxfire class and later in the Modeling Program, he said that he now has come to value the importance of

> the courage to let go, the courage to kind of take your hands off the wheel as it were and say to the students ‘What do you think? How should we do this?’ (initial interview)

His trust in the students is echoed in the statement:

> There's so much more that those students can contribute to the class than I can. There's so much and so it’s always something that I want to keep trying to do is to

> keep involving the students in the learning process so that we can work together, so that I can get their good ideas. If I could find a way to tap into their creative energies, and have that work for the class that would be the best thing. (initial interview)

Robert also felt, in a perception that only he verbalized, that it is essential for the effective science teacher to teach his or her students the nature of scientific theories and models, the limitations of our understanding, and overlay it all with a sense of humility. This is probably where Robert's tendency to philosophize became most apparent. For instance, near the end of a long discussion of a favorite Einstein quotation, Robert said:

> I would be very, very arrogant if I were to say that, you know, that we know the workings of the universe, because we can't. All we have are our five senses, and we only have the best model that we have. There is no, and I do believe this, ultimate knowledge that we will ever have where we say now we know everything about the way the universe works. You know, any time that human beings throughout history have thought that about the universe, they have proved themselves wrong shortly thereafter. (initial interview)

He continued:

> I tell my students we're going to study Newtonian physics and I have to tell you that it's a really good model if you're building bridges but when we really look deeply at the universe, it doesn't do, it's not right, it just doesn't work. I mean you can't use Newtonian physics to explain black holes or the motion of atoms. Therefore, Newtonian physics is a severely limited model but it's a really great model to *learn* for somebody who wants to understand *that* model. And if kids could get that that's the nature of science, then we don't have all this crap with evolution, and this thing about the deification of science. . . So people in general, and especially through science classes, misunderstand the concepts of science. What science is really all about. How they misunderstand the nature of scientific research and the nature of scientific models. And that continues to do a disservice to people in general, to humanity. (initial interview)

This issue of the "deification" of science and science as some form of absolute "truth" was a particularly passionate issue with Robert:

> And the reason that this is happening I have to believe is because people have put science on this pedestal of being some kind of truth that someway competes with spiritual truths and nothing could be further from the truth. Nothing. Science doesn't, is not about truth. Science is about good models (laughter) and if you

> can make a good model, that's great, and it helps you to figure out how things work and make bridges and to figure out when the next eclipse is going to be and all that *stuff* but just because it predicts things well doesn't mean it's the truth because we know that Newtonian mechanics predicts a lot of things well but certainly if we really look deeply enough it is so flawed that we have to absolutely throw it out when it comes to understanding *the* most fundamental things about the universe. You know, I get kind of passionate about this. I know I'm going on and on and on but it really annoys me when scientists and science teachers really misunderstand the nature of science or they completely fail to communicate to their students that it's all made up. . . But there is no ultimate explanation. I do believe that. That's a really heavy philosophical point that I hold, so a didactic approach to teaching physics or teaching any science comes across as if what's written in that book is the truth and the students come out of that class thinking that if they did well they learned the truth and in that way we do a disservice to everybody. (initial interview)

This issue of science as being "all made up" extended, in Robert's mind, to the most fundamental concepts in physics:

> I really do believe to the depths of my soul that there is no such thing as gravity, there is no such a thing as mass, there is no such thing as force. That all of these things are human inventions and that they are *really* good models that we have of predicting the future. (initial interview)

He felt that an understanding of the history of science can help us understand the limitations of our present knowledge:

> But there are some really specific times in *physics* when no teacher should miss the opportunity to show the progression from the Aristotelian view of the world to the Newtonian view of the world to a relativistic view of the world to a quantum view of the world and to show the position where we are today . . . If you *don't* show your kids that, then you just missed one of the best opportunities to really show them that we just don't know. That our models today are severely limited. (initial interview)

Robert acknowledged that these limitations in our knowledge exist outside the world of education as well. He told a story of a friend of his who is an engineer for a semiconductor chip manufacturer and who made a startling confession:

> Over half of this stuff that they make the chips *do*, the way they make them behave, they don't have physical models for why they behave that way. So, contrary to what I think is a popular belief that we understand the world and that

> we've got it all explained, here's a guy saying well, no, we just make the chips. It's like alchemy. We basically know that if we do this, this, and this, that the chip will behave in this way but we don't have a model that explains it. (initial interview)

His feelings on the subject came through again during the follow-up interview:

> A lot of very intelligent people, I mean *really* intelligent people, with PhD's and, you know, just don't *get* what a theory is or how an idea becomes a theory or why we do science the way we do it. It's all a lot of junk, you know, in a lot of places. (follow-up interview)

Robert summed up his sense of intellectual humility in this final quotation:

> I think that sense of humility is important. As the field changes, as we learn more about things, and also just, something particular to science, a scientist has to be able to get up in the morning and say 'You know what, everything I have been thinking or preaching is wrong. The evidence shows it.' And good scientists do that. They concede defeat. I'm hopeful and I think I see evidence that we're all learning how to be more humble. (follow-up interview)

Robert felt that it is important that effective science teachers exude a sense of excitement about science. His passion for what he does is evident in his thoughts on the subject:

> But I wanted to say also about excitement, I think that it actually provides something for the students if the teacher is interested in what they're doing and excited about what they're doing. . . The best thing I can say about myself as a teacher, as a physics teacher is that I *love* physics, I absolutely *love* it. It's my favorite thing to talk about or to learn about, so much so that I don't think anything else is all that much worth. . . I actually love physics and I love science and modern thought and I love, you know, sharing those things with my students and sharing with them models of the world and how it all seems to work together in just incredible ways. (initial interview)

He laughed outloud after making this comment on the subject during the initial interview: "I'll put it this way -- being excited, I don't think it can hurt."

Robert lamented the lack of student involvement and student questioning in most of the science classes he has observed:

> I wish that science classes were filled with more of that because then students might understand the awe of science and the wonder and the excitement of being a scientist as opposed to learning some canon that we call, you know, this is science. (initial interview)

He revisited the idea one last time during the follow-up interview by commenting on one of his fellow teachers while trying to enumerate the factors that make a teacher effective:

> I was going to say that you have to be up on science but you know we have a teacher in our school who's very forward with the idea that he can give a flip about chemistry but he's our chemistry teacher. It's kind of unusual to come across that and I would add that I think he's a very good teacher but maybe there's something that he's missing or that his kids miss. Maybe they do pass the AP test but, you know, maybe they're missing something without that kind of love. I don't know, but for me anyway, I just love science so much I can't imagine me being a good teacher and not really having a good interest in my field. (follow-up interview)

The energy he expended during the classes I observed and his animated voice and mannerisms were certainly consistent with his expressed thoughts on the importance of a sense of excitement about and love for his subject.

Robert felt that it is essential for effective science teachers to show sensitivity to students with diverse abilities and use techniques that are appropriate for students with different learning styles or learning modalities. When he was in high school, physics was an elective class for the brighter students ("only a real small percentage of the students took it") and just being in the class made him feel like an "advanced person." Now that he is teaching it, his feelings about it have changed:

> I think one of the ways I'm different is that I think that physics is for everyone. It's not just for the top fifteen or twenty percent. It is our duty, I believe, as his teachers, to create classes that work *for* the student. . . I think we have to make classes that work for the student and that work for *all* the students. Not necessarily the *same* class that works for all the students, but every student deserves to have a class that works for him or her, within reason I think. (initial interview)

During the follow-up interview, Robert brought up the issues of learning styles, learning modalities and multiple intelligences:

> Going back to a teacher, a good teacher is someone who uses as many of the modalities as possible to have it come at the student from as many different angles as possible. . . One of the fundamental concepts in the modeling method is that you present as many different representations of a physical situation in as many different models as you can. . . That expands to learning styles. The more different ways that you can present material, as far as touching on different modalities, the more kids that you're going to reach. So it becomes not just within a certain kid but the different kind of kids. (follow-up interview)

He has become a big supporter of the use of technology in the classroom because it accesses different learning modalities for students. After describing the way in which a professor had taught him about wave motion with just chalk and blackboard, he added:

> You can draw it on the board if you're a good drawer, you can wave your hands around, but you're only going to get some of the kids, but if you can show them an animation of that, let them take a computer mouse and make a, in quotes *make* because they're not really making anything, but create on the screen a transverse wave and watch it propagate, that's a whole different experience. That kid now has the physics that they wouldn't have had without the technology, so I think this technology that we have is so huge because it allows us to open up our fields of science to so many new customers that in the past have just had to survive our classes or survive the course. So we have so many things that we can do now that are different, and that's pretty cool. (follow-up interview)

Robert felt that this awareness of learning styles and modalities should work toward making physics accessible to students that probably would not have taken it when he was a student:

> It's also a question of diversity. We are starting to learn as a society that we have so much to gain from seeing those different intelligences, seeing those different expressions of being a human being, that we're much, much better off having someone like that in our class and being challenged to bring the material to them as a society than we would be by just saying 'Well, you don't need to take physics. You just take an art class or some English because that's what you're good at.' (follow-up interview)

Robert felt that effective science teaching involves an inquiry approach with each concept being introduced by a laboratory experiment. As opposed to the “traditional” method of physics teaching which he described as “giving” the concept, working problems from the given formula, and then doing a “reinforcement” lab, he described his own approach:

> I don't say ‘Today we’re going to learn about constant velocity,’ I say ‘Today we want to learn about the motion of this buggy and let’s see how we can characterize it and we’ll look at the buggy and we’ll see how it moves and how could we study this’ and students will suggest we could see *where* it is *when*, or whatever and then try to tease out from them all the variables from the experiment. See what we could measure, have them *design* an experiment and then have them create, see what the relationships are, write a procedure, make a hypothesis about what they think is going to happen and then go ahead and perform the experiment, maybe refining the process as they go along, *changing* the procedure as they go along and then looking and seeing what they got and what does it mean and then also bringing in the mathematical/graphical interpretations of that, and then we would go on from that we would say that it *appears* that, hopefully we would be able to say that it appears that this thing for every certain measured amount of time goes the same distance. And we would be able to then create for ourselves the concept of a constant velocity model. (initial interview)

This is truly an inquiry approach because he leaves it to the students to isolate the variables, design the experiment, analyze the data, and draw their own conclusions. The key, of course, is starting with observation of a phenomenon that immediately leads to formal lab investigation. Although he used the term “we” throughout this description, his own role, as I observed in class, was mostly as an observer and facilitator. Students were allowed virtually all of the decision-making responsibilities, right up to the final whiteboard presentations.

Robert felt that effective science teaching is a mix of concepts, process, and content, not just problem-solving. In his words, “To have effective science teaching you have to have process, science process, and content, curriculum content." There needs to be a balance, however:

> There has to be a healthy dosage of content *and* methodology. Content and process, I guess, are the two kinds of things. I think we do a very, very poor job of teaching kids what science is and how it works and I think we're too heavy on the content, covering so much material. I think the teacher needs to cover a good deal of material but also has to really make sure that the kids have an understanding of what science *is* so that when they go to read a paper or something, you know, that whole thing of science literacy, that they understand what a scientific idea is. (follow-up interview)

This echoes and plays off his statements on the nature of scientific theories and models.

He is also concerned that the teaching of concepts not degenerate into some sort of mechanical problem-solving exercise. After describing how models are created from lab work, he cautioned:

> We kind of develop that, and then we say well can we use this problem to solve any real world problems with this model and do some problems like that. Then more testing, to see at the end if they got it. But also there's a real, I think, a real emphasis on making sure that what you are testing is what you want them to learn, and it's really very hard, as you probably know, to test for comprehension of physical concepts as opposed to testing for ability to solve a particular problem or set of problems. (initial interview)

This concern with learning concepts as opposed to merely the steps of problem-solving will be addressed further in the next section.

Robert has certainly become a passionately student-centered instructor. His teaching agenda includes inquiry-based teaching, instruction that is molded to the needs of individual students, venturing into the philosophical frontiers of the nature of science itself, and always the demonstration of an almost child-like enthusiasm for the subject he teaches. His devotion to his craft, his comfort level with his students, his knowledge of his subject matter, and his intellectual humility have combined to make him a most memorable instructor.

Perceptions of Effective Student Science Learning

Robert expressed an equally varied set of perceptions about effective student science learning. The key words that describe these perceptions are involvement, interaction, awareness, and responsibility. Several of these perceptions are mirror images of the characteristics he expressed in the previous section.

During the interviews, Robert felt that effective student science learners learn best by doing. After describing to me how he was one of “those three percent that really thrived on” the very “lecture-based, didactic” style of his own high school physics teacher, he responded to my question about how the other ninety-seven percent learn best:

> Well, I think by *doing* they learn. Well, maybe it's not even the other ninety-seven percent. Maybe it's the hundred percent because I can remember that through the Modeling method was when I finally understood Newton's Third Law. (initial interview)

Robert further felt that this “doing” extends to such issues as homework, reading, and notetaking. Speaking from the point of view of a supposedly effective student learner, he said:

> You gotta study. I don’t, there has to be some kind of work outside of class. *You* have to do most of the learning. It’s the teacher’s responsibility to spell it out for you, here’s what you have to do, it’s the student’s responsibility to do those things, and that certainly is a huge oversimplification, but a student has to read assigned text, a student has to read over his or her notes, a student has to go to assigned websites or do assignments, ask questions, a student has to take notes, read over their notes, keep their notebook up, and study in a way that there is a cumulative kind of, every day I’m going to give twenty minutes to physics. (follow-up interview)

Robert also felt that student interaction is essential for effective student science learning. He said “I want the kids to be explaining things to each other.” He continued:

> What really is going to cause learning is, probably, *interactions* for most people. And there are few kids that that's not true for. They don't have those kind of interactive skills and they should. (initial interview)

He recognized the value of interaction in his own experience. While describing a hypothetical effective physics teaching program, he reminisced about what he felt was so special about the Modeling Program: “You know, a very tremendous amount of interaction, and that was huge for me and so I don’t know if that will ever be duplicated.”

Robert felt that, in order to be effective science learners, students need to focus on understanding concepts, not just a set of steps to be used in problem-solving. He also felt that students must pay attention to the context in which various concepts apply. He said:

> When the students do their whiteboarding, a good teacher has interactions with students that causes the students, that forces the students to answer questions about what's going on such that the answers are not about what *steps* were followed but the answers are about *why* the steps were followed. Where this thing went and why’d you do it. (initial interview)

He can tell when the process has not been successful:

> Later on I’ll be grading quizzes or grading tests and go “Oh, I know why they didn’t get it,” because I had them solving problems. I had them learning the steps to solve problems but I didn't get the concepts across. (initial interview)

These concepts must be learned in context, according to Robert:

> Effective learning is understanding concepts and their context within a framework of understanding, and when I say framework of understanding I mean the canon of physics or the canon of chemistry, the things that you learn in an introductory high school class. Often times the kids get the concepts but they don’t understand the context in which it applies. So you get kids, for instance, using distance equals rate times time for an accelerating object. It won’t work. So that kind of thing, they don’t understand the context. (follow-up interview)

Robert felt that effective student science learners need to learn to think and ask questions like scientists. This is another perception that was uniquely his. He stated directly that the purpose of science teaching is “to try to get the kids to think like scientists.” For Robert, being a scientist starts with asking questions:

> There is no shortage of questions that are unanswered in science but that's not known in the world. I don't think people really know that and don't see it that way. So there are lots of lots of opportunities to bring that up, and the more we do that, and the more we say ‘I don't know.’ That's one of the reasons why I really like to have students ask questions every day. You know they get a point for asking a question and it could be ‘Why is the sky blue?’ A great question. (initial interview)

I observed that he began each class by offering students a chance to ask science questions. They had to submit them in writing <u>and</u> ask them outloud in class in order to earn the bonus credit. Robert attempts to answer them in class, or have other students answer them, and publishes most of these questions on his own school webpage. Sometimes he is unable to answer a question and uses this as a motivational tool:

> Any question is a great question and a lot of them, I say ‘Well here's what I've heard’ and most of the time I say, and I steal a phrase from (one of his professors), ‘I'm dancing on the horizons of my ignorance.’ And I say ‘This is why I think it would be. Just know that I don't know for sure’ and then I start to explain things. There's so many ways that we can do that and I wish that science classes were filled with more of that because then students might understand the awe of science and the wonder and the excitement of being a scientist . . . (initial interview)

Robert felt that effective student science learners take some ownership of what they learn and how they learn it. While discussing his experiences in a Foxfire course he had taken before participating in the Modeling Workshop, he pointed out what he liked most about the Foxfire philosophy:

> I thought that this is incredible because it’s student-centered. Students get to make choices about how they’re going to learn new material. There's ownership of the learning process and the things that I heard from successful Foxfire teachers were always just unbelievable. And they talked about things that are similar to what modelers talk about, about the courage to let go, the courage to kind of take your hands off the wheel as it were and say to the students ‘What do

> you think? How should we do this?' To really empower the students to have some responsibility for how they're learning . . . (initial interview)

He explained how he had had difficulty implementing the Foxfire method and then lamented "I always wanted my classroom to be a classroom where the kids really enjoyed and they felt an ownership and that there was a real partnership of learning."

In another unique perception, Robert felt that, to be effective science learners, students must develop an awareness of their own learning styles or learning modalities. During a discussion of multiple intelligences, he explained his understanding of the "current buzzwords," learning styles and learning modalities:

> The idea that we all have different ways in which we process better than others. We say 'Well I'm not an auditory learner.' Well you are *somewhat*, but maybe the way you favor, the way you most *efficiently* take in information, is *this* modality. (follow-up interview)

He then applies this to effective student learning:

> A good student is somebody who is going to hopefully know what their strength is and work with their strength and know what their weakness is and compensate for it, be aware of it, that kind of thing. (follow-up interview)

When I asked him which of the various learning styles was most useful in physics, he replied:

> I would say that traditionally I think it's the abstract reasoning, the person who can see it in their imaginations, who can imagine a wave traveling across the board so I don't know which one of the intelligences that would be and it has to do with visual, it's very abstract, spatial, that kind of thing. (follow-up interview)

Finally, Robert felt that it is essential for effective student learners to be open-minded and coachable. He said "I guess I would say a good learner is someone who is, I would say there is like a trust in the process, or kind of you've got to be coachable." He continued:

> You have to be a little bit open-minded, I think that makes great learning, and of course the best learners are the people who can learn from all situations all the time. They learn from their failures, their mistakes, they learn from, so that's not so much specific to science but it's important. (follow-up interview)

Effective student science learners, in Robert's view, have many of the same characteristics as scientists and effective teachers. They need to be excited, they need to be active and involved, they need to ask questions and be open-minded, they need to interact. His standards for his students are nearly as high as the standards he holds for himself and his colleagues.

Perceptions of the Influence of the Modeling Program

Robert had less to say about the influence of the Modeling Program on his views of effective science teaching and effective student learning. Much of what he had to say echoed his comments on the previous questions but the lid came off when he discussed the influence it had on his own personal understanding of physics.

During the interviews, Robert felt that, as a result of participating in the Modeling Program, he has shifted from a more didactic teaching style to a much more student-centered style. This perception was one that only he verbalized. He compared his style to that of his own high school physics teacher:

> My classroom looks a lot different than his does. His was very lecture-based, didactic, and you would get the idea and here's the thing and take the notes and learn how to do it, and that was very appealing to me and I was one of those three percent that really thrived in that method of learning, so, and also I thought that that was really cool. (initial interview)

Although that was "cool" when he was a high school student, and he clearly realized that that method only worked well for a small percentage of students, he has now come to view it as "traditional," as opposed to how he now teaches. When I asked him to describe what he meant by the term "traditional," he replied:

> If I were to say, well, today we're going to learn about constant velocity and then I'd draw maybe a picture of a car and I would say ‘OK, in one second it goes this far and then after three seconds its here and then it goes that far from three to four seconds’ and I would *explain* the concept of constant velocity and then I would give them, *show* them a formula that you could use to relate displacement and velocity in time . . . and then I would give them some problems to solve about that and then I would give them a lab in which they would demonstrate or they would see that principle applied to a buggy or something like that and then we would do some more problems and then they would take maybe a test or quiz and maybe build on that. That's the traditional way, that's the way I *used* to teach physics before modeling. (initial interview)

He described how he would approach the same lesson after his participation in the Modeling Program:

> The way my classroom is different now is that I don't say ‘Today, we’re going to learn about constant velocity,’ I say ‘Today, we want to learn about the motion of this buggy and let’s see how we can characterize it and we’ll look at the buggy and we’ll see how it moves’ . . . [lengthy description of the modeling methodology] . . .and we would be able to then create for ourselves the concept of a constant velocity model. (initial interview)

He uses the pronoun “we” throughout this description of his classroom approach after modeling as opposed to the use of the pronoun “I” in describing the “traditional” method he used before.

Although he is a strong supporter of a more student-centered, less didactic approach to teaching, Robert showed evidence that the transition has had somewhat of an emotional element to it when he said: “So, I guess you kind of become a convert and then you lament the loss of your old self, of your lecturing, of your didactic, authoritative person.”

Robert, in another unique perception, also felt that, as a result of participating in the Modeling Program, he has become much more constructivist in his teaching and has adopted more of a “lab first” philosophy of science teaching. In addition to the quotations above, which show quite clearly a movement toward starting each unit with a laboratory exercise, he told me the story of how he was introduced to the concept of constructivism:

> In my master's work at [his graduate school], I was introduced to the idea of conceptual change. However, how was I taught conceptual change or how was I taught constructivist education? In a completely non-constructivist way [laughter]. Completely didactic, learning about it, so I didn't internalize a thing about it. It sounded like some sort of research phenomenon that really didn't apply to me as a teacher or that I didn't see how it applied to me. (initial interview)

It took an exposure to modeling to create an impact on him:

> Before I took the modeling workshop, I don't think I understood constructivism very much and I don't think that I believed it was important and I would kind of echo a lot of those other things, those things that I said about the learning modalities or about lecture. I hated, I don't think I understood the importance of labs before I did the modeling workshop because when I came up, the labs were all plug-and-chug. . . I think it made me the teacher that I am today, it's effect was so profound. (follow-up interview)

Robert felt that, as a result of participating in the Modeling Program, he has developed a much greater sense of humility about his effectiveness as a teacher. This is yet another viewpoint that was his alone. As described in the earlier section on Robert's perceptions of effective teaching, modeling has given him a sense of the limits of scientific knowledge. This sense of limitation extends to his perception of the effectiveness of his teaching as well:

> The teacher needs to have a tremendous sense of humility and you have to always be willing to ask the question 'Am I being an effective teacher?' . . . I'm light-years away from where I was before I took modeling. And maybe not so much for the modeling technique but just for the realization that, guess what, you're working really hard, your kids are working really hard, you're not learning much physics. I think that sense of humility is important. (follow-up interview)

He elaborated on this point:

> Effective teaching requires a teacher that's going to say 'You know what, they're doing everything that I've asked them to do and I'm not teaching them anything.' It's like you have to always be willing to understand that learning is an internal

> process and our measurements or our quantifications of have I been effective or did the kids learn it, those questions are never easily answered and a good teacher is someone who's willing to ask the question in a different way and maybe find out that they're not getting it done and be willing to go back to the drawing board. (follow-up interview)

A process of introspection seems to have taken place both in the realm of scientific understanding and in the realm of teaching effectiveness.

Finally, Robert perceived that his exposure to the modeling methodology also impacted his personal understanding of physics itself. During the initial interview, he specifically singled out Newton's Third Law as a fundamental concept that became much clearer in his mind through modeling:

> I can remember just that through the Modeling method was when I finally understood Newton's Third Law, and it was not until it had been presented in the context of a force being an interaction between two objects, that there's the originator and the receiver of the force and just that simple way of dealing with a force, that operational definition giving me that where I *really* grasped completely Newton's Third Law of Motion and this is after I have a degree in physics from [his undergraduate school], one of the greatest schools in the world. And I'm not saying I'm a genius but I don't think I'm dumb either. Why should it take me that long to learn that stuff? (initial interview)

He repeated these sentiments during the follow-up interview. In response to a question about what constitutes an effective teacher, he flashed back to his experiences in the Modeling Program:

> Going back to my own experience in the modeling workshops that I took, even if I were never to teach physics, or teach another science, the fact that I did those workshops, I learned *so much* about physics from doing it through the modeling method that I didn't even know. You know, as embarrassing as it is for me to admit, I really don't think that I had a really good grasp on Newton's Third Law before I did modeling. Now, how the *hell* can that happen, that I could have a degree from [his undergraduate school] in physics and not understand Newton's Third Law of motion? (follow-up interview)

The fact that he repeated the almost identical story shows how much impact this experience has had on his physics understanding, or at least on his perception of his understanding of Newton's Third Law.

Modeling has clearly had a major impact on Robert. From his increase in student orientation to his constructivist turn to his increase in intellectual humility and finally to his understanding of physics itself, he is certainly a changed man. The total impact that modeling has had on his teaching philosophy can clearly be seen in the following comment, which brought the follow-up interview to a close: "Modeling still completely informs my whole philosophy and so I'm so grateful for that."

Mike – Chemist, Physicist, and Sailor

Mike is a forty-nine year old chemistry and physics teacher at a suburban high school in a large southwestern metropolitan area. He has been a teacher for fifteen years, the last ten of these at his current school. His first two years of teaching were in a private Christian academy and the next three were spent substitute teaching "all over the place" while he pursued his M.A. degree.

Mike earned his B.S. in chemistry in 1975 at a northwestern state university. He then spent eight years in the Navy, serving in a large variety of capacities. In 1983, he completed his M.B.A. degree from a different western state university, left the Navy, and went into business for four years as a computer consultant. In 1987, he began teaching and in 1992 he completed his M.A. in chemical education from a local state university. He attended the Modeling Program during the summers of 1997, 1998, and 1999. Since then, he has continued to be involved with the program as an instructor and with a team of teachers attempting to formalize modeling instruction in chemistry.

Mike's current school is socioeconomically middle to upper-middle class with an enrollment of 1850 students, 90% of whom are White, 8% Hispanic, and the remainder

Black, Asian, and Native American. His school uses block scheduling, giving him a first semester schedule consisting of A.P., honors, and regular physics, and a second semester schedule consisting of A.P. and gifted chemistry. He is married and has an adult daughter and a son who is currently in college.

Mike's classroom is rather tight and square with a low dropped ceiling and only one four foot wide, six foot tall panel of glass to let in outside light. A wide demonstration bench dominates the front of the room and two large, brown chalkboards cover most of the wall behind the demonstration bench and the wall to the right. The back of the room is a long lab counter with one sink on top and closed cabinetry beneath. Students sit at fixed biology-style tables arranged in four long rows of eight seats all facing the front of the room. A wide center aisle separates the rows into four seats on either side and there is a side aisle down each side of the room.

The available wall space on the back wall above the counter and on the left wall is covered with posters of astronomy, astronauts, European ski areas, baseball players, and a large periodic table of the elements. The narrower strips above the window and the two chalkboards are covered with dozens of college pennants representing schools from all over the United States. A cluster of six of Mike's personal teaching award plaques is mounted just to the right of the classroom door at the front of the room. A large screen for the overhead projector covers the right end of the front chalkboard and a wall-mounted television monitor is squeezed between the projector screen and the window in the right front corner of the room. Video announcements scroll continuously across the television screen during class. A free-standing cart in the front right corner of the room serves as a makeshift easel for students to display their whiteboards during presentations and a free-standing podium next to it was used by some of the students. Eleven Macintosh computers sit on carts along the two sides of the room facing the center. Student project display boards and student-built styrofoam molecular models were piled on the last row of student desks and several molecular models made out of balloons were attached to the ceiling.

The two Honors Chemistry classes I observed were studying pressure and temperature relationships for water, leading to an understanding of the Law of Gay-Lussac. Mike worked from the students' side of the front demonstration bench and collected pressure data over water in a flask on a hotplate using a CBL (Calculator-Based Laboratory) unit. A student recorded the pressure vs. temperature data on the front board as the demonstration progressed. Mike fired constant questions at them about the emerging data and then had them break up into lab groups and graph the data on the computers spread around the room. Each group then reported their preliminary findings on whiteboards and took turns presenting them to the class.

Mike has a very rapid-fire talking style, rarely finishing a sentence. He speaks in abrupt phrases and I found it a challenge to keep up with him. His students seemed more comfortable with his style, possibly due to the fact that they had worked with him for four months, an hour-and-a-half a day. He fired questions at students continuously and was in almost constant motion, moving all around the classroom while students were presenting. Even as he was asking questions, he was arranging student projects on the back table or picking up trash off the floor. He only answered questions with questions and redirected questions to students whenever possible. He interrupted students constantly with more questions, even as they were trying to answer the previous one. His students were all alert and on the edge of their chairs, trying to keep up with the breakneck pace of the discussion.

The size and tone of his Advanced Placement Chemistry class was more intimate and less hectic. The students were studying the colligative properties of solutions and were troubleshooting a lab on the freezing point of solutions at the beginning of the period. They then whiteboarded problems from a homework problem set and took turns presenting their work to the class while Mike sat in the back of the room and fired questions. His voice was softer than in the two previous classes and I noticed that he took more time to finish his thoughts. He didn't move around the room as much as he had earlier, choosing to sit on a student desk and swing his legs constantly. After finishing the problem set, including putting me on the spot for the entertainment of the students, he assigned them a worksheet and gave them class time to work on it. He drifted around the room, looking over the students' shoulders and commenting on their work, and then stood in front of the demonstration bench and went over the answers with them just before the bell rang.

Perceptions of Effective Science Teaching

Mike described a wide variety of perceptions, many of them uniquely his. They ranged from the teacher's role to student strategies, hypothesis-forming to paradigm-shifting, from fundamental concepts to "real world" experiences. His perceptions were possibly the most unique and varied of the six participants.

During the interviews, Mike felt that effective science teaching requires a teacher to focus on a few basic, primary concepts. The teacher should be the one responsible to identify and specify these concepts:

> One of the things about effective physics teaching is that you, as a teacher, teach to what *you* think is important. That you define *these* are specific concepts that I want to teach . . . These are what we want to call the primary concepts that we want to teach. (initial interview)

He continued:

> I really stress for the kids to come up with some basic ideas that they can hang their thoughts on. Like forces and particles and objects and that they can come up with some basic rules or laws then that they can work things out from. (initial interview)

Mike was the only participant to express the perception that effective science teaching should focus on creating a variety of strategies students can use to approach new situations and problem-solving exercises. These strategies should encourage the use of analytical and deductive reasoning and discourage students from reverting to “common sense” approaches. During the initial interview he said:

> If I can get kids to walk out of here both having a good set of concepts to use and also learn how to walk out of here having some strategies, how to *develop* strategies, not just some simply say ‘OK, always do the problem this way’ but have some strategies they can go out with, then I think I’ve been an effective physics teacher. (initial interview)

As he continued to discuss effective science teaching, he became a little more specific:

> I think I’m effective if I can have the kids be able, not so much be able to use equations but the kids can be able to take a situation that’s new to them, be able to determine *these* are the physics or science concepts that fit that particular problem like this is a problem that has to do with rotation and this is a problem that has to do with forces during that rotation and then from there they can throw in whatever kind of math tools or graphing tools or whatever they need and then they can develop their own solution for it, their own strategy for solving it. (initial interview)

He repeated his feeling that students should avoid the “equation” approach:

> I try to stay away from a lot of a memorized equations instead of more ‘OK, this is this situation, the problem we have. What is the physics that matches that problem and then how are we going to use that physics to deal with it?’ And so I give the kids a lot more freedom on exploring different ways of solving a problem

> so they don’t always have to use just one solution or one procedure to a solution. (initial interview)

He expressed considerable concern about the “common sense” approach to problem-solving:

> You’ve got to be careful about common sense. It gets in the way. And you’ve got to start thinking more in terms, start developing some analytical tools, do some deductive reasoning, these are terms I would never use with the kids but you know what I mean. (initial interview)

He repeated a similar sentiment during the follow-up interview when he said that his goal was to

> help students move from more of a point of view that’s more towards, I call it Aristotelian, basically, they go by their own reason versus going into actually collecting information and seeing where the real trends lead to. (follow-up interview)

Mike judges his own effectiveness by his students’ ability to demonstrate these strategies. He said:

> I think it’s important that when they get done after the nine weeks or the eighteen weeks or however many weeks, thirty-six weeks, I have them that you should be able to evaluate them and have them be able to, at least in a general sense, be able to demonstrate to you that they got the concepts and that they’ve got the strategies. So I think that’s another good tool to help you measure effectiveness is how well they do at the end. I worry when I get kids who can who can get an A, A, A on all the tests but when it comes down to the very end and you ask them some simple questions and they just go like ‘I don’t have any idea’ and they drop back to their common sense solutions. So being able to evaluate them with A.P. exams and FCI’s or longitudinal tests and if I see some good results come of that, some good gains, then I think I’ve been awesome and a good quantitative measurement that I’ve been effective. So that’s also very important to me. (initial interview)

Mike felt that effective science teaching should strongly emphasize the hypothesis-forming process. This was another perception unique to him. He felt that the hypothesis is crucial to the design of the experiment:

> I take more of an approach where I want the kids to do a lot more of defining for themselves how *they* think the world operates. Developing a lot more hypothesis development and then to go in and instead of simply say following a set of instructions, we actually sit together and we think out how we can explore this situation. (initial interview)

He also felt that this is a process that most teachers downplay:

> I tell them I think the most important part of lab is the hypothesis. And yet most teachers don't even have them do a hypothesis because ninety-nine percent of the time it's just pure guesswork. And ninety-nine percent of the class doesn't even care what the hypothesis was anyway. But I really make them spend some time on that and it doesn't have to take a long time, just two or three minutes. (initial interview)

During the follow-up interview, he offered a strategy for taking the "pure guesswork" out of the hypothesis-forming process:

> I actually require the students to do quite a bit of initial observations before they make their first hypothesis and then I help the students develop or send them through a possible way to test their hypothesis. (follow-up interview)

Mike felt that effective science teaching should attempt to help students identify misconceptions and encourage them to be willing to shift their worldview or "paradigm." This goes all the way back to the beginning of his teaching career. He said:

> In fact they have a lot of misconceptions and a lot of those misconceptions is what is sometimes called their worldview or their pedagogy or their paradigm and there's quite a bit of research, this was in the mid 80's, on that topic. At that time I was looking more for how can we help chemistry students and also physics students be able to overcome their misconceptions. (initial interview)

This has developed into a major philosophical issue for him:

> What got me into the modeling and really got me going with that and why I say it's more of a philosophy is that this is really what you are trying to do is to help the students understand that they have a particular way of thinking about the world and that we need to have them reconstruct their paradigm, how they think that the world is constructed. (initial interview)

This concept of "paradigm shifting" recurred many times during the interviews. In a later portion of the initial interview, he said "So for me that's the whole idea behind modeling is it’s a philosophy of helping students be able to reshift their paradigm.” In the follow-up interview, after describing at length his interpretation of the modeling methodology, he ended the description with:

> And then I would have them go back and consider their hypothesis and evaluate it versus their observations and modify themselves, modify their paradigm to what they actually collect and analyze. Hopefully it will lead to, for them, a paradigm shift. (follow-up interview)

Still later, while discussing the value of teacher demonstrations, he said “but I don’t think they really make a paradigm shift until they do science.” In an e-mail message he sent me after I returned from the first interview, he repeated this call for having students “do science”:

> When it comes down to it, we as science teachers want our students to learn science by doing science. That is for me what modeling is all about and for me that has always been my goal in teaching.

Mike felt that effective science teachers need to incorporate as much “real world” experience as possible into their teaching. Given his extensive array of “outside” experiences, I do not find it surprising at all that he would feel this way. The importance of real-world experience came up innocently enough in a comment about modeling during the initial interview: “So the philosophy that I like in modeling is that it’s helping the students develop a concrete set of models that they can then be able to apply to different real-world situations.” Later on in the same interview, I asked him what his Navy experiences had contributed to his teaching and the floodgates opened:

> Well, I think it’s really cool because with that kind of experience it’s easy a lot of times to come up with real-world examples and talk about ‘Hey, guys, this is how things really worked out there,’ and so I can talk about ‘Hey, I know what it’s like to have the bends or be in a situation where you can get the bends’ and talk about pressures and changes and talk about torpedoes moving through the water and the forces involved and I can talk about projectiles because I used to do missiles and so it’s given me a real chance to be able to tell the kids ‘Hey, this is what’s really

> going on out there' and also this is the kind of level of people that they expect to be working out there. . . . I kind of like it, it gives them an extra flavor they normally wouldn't get if I just was only a teacher, never had any real world experience, not to say that this isn't the real world but *outside* experience. (initial interview)

Still later in the same interview, Mike described his experience in a submarine that power-surfaced and accidentally rolled over on its side. He brought the story back around to its educational value:

> But it still is kind of awesome to have that experience and see everything just falling away from you. And so you can talk about things like, experiences and the kids go like 'Mr. _____, you almost died a few times.' 'Well, yeah, kind of.' And then I say 'But I'm still here so you still owe me homework.' (initial interview)

Mike felt that effective science teaching should involve a reduction in the visible role of the teacher in the classroom instructional process and an increase in student-led activities. Early in the first interview, he said "Now I take more of an approach where I want the kids to do a lot more of defining for themselves how *they* think the world operates." Then, while describing a typical lab experience, he commented on the roles of students and teacher:

> We together come up with some ideas and think about what kind of variables we want to work with and how we're going to collect that information. And I guide them as far as what the equipment can and can't do and then I let the kids work with it and try to come up with their own general feel for what's going on. (initial interview)

When the discussion later came back around to the way labs should be conducted, he expanded on his earlier comments:

> You start with this idea of starting with the paradigm lab, like I mentioned earlier, where they take a situation and have them come up with their idea of how they think what's going to happen. Have them collect data, simplify data, maybe, and have them maybe sometimes graphically present it. (initial interview)

He consistently used the pronouns “they” and “them,” emphasizing the student initiative and control of the discovery process.

During the follow-up interview, Mike becomes even more direct in his views. When asked to describe effective science teaching, he immediately described what a lab exercise should look like:

> It would be directed or might be just more student-led and the teacher would have to, of course, show how to use the equipment and stuff so there would be quite a lot of teacher guidance and direction on that one, but not where they are just simply given, rarely would they be given a handout. Sometimes I might have to because they just need assistance on how to do the technical details, but only in that regard. And then the students would be doing a lot of collection of data and analyzing the data. (follow-up interview)

When I pinned him down on the teacher role in all of this, he elaborated:

> The teacher might just be staying back and making sure the kids don’t blow themselves up or cut themselves or something like that. Or sometimes might go around and check to make sure they’re on the right track, if they’re maintaining their variables or not off in some direction other than what they’re trying to test. Sometimes they are assisting with the technical details of analysis or making sure that they’re keeping things going the right way. Or sometimes asking questions to make them think about what they’re doing and try to answer like ‘How come you see that spot way over there,’ or ‘What’s that going on? Is there anything you can do about that?’ There’s a big role for the teacher. (follow-up interview)

The ultimate comment came at the very end of his description: “I guess it’s sometimes just sit back and watch the show. Make sure things are going the right direction.” It would certainly be difficult to reduce the teacher role beyond sitting back and watching the show.

Mike’s perceptions of effective science teaching seem to focus on the conceptual pillars of modeling – identifying misconceptions and working for conceptual change, all the while using a constructivist teaching style built on varied strategies and “real world” examples. He is a natural instructor in the modeling methodology.

Perceptions of Effective Student Science Learning

Mike's range of perceptions on effective student science learning was considerably narrower and focused on very specific student behaviors. For the most part, Mike was concerned with either issues relating to habits of mind or on issues relating to student work ethics. Many of these issues were also uniquely his.

During the interviews, Mike felt that in order for a student to be an effective science learner, that student needs to demonstrate an open-mindedness and willingness to shift their "paradigm." This perception goes hand-in-hand with his feeling that effective science teaching involves the promotion of this same paradigm-shifting. He seems to feel that the process is a team effort. This teamwork is embodied in the phrase "it's a philosophy of helping students be able to reshift their paradigm." The teacher's role is to "help" the students but they must "reshift" their own paradigms. As quoted earlier, his emphasis is on having the students "go back and consider their hypothesis" and "modify themselves, modify their paradigm" so that "Hopefully it will lead to, for them, a paradigm shift."

He emphasizes the importance of open-mindedness and the willingness to change. During the follow-up interview, he said:

> They have to be willing to have their paradigm shifted. They can't be afraid of that. They have to go in with at least a consideration that they're going to have their ideas challenged, and that demands that they have ideas to begin with. (follow-up interview)

This willingness needs to play out as active participation on the part of the student. He said that, based on his graduate work and personal research, he believed that

> students really don't change their paradigms unless they test it themselves. If you do it for them, even with a demonstration, which is still good, I don't throw out demonstrations, they're good for additional observations or for 'ooh-wows'

> afterwards, to show how you can use this information you just came up with, but I don't think they really make a paradigm shift until they *do* science. Not just hear science, they've gotta *do* it. (follow-up interview)

His ultimate goal is to have the students "think about this world that we live in different from what they had before." And therein lies his purpose:

> It's been exciting for me because when students usually leave my class they come up and say like 'Mr. _______, you've ruined me. I don't think about the world and same way I used to think.' And I say 'Cool, that's the whole idea.' And so they leave here and they realize another thing too is that how they come out of my class will be a lot different than their peers and not just their peers but even the adults in the community and now they are thinking a different way and with a different structure than the general populace. And hopefully that will make them better citizens and better engineers and scientists and whatever else they want to go into. (initial interview)

In another unique perception, Mike felt that effective science learners focus on developing a variety of concepts and strategies to use when facing new situations. In response to a question about how he approaches problem-solving, he said:

> A lot of modeling, a lot of them seeing other people do it, they have to learn how to not just plug-and-chug but they've got to figure out what's the concepts involved, what are some strategies that can be used on this problem like identify variables, identify unknowns, come up with different ways to express what's going on, what's the relationships, and then put them together. (follow-up interview)

His goal is to help his students reach the point where they are "not so much able to use equations but the kids can be able to take a situation that's new to them, be able to determine *these* are the physics or science concepts that fit that particular problem," that they can "develop their own solution for it, their own strategy for solving it." (initial interview) During the follow-up interview, he elaborated:

> You have to get them to the point where they can understand the concepts as well as develop their own strategies. I can model different strategies that they can use, you teach them how to do things strategically, but I don't prescribe where it's just plug-and-chug, where you simply say 'Oh, here's an equation, put in the numbers and solve for it.' I like giving them situations where they are going to have to

> think about what's this physics or this chemistry or biology behind it, the concepts behind it, what are the different models, equations, strategies, graphs, whatever, that might apply to this and then use it in as many different ways as they can solve a problem. (follow-up interview)

Mike felt that effective science learners should formulate hypotheses as they investigate and use "upper-level" thinking skills to evaluate their results and hypotheses at the conclusion of each investigation. This theme showed up repeatedly through both interviews and he was the only participant to verbalize it. In the first interview, while describing the modeling methodology, he said "If you use the philosophy that having the kids develop a model on their own from their own collection of data and then comparing it to what they thought was going to happen, that works." He repeated a similar sentiment shortly thereafter:

> Part of the philosophy of modeling is that you just simply don't do an experiment and then just go on but you spend time having the kids analyze it and evaluate what they got and then come up with the concept. And that's really good, too. (initial interview)

Still later in the same interview, he focused even more sharply on the importance of evaluation of the hypothesis:

> I don't want them to just simply say 'My hypothesis was correct or incorrect,' I want them to go back and evaluate 'Hey, what did I learn here, how did it compare to what I thought before?' (initial interview)

During the follow-up interview, when asked directly about effective student learning, he said "I would have them go back and consider their hypothesis and evaluate it versus their observations and modify themselves, modify their paradigm to what they actually collect and analyze." This would involve "A lot of upper-level thinking. A lot of analysis and synthesis. And I think it's important that they evaluate at the end."

Mike felt that effective science learners should be willing to defend their viewpoints and critique, but not criticize, the viewpoints of others. When I asked him to describe the interactions in an effectively-taught classroom, he said:

> I would see lots of students presenting and sharing and collaborating as far as defending their results to the class. It may not be all the information but some of it and then that would be really cool. You don't see a lot of that because kids are afraid to defend themselves, but I think that that's really important. And a part of science is being able to show why your results are the way they are and deal with any problems that come along the way. (follow-up interview)

Later in the same interview, he expanded on this issue of students critiquing the work of their classmates. He was especially sensitive to the distinction between critiquing and criticizing:

> As I said before, a lot of testing and hypothesizing requires a lot of guidance and I said before that the students have a very hard time critiquing, they don't like to critique each other. It's sort of like not cool, so you sometimes have to teach them or take the role yourself because they won't do it. To me, it's more important that they learn to defend this material than criticizing each other. They're good at criticizing each other, they just don't want to do it in class. (follow-up interview)

Mike felt, again uniquely, that an effective science learner must be willing to invest whatever time is necessary to read for understanding and to do the memory work necessary to learn a necessary set of scientific facts which he calls "to knows." Early in the follow-up interview, he commented:

> Science is learning from others, like my sharing and your doing preliminary research on what others have said about the subject. I do think reading is very, very valuable and reading what others have said is very, very important, but another thing I get a lot of rebellion on. (follow-up interview)

When I asked him to describe effective student learning, he echoed his previous comment on the importance of reading and added some disagreement with what he perceived to be the attitude of many of his colleagues:

> An effective student also has to be willing not just to learn what the teacher presents up front but to learn from all the resources, and I don't just mean the one that comes off the Internet. They've got to be willing to read. I find too many times ineffective students only use their text as a workbook and I know there's a lot of teachers at a lot of universities and colleges saying you shouldn't use textbooks and I say 'Yeah, but there's a lot of stuff you learn from reading and probably the reason why kids aren't effectively learning from reading is they are not reading effectively. They don't read to learn. They just read for entertainment.' And so they've got to be willing to do that. (follow-up interview)

His perception of the importance of learning a certain set of scientific facts came up during the initial interview when he was discussing the impact of his Navy experiences:

> This is something that maybe came out of both my college and my Navy background, is that it's very important for students to be able to deal with situations that they've never been in before and so you've got to give them good concepts to hang their hats on, there's things to know, they've just got to know it. I kind of disagree with some of the things I've heard before where you don't have to know masses, you don't have to know numbers, 'g', you don't need to know g, you just have to know how to use it. No, I think they're things you've got to know. (initial interview)

During the follow-up interview, he again expressed his disagreement with what he perceived to be the attitude of many of his colleagues:

> I think there are a lot of 'to know' things, I just call them 'to know.' Try to go into a Spanish class and say 'Well, teacher, I just want you to teach me the concepts. Teach me the proper way to speak Spanish but I don't want to memorize any words.' You can't really do that in science and there's just a lot of memory work. I hear a lot of teachers today say science shouldn't include rote. Well, I'm sorry but there is a lot of rote stuff, I mean you gotta know some major elements, you gotta know some, you just gotta know them. I call them "to knows." You can't get away from it. They gotta know what 'pi' is, they gotta know what little 'e' is, you just can't get away from that, and I don't think there's anything wrong with that. You gotta know your 30-60-90 triangle. That's another thing I run into a lot today, a lot of inertia and resistance and saying 'Well, I don't want to really know anything, Mr. ____, just teach me the general ideas.' And I say 'Well, yeah, we'll do a lot of that but there's just stuff you gotta know.' (follow-up interview)

He summed it up with the comment “They have to be willing to just know things, to not be afraid to learn some facts.”

Mike felt that effective science learners must have the willingness to roll up their sleeves and learn the mathematics required to solve problems, a perception that was uniquely his. In his own words, “They’ve got to be willing to think analytically, which means they’ve got to be not afraid to use numbers.” He related the story of one of his former students:

> I had a kid, the highest level of math he had was geometry, he was a music major, he got a four on the A.P. Physics test. That’s pretty good for a music major. Now he’s a youth minister at a church. But he got a four on the A.P. Physics test because he was not afraid to at least do the numbers, do the number-crunching, he wasn’t afraid of it. (follow-up interview)

He felt that effective students need to have a certain comfort level with basic arithmetic and estimation:

> You’ve got to be willing to at least *know* your numbers, as far as the size and value of them and what’s reasonable. They should be able to do basic multiplication arithmetic in their head. I’m ready to give them all slide rules just because it forces them to think about estimating an answer and then think about how big the answer’s going to be. That might help them but they’ve got to be willing to do that. To estimate. (follow-up interview)

Finally, Mike was again alone in the perception that an effective science learner must be willing to recognize when their data is incorrect or insufficient and be willing to invest the time to repeat the data collection process. As part of his final comments during the follow-up interview, he said “They have to be willing to do the work it takes to collect data and do analysis and if something doesn’t work right don’t be afraid to do it again. . . . The poor science student will just basically give up.” He differentiated again between effective and ineffective student learners:

> I have too many students where they went all the wrong direction and they said 'Well, that's it. We're not going to try this any more.' The good students I've had before said 'Well, let's run it all over again.' 'OK, that's great, let's do it all over again. It'll probably run faster the second time then the first time. Now you know what you're doing wrong.' (follow-up interview)

Mike clearly has high expectations for his students. Intellectually, he requires both open-mindedness and a willingness to defend a viewpoint. In terms of a work ethic, he expects persistence, a willingness to do the brute memorization, and the willingness to "do the math." These are characteristics admirable in adults, let alone adolescents. Through modeling, he has found a way to bring out the best in his students.

Perceptions of the Influence of the Modeling Program

Mike's perceptions of the influence of the Modeling Program showcase his self-confidence and strong background. He seemed to feel less of an influence than any of the other five participants. Verbalizing a perception that was totally his own, Mike felt that his participation in the Modeling Program had not really taught him much new but instead had been a "confirming" and "validating" experience. In response to my question about what had motivated him to attend the Modeling Program, he said:

> When I heard what we were going to do, I thought that this was going to be neat because I'll actually have something I can take back and show to other teachers and incorporate it right into the classroom. And another thing I liked about it, I was already doing a lot of the modeling in my course, always making the students think in terms of models and so in a lot of ways this was more confirming for me, so it wasn't like it was a *new* concept, instead it was confirming what I was already doing. (initial interview)

He reiterated this feeling later in the interview while allowing that participating in the workshop had given him some research validation:

> I think a lot of it had already come to me before I was gone to the modeling project, and that the modeling project formalized my thinking. It gave me some vocabulary, it gave me something to put my hook on, it gave me some research to validate what I was doing and thinking about. (initial interview)

Mike also felt that his Modeling Program participation had "enhanced" his teaching by giving him new insights, teaching tools and teaching strategies. In reference to his own teaching, he said:

> I think the modeling enhanced what I was already doing. It gave me a lot more things that I can do to help students be better at modeling their world. It enhanced my thought process and how I approached class to be better at helping kids develop models and it gave me some tools that I could use to make that happen. (initial interview)

As he discussed his own understanding of physics itself, Mike allowed that his participation in the Modeling Program had also enhanced his understanding of certain specific areas of physics:

> I think the biggest thing that helped me that I got, enhanced my understanding, in a way was a lot more eye-opening, was electric fields and working through and understanding how conductivity works and that really helped a lot. I got a lot better understanding of electricity working with the other teachers through that concept. (initial interview)

When I asked him if it had effected his <u>teaching</u> of that concept, he said "Yeah. I talk a lot more in terms of fields, in that sense, yes." He now thinks more in terms of "interactions" with fields. He has tried to help his students think in terms of these interactions:

> I make the kids be a lot more specific and think through 'OK, what is this object really interacting with?' . . . I think in one sense it's really been good to help the kids really start to think about what is the interaction that that object is having in whatever the situation is. Always go down to *who* you're interacting with and once you identify that then what kind of interaction is that, electrical, magnetic, contact, so that's been probably also very helpful. . . . . And so that's probably where I got enhancement in my physics itself. (initial interview)

Mike was also alone in expressing the perception that an important influence of the Modeling Program had been to expose him to many new and different viewpoints from instructors and colleagues on a wide variety of topics. Still talking about electricity, he said:

> I think the biggest thing that I got from modeling is just hearing all the different ways people think about the concepts. I didn't realize how people thought about electricity and magnetism, and then go like I never thought about it being in that kind of sense. (initial interview)

The concept of energy is another area where he welcomed hearing the thoughts of his colleagues:

> And I think what I got for my physics there is just a different viewpoint on physics ideas like energy. I was surprised to see how many teachers and university people think differently about energy than I do. I look at energy as more of a result, the fields, you know, more of a property of the particle. But that didn't change how I thought, it's just kind of illuminating to see how many other ways that you can think about it and incorporate it. (initial interview)

Finally, Mike perceived that his modeling experience had provided him with more structure in his teaching. He said "It gave me some more techniques to help me process that philosophy, use the philosophy, it gave me some more discipline, it gave me some structure." Summing up the impact of the program at the end of the second interview, he said:

> Well, I would say it gave me a format, it gave me a platform to put this together. As I said last time, I've been thinking about this for many, many years, long before I knew about modeling, but it gave me a formal way of putting it together. (follow-up interview)

One final quotation that would surely warm the hearts of the creators of the program: "And that's something I got out of the Modeling Program. How to get the kids to develop a model for thinking constructively."

Mike is an enthusiastic modeler and yet he seems to give the Modeling Program minimal credit for his current perceptions on effective science teaching and learning. I find it an interesting contradiction that he is so devoted to teaching modeling to other teachers and expanding it into the realm of chemistry. Mike's uniqueness will be discussed further in Chapter 5.

Diane, the "Control Freak"

Diane is a thirty-six year old physics teacher at a suburban high school in a large southwestern metropolitan area. She has taught high school science for fourteen years, the last eleven at her current school and her first three at two other high schools in the same district. Her current school is socioeconomically middle class with an enrollment of 1700, approximately 75% White, and the remainder predominantly Hispanic.

Diane earned her B.A. degree at a midwestern state university in 1988 in broadfield science, three credits short of a biology major. She recently completed her M.Ed. in secondary education at a state university. She did not begin teaching physics until she came to her current school in 1991 and she attended the Modeling Program in 1992, having taken only twelve credit-hours of physics prior to that time. She attended the Modeling Program again in the summers of 1997 and 1998 in the midwest.

Diane's teaching schedule consists of two sections of A.P. physics and two sections of regular, college-preparatory physics. Rather than be forced to teach more than two preps next year, she has volunteered to teach a schedule consisting of all college-preparatory chemistry. She is attempting to obtain materials from the creators of the Modeling Program to teach chemistry using the modeling methodology.

Diane's classroom is almost square with high dropped ceilings, a linoleum tile floor, and a row of narrow windows across the top of the right side wall. The opposite side wall is floor-to-ceiling brown brick. The front wall has a wall-to-wall whiteboard and a standard science demonstration table in front of it. The back wall has a door to a preparation room, a large window with a closed blind also leading to the prep room, and a large bulletin board. The walls are sparsely decorated with a large periodic table on the brick wall and nine large matching biographical posters of famous scientists on the side walls and back bulletin board evenly spaced and all mounted at the same height. A poster of a lightning storm is mounted on the front face of the demonstration bench facing the students.

The student desks are lined up side-by-side in four straight rows of six desks each, three on either side of a wide center aisle. Four extra desks are lined up along the side wall under the windows. The only flat surfaces for performing lab experiments are the students' desks. There are no built-in lab tables even though the demonstration bench shows that the room was intended to be used as a science room. Diane has set up her teacher desk and computer table in the back of the room, in front of the door to the prep room. There is a podium at the front left corner of the room, next to the door to the hallway and under a wall-mounted television monitor. Video announcements scroll continuously across the monitor.

Diane is not physically imposing and has a soft voice but still manages to maintain total control of her classroom. Two of the classes I observed were in the process of preparing for an optics lab to investigate the behavior of converging lenses. As the classes discussed the procedure for the lab experiment, Diane was in perpetual motion, walking up and down the aisles and questioning students. She used her soft voice very artfully to keep the tone of the room quiet and attentive. She pinned students down on word usage, requiring them to say exactly what they mean and rephrase their comments before she would respond to them. She encouraged students to ask questions by honoring all of them equally with comments like “good point” and “excellent question.” When the lab began, the students helped themselves to the equipment and set it up on their desks. Since the source of the image was a candle flame, Diane turned off the lights and continued to move up and down the aisles, asking questions constantly.

Two of her classes were in the process of preparing for a district test involving extensive writing on science in a very rigid format. Diane led this discussion from the front of the room, standing on the students’ side of the demonstration bench. She had students read some of their practice writing and then offered constructive criticism. She also had students volunteer alternative hypotheses that would address the topic of the essays. Again, she honored all comments equally and very gently found ways to suggest that students rephrase or reorganize their thoughts. Overall, I would describe her as simultaneously very professional and very comfortable with the students.

Perceptions of Effective Science Teaching

Diane’s perceptions of effective science teaching seem to be the most closely tied to the modeling methodology of any of the participants. Her entire approach is tightly focused on student performances and inquiry teaching and a video of one of her classes could be a promotional video for the program.

During the interviews, Diane felt that the effective science teacher needs to create a series of uniform, shared, common experiences around which students can build their conceptual understanding. These experiences are usually lab experiments that typically begin each new conceptual unit in the modeling methodology. In describing how her current mode of instruction is different from the “traditional” way she was educated, she stated:

> The biggest difference is trying to give kids a uniform experience. All kids, not just those kids good in math and/or interested in science but the uniform experience where they do a lab and then we can build on it and make sense of that lab, as opposed to me giving them information and then doing the lab because it fits in with that particular, verifies that information. (initial interview)

Later, she elaborated:

> When we have that common experience and then go back to that common experience often times in class. And I have the kids try to verbalize that common experience so that everybody has that shared experience that we can talk about. (initial interview)

Her perception of the importance of creating that common experience was highlighted in the following comment:

> I used lab experiences as a verification of a particular rule or law that we were studying. When we were in constant motion, I discussed constant motion first and we gave maybe some problems and then we did a lab that showed them constant motion. Now I do it backwards. Not backwards, the right way. You get that common experience out there. (initial interview)

She perceived that this common experience is the foundation for expanded learning:

> So I guess in order to be an effective teacher, I need to provide students with concrete experience and then time to integrate that new learning into different experiences or apply it to different experiences. (initial interview)

Diane also felt that the effective science teacher needs to encourage students to verbalize their understandings through interviews, presentations, and other opportunities for public explanation. This was her first comment when asked to describe effective physics teaching:

> I think effective physics teaching is where students understand the major ideas of physics. And what you have to do to do that is you have to have kids be able to explain to *you* and you need to interview the students in order to insure that. (initial interview)

This ability of her students to verbalize their understanding is the yardstick by which she measured her own effectiveness:

> When I don't feel I'm *as* effective, I present the information and *presume* the kids understand exactly what I said. When I find I'm doing a better job or being more effective, I have the kids verbalize back to me because so many times I have found that I can say one thing and half the class heard something completely different, the other half of the class didn't hear anything at all, and/or maybe one student in a class of thirty heard exactly what I said. (initial interview)

Frequently, this verbalization occurs during whiteboarding sessions following a lab experiment or other group work:

> So I guess in order to be an effective teacher, I need to provide students with concrete experience and then time to integrate that new learning into different experiences or apply it to different experiences or different, it could be a worksheet or a problem and then be able to present their findings to me and/or the class, where I can then question them which would ensure that they understand what they need to learn. (initial interview)

Whether this student verbalization is public or private, the important thing is that the student does the talking:

> So I guess to be an effective teacher you need to do a lot of things. Most importantly, provide them with experiences, interview kids, and then have them have to apply that experience into a different situation and then talk to them. Actually not talk to them, get them to talk to *you*. (initial interview)

Diane felt that an effective science teacher needs to create what she calls "authentic" experiences for his or her students:

> I think, and it's sometimes difficult to do, especially in science, although it's there, it's hard for teachers to do because I don't think they learned it this way, is to try and make it an authentic experience for students, meaning where learning science is not just memorization of facts or little nuggets that they're going to lose and not internalize or not generalize into their thinking. (follow-up interview)

When I asked her to explain exactly what she meant by the term "authentic" experience, she said:

> One way, teaching science can become authentic when students become like mini-scientists to a certain extent where they experience what a scientist, and the method a scientist thinks. Another way, and it's taking another sort of angle here, is where students are given, for example, a project that is authentic, something

> authentic where it might spark them into thinking about things that they need to learn or delving further into a topic. (follow-up interview)

She then described a solar energy project in which students researched solar energy in order to build small solar-powered cars.

This issue of “thinking like a scientist” was a repeating theme in Diane’s discussion. While describing the various modeling techniques she has adopted, she mentioned “allowing the students the time to think like a scientist instead of telling them exactly everything they need to know” and later, while assessing the overall impact of modeling, she said that a major benefit is that

> they really learn to think like a scientist and how a scientist would have to discover the relationships and be able to prove and show and explain those relationships to others. (follow-up interview)

Diane felt that effective science teaching involves minimizing the visible role of the teacher and increasing the role of the student in the educational process. As she fully admitted, this does not come easy:

> The hardest part, as I learned going through the modeling workshop, is closing your mouth and letting them answer their own questions. They’re so easy just to blurt out questions and expect you to just regurgitate the answers back instead of them having to stop and say ‘Oh, I know this.’ They’ll ask themselves the questions and they know the answer, a lot of times they just need reinforcement from the teacher and they need to start finding that reinforcement in themselves. (initial interview)

This change in roles goes against what she perceived as the “conditioning” that both teachers and students are subject to:

> So that’s the hard part because kids are conditioned and teachers are conditioned to want to help and want to do the work, not necessarily to do the work for them but let me show you, let me teach you how to do it, instead of just guiding them a little bit and letting them do it on their own. (initial interview)

She reiterated this diminished role of the teacher:

> Using the modeling method, I think the students can learn a lot as long as you make sure the students verbalize and the teacher is just on the side, making sure that everything is happening in the right mode. (initial interview)

She succinctly summed up her feelings:

> So I guess where I see that I need to work towards being a more effective teacher in my own classroom is to become more quiet and let the kids do more talking. (initial interview)

Diane was unique in expressing the perception that effective science teaching involves the creation of multiple representations of the concept or phenomenon under discussion. Motion maps, force diagrams, graphs, formulas, and verbal descriptions are examples of these multiple representations:

> I mean they have to do the first diagrams, too, but they can learn a lot from the motion maps and I don't think, had I not gone through the modeling, I would've seen the value in that. Now I just see the value in all of the multiple representations like drawing force diagrams. I understood how to draw them and the purpose but now I see, and my students I hope see, that all of these pieces work together and they are all different ways of representing a similar situation. (initial interview)

Her goal was to have the students be able to explain back to her in these multiple ways:

> I could say 'Tell me, explain to me five different ways to explain constant speed' and maybe they could show me five different ways to explain constant speed. I couldn't do that after my high-school physics class. (initial interview)

She seemed to feel that different representations might appeal to students with different academic strengths or learning modalities:

> A student who is really good at math might want to use a math model and a student who is really good at pictures might want to use a pictorial representation or a motion map and a force diagram along with that. (initial interview)

Diane's approach to physics instruction has changed dramatically from her own description of herself as a "control freak." She has learned to relinquish much of that control and instead has come to concentrate on creating that shared, authentic experience for her students and then encouraging her students to verbalize their understandings. She has become a textbook example of the effective modeling instructor.

Perceptions of Effective Student Science Learning

Almost all of Diane's perceptions of effective student learning center around the issue of student-student interactions. For her, this is where students develop, defend, and deploy their understandings.

During the interviews, Diane felt that effective student learners will develop the ability to communicate and explain their thoughts through in-class presentations and cooperative group work opportunities. Just as effective science teaching involves creating those situations, so does effective student learning involve using the verbalization process to improve their thinking processes:

> There is a method that you have to think through to get to it and have to be able to explain on how you got to that correct answer. There's some right reasoning to get to that right answer and so I think that, in being able to think through to get that and have kids verbalize to me that thought process on how they know these things to be true, I think that's helping them to be able to learn how to think and it helped me learn how to think through the problems in a methodical way. (initial interview)

This comment shows that, at times, Diane considered herself a student as well as a teacher. While discussing the process of developing new materials, she commented on the personal value of verbalizing:

> And that's where I think I need, what would be helpful to me is to have a group of teachers were you can get together and develop these models and these other units because what it takes is just time to be able to verbalize with other teachers what the model is and come up with some good questions that address the model and come up with a good lab that addresses it and then go from there. (initial interview)

The ability to explain to others is a necessary step in the process of students becoming the "mini-scientists" she is hoping to create:

> That’s what makes the Modeling Program so good because they really learn to think like a scientist and how a scientist would have to discover the relationships and be able to prove and show and explain those relationships to others. (follow-up interview)

Overall, communication is the key. During the follow-up interview, she stated it very succinctly by saying that an effective student would be one who “contributes to the classroom discussions by asking questions or by making presentations and/or by communicating with their peers in a positive and constructive manner.” Later, while discussing cooperative lab groups, she stated that “when they’re in groups, these groups are working with their peers and they need to be able to cooperate and communicate effectively with them.”

Diane also felt that effective student learners will show a willingness to learn from their peers, not just from the teacher. Although she felt it is important, she was also aware that the process is not always easy for students:

> I know my physics classes will sometimes get very angry at me because they don’t feel like I’m teaching. They really like it when they have another student get up there and they say like ‘Why don’t *you* teach the class?’ Because they see everything that they need to do and they learn from the other student. They didn’t learn from *me* telling them. (initial interview)

She felt that this is a particular strength of the whiteboarding process. She described to me a situation in which one of her students did an exceptionally good job on one particular presentation:

> Well, he whiteboarded this lab brilliantly. The students were all thrilled because he was able to explain exactly what happened in the lab and the comment was made ‘Well, *you* should teach the class,’ and part of me I guess I should be thrilled with that because they realize that they can learn from not just the teacher, that they need to become dependent on themselves for learning and their peers for learning, that they can seek out help from peers and not just from the so-called authority figure in the classroom, the teacher. (initial interview)

She perceived that students learning from other students is an essential part of effective student learning:

> Oh, I could say it that well but I’m happy that my students can too and that’s where it needs to be. It needs to be in their hands. They need to explain that. (initial interview)

Diane felt that effective student learners must show a willingness to stand up and argue for their understandings while still being willing to listen and compromise. Although she only discussed it once, she did so with conviction:

> They also need to be able to stand up for themselves and their ideas, with compromising somewhere. If they have a strong belief, they should continue that discussion until that belief has been agreed on. There is some compromise in here, some ineffective students I have had in my classroom will not compromise. The effective students I have had usually will compromise to a certain extent. When they feel strongly about something, they will keep trying to communicate their ideas in a different way. (follow-up interview)

Strong beliefs and compromise don’t always go together but Diane made her case with an emphasis on the role of communication. Having already expressed the opinion that “the neat thing about physics is that there *is* a right answer,” she seemed to feel that sufficient communication between students and the ability to compromise should flush out that right answer.

Diane felt that effective student learners concentrate on integrating their knowledge, generalizing that knowledge, and learning to apply it to a variety of situations. This is another perception that was uniquely hers. In describing the modeling philosophy, she showed what it all leads up to:

> I guess that’s where I see modeling’s biggest strength is that it just seems to be able to take the common experience, which is your introductory lab, and then be able to make a graph, make a picture or a motion map, make a force diagram, and see how they all relate and then see how they form that model of what is constant motion or what is accelerated motion and be able to then apply it to different scenarios. (initial interview)

Without the ability to apply knowledge to different scenarios, it all becomes just a series of discrete units or "little nuggets that they're going to lose and not internalize or not generalize into their thinking." Effective students need to take the "time to integrate that new learning into different experiences or apply it to different experiences." Describing a workshop experience of her own in which too much was attempted in too short a time, Diane observed:

> But the other units, like optics and electricity and magnetism, this was all crunched into a couple day time period, at the time I took the class. It wasn't long enough for me to start to truly integrate it into my own classroom and totally get the whole idea down. (initial interview)

Her own experiences as a student have shown her the value of making the effort and taking the appropriate amount of time to integrate learning.

Diane's perceptions of effective science learning would clearly place her in the realm of the social constructivist. The combination of individual encounters with "authentic" phenomena coupled with the extensive interactions between students is the mix envisioned by the creators of the program.

Perceptions of the Influence of the Modeling Program

For Diane, participation in the Modeling Program was a major transformation in her career. The intensity of her feelings showed through such comments as "I am so thankful that I was able to do that" and it made an "immense change in my understanding of physics" and "It made a *world* of difference." The effect it had on her grasp of physics was almost a religious experience: "I probably had any epiphany in *all* areas since I'm not a physics major." She revealed her dependence on this newfound approach to teaching in the following comment: “When I get out of areas that modeling hasn’t been completely developed, I do feel a little lost.”

Diane uniquely perceived that the Modeling Program helped her shift her focus as both a teacher and a learner from memorization to understanding. Her entire thought process had been changed by modeling:

> If I take a class I think about it in a different way. I’ve taken graduate classes in statistics and in different education classes and I think differently now. I understand learning a little bit better and can process things better. I feel like I could much more easily conquer some topics that I did not study in college, such as more modern type styles of physics and those concepts. So I see that the modeling has helped try to focus on understanding and not just memorization. (initial interview)

This rejection of the memorization approach to learning dates back to before she was even aware of modeling:

> I really struggled those first four years whether or not I wanted to stay in teaching because certainly I knew students were learning. We have a district-based content knowledge test and my students always did very well. But again it was memorization, it was rote memory, it wasn’t really, I would say, *learning* or internalizing their learning. It was learning for a test and then taking the test and then moving on. (follow-up interview)

Diane also perceived that the Modeling Program showed her the value of reinforcing concepts by finding multiple ways to represent them. While commenting on the process of model formation, she said:

> It was natural for me ask questions but the process that modeling has done for me has changed the way I’ve thought about what students need to learn, how you form models in your brain, and then how those models can be applied to answer questions. And that’s where it changed my whole thinking process myself. And now I think about things a little differently and plus it makes me think about things in multiple ways. (initial interview)

Not only did Diane see multiple ways to conceptualize using models, she also saw multiple ways to approach the problem-solving process:

> That’s what it did for me, just being able to, what was so enlightening is being able to just see there is different ways to solve problems and be able to realize that that there are, not just the math, the plug-and-chug the way I learned, was the only way to solve these physics problems, that there were other ways of looking at it. In many cases, the other ways of looking at it helped form better concepts in my own thinking and the correct concepts of the physics thinking in my head. (initial interview)

One of the new ways she had discovered for representing motion in physics is the motion map. Motion maps certainly pre-date the Modeling Program but have been adopted as one of its recommended tools. Diane commented:

> For example, seeing motion maps before and not realizing that they had a purpose, was something that was very enlightening. I knew I didn’t solve problems that way. (initial interview)

She had first encountered them in college:

> I had a friend in college who always drew motion maps and I looked at those and I didn’t know what she was drawing. Now I can teach a whole unit on motion maps or we can talk about motion maps exclusively. Kids can learn exclusively from motion maps. Almost. (initial interview)

Another weapon in the arsenal is the force diagram. Although she had encountered them long before modeling, her perception of their value changed significantly:

> Now I see the value in all of the multiple representations like drawing force diagrams. I understood how to draw them and the purpose but now I see, and my students I hope see, that all of these pieces work together and they are all different ways of representing a similar situation. (initial interview)

Another major influence of the Modeling Program on Diane was the value of creating and using graphs as a learning and teaching tool. Collecting data, graphing it, and extracting a formula from the graph is a technique frequently used in physics and it is one of the fundamental discovery tools of the modeling methodology. Using graphs as a problem-solving tool, however, was a revelation to Diane:

> Using graphs in order to solve a problem was not new to me but being able to use it in work and energy and not just in kinematics. So many times, I think the textbooks used the graphs in kinematics and then, when you get to work and energy and/or other areas like circuits, now I can use a graph here, too, and use graphs in different aspects and they can tell you a lot about what's happening in relationships. That was something that was brought to my attention so now I could, if I saw something I could make sense out of it or better sense out of it. As far as, I knew if I saw a graph of let's say force versus displacement, I could say 'OK, oh, the area underneath that would be the energy stored' and so then therefore I could then apply that knowledge to something else and not just rely specifically on my math ability of being able to solve algebraic equations. (initial interview)

She now could see a much wider range of applications for graphing and it gave her a new tool to use in problem-solving.

Diane felt that the Modeling Program had influenced her teaching by overlaying it with a strong sense of organization and coherence. She testified to the change modeling had made in her teaching:

> I always put in some interesting labs here or there, you know, you do the show-and-tell, the demo-a-day in chemistry, those sorts of things. However, once I went through the Modeling Program, what really, when I went through it, I was surprised by how much physics I learned, and it also gave me a confidence in how much physics I already knew, and an organizational way of presenting the material and effectively communicating that material to students. (follow-up interview)

This "organization" gave a purpose and a relevance to her teaching:

> After the Modeling Program it just gave a better purpose to me for teaching, because it made the learning relevant, it made the learning important, it cycled through, once I knew constant motion then to go to accelerated motion, it made sense to do that, and then projectile motion where you put the two together and then it made perfect sense. (follow-up interview)

The organizational structure of modeling provided a sense of coherence and logic to the physics Diane teaches that she was unable to find in the textbooks with which she had been supplied:

> The system makes sense and then with the force diagrams and how that's presented and how everything's connected was very clear in the Modeling Program and that's not clear in textbooks, which is our general source of teaching material. And you can go through all the physics teachers you want and get great ideas but it doesn't show you or teach you how to present that to kids in a coherent, logical manner for an entire year. Sure, it might take up a week, but it is just piecemeal. And so I guess that's what I was most impressed by the Modeling Program, it was so cohesive. (follow-up interview)

For Diane, the Modeling Program's coherence, logic, multiple representations, and focus on understanding had certainly changed her entire approach to the teaching of physics and, in fact, to all of her teaching. Her perceptions of effective science teaching and learning are probably more closely aligned to the modeling methodology than any of the other five participants.

Jack -- the Zoo(logy) Escapee

Jack is a forty-nine year old physics teacher at an urban/suburban high school in a large southwestern metropolitan area. He has taught at this school for eighteen years, his entire teaching career. The school has an enrollment of 1950 students, approximately 50% White, 33% Hispanic, and the remainder spread among Black, Asian, and Native American. In terms of socioeconomics, it is classified as predominantly lower-middle class.

Jack earned his B.S. in zoology from a large, local state university and returned to earn his M.A. in Curriculum and Instruction from the same university. His state certification is in zoology and he taught one section of physics for one year before attending the Modeling Program in the summers of 1990 and 1991. He returned to the Modeling Program again for one more summer in 1995. His current teaching schedule involves teaching two sections of honors physics, two sections of regular college-preparatory physics, and one section of freshman chemistry/physics.

Jack’s classroom has no outside windows but is brightly lit from the high, dropped ceiling. It is long and narrow with linoleum floors, a set of fixed lab benches in the back and a lecture area in the front. There are six free-standing physics-style lab benches in back of the room mounted in two rows of three and continuous, narrow lab benches mounted along the back wall and the back half of the left wall. There are twelve Macintosh computers for student use, four on the free-standing benches, two on movable computer carts, and six on the wrap-around benches. The front half of the room has twenty-five student desks organized loosely in a five-by-five configuration facing a standard science demonstration bench.

Jack has located his teacher desk and computer table to the left of the demonstration bench, in front of a large glass-front storage cabinet and under a wall-mounted television monitor, which would display continuous video announcements if he would “remember” to turn it on. In the right front corner is a cabinet with another large television monitor, a videotape player, and an attached computer, which he uses for physics programs and videos. Two portable easels stand in front for students to use during whiteboarding sessions.

The long side wall on the right side has two doors to the outside and a long, wall-mounted whiteboard in between them. The board has clearly organized assignments for each of his class periods. To the left of the left door, near the front corner of the room, is a small bulletin board with a few notices thumbtacked on it randomly. The back wall has one small wall-mounted glass-front cabinet filled with books but is otherwise bare. The long side wall on the left has an open door and large window into a prep room and a second door and window into a stock room. Jack did not appear to restrict student access to these areas. Filing cabinets stood in front of the window to the prep room and a free-standing bookcase partly obscured the window to the stock room. This appeared to be necessitated by a general shortage of available wall space. A large, green, sliding chalkboard is mounted on the front wall behind the demonstration bench. There are no posters or decorations of any kind in the room except one laminated map of the world taped to the stock room window.

Jack has a strong voice and a very fast-talking style with the students. The first class I observed was in the process of discussing one of the modeling worksheets they had worked on the previous day. Jack had them read each other's conclusions and score them against a rubric that he distributed in class. They then took turns reading the conclusions to the class. Jack honored all their contributions and the class applauded each group as they finished presenting. During the presentations, he tolerated a lot of work without units or equations, waiting patiently for students to catch each other's mistakes. He constantly bounced questions back to the class, forcing them to explain their reasoning. At one point, Jack calculated a different answer to one problem as a result of a decimal point error and admitted it to the class, following up with a long but humorous story of another decimal point error leading to an auto accident in which he ended up hitting a school bus. His comfort with and affection for his students was obvious.

The tone of his freshman chemistry/physics class was considerably different. Jack chided them for leaving the room a mess and outlawed food or drink for a week. He talked noticeably louder and the class was less settled. After reviewing some work and power formulas, he moved into a demonstration of a lab on pulleys. After pointing out the difference between fixed and moveable pulleys and answering more of his own questions after shorter wait times, he summarized some data the students had collected two days earlier when he had been absent. He then suggested a more extensive lab procedure, giving them a purpose statement, identifying the variables, and showing them how to set up the graphs to analyze the data. The students then broke up into lab groups and proceeded to collect data. Jack drifted around the room, questioning students on their procedure and suggesting easier ways to set up their equipment, always speaking in short, clipped sentences. The quick smile and playful sense of humor he had displayed in the previous class was noticeably missing. Some of the students began graphing their results on the classroom computers but the majority of the students were still collecting data at the bell.

During his Honors Physics class, Jack returned to the softer-spoken, friendlier style he had used during the first period. This class was engaged in a post-lab discussion of a circular motion lab and he worked out a theoretical derivation of the circular force formula on the front board to show that it exactly matched their experimental results. When one of the students questioned what it was useful for, he spontaneously began to swing a rubber stopper around his head on a string and challenged the class to find its mass by measuring any other variables they chose. They quickly took measurements and then broke up into lab groups and prepared whiteboards with their calculations. He drifted around the room, looking over shoulders and asking troublesome questions and then drifting away with a grin on his face. When they finished, they took turns presenting their solutions, with Jack firing questions at them constantly and encouraging them to critique each other’s work. He had them select the best whiteboard solution from the group and then they actually took the stopper to a balance and measured its mass. Jack laughed outloud as they discovered that the group they had selected had not come closest to the actual mass. This led to an interesting discussion of precision, accuracy, and measurement error.

Perceptions of Effective Science Teaching

Jack's perceptions of effective science teaching spanned a wide range of topics. He touched on issues as diverse as inquiry, empowerment, reflection, and interaction. Through it all, his enthusiasm for the modeling methodology shone bright.

During the interviews, Jack's strongest perception about effective science teaching was that an effective teacher must set up an environment of genuine inquiry and discovery and must stimulate student curiosity. He immediately and unhesitatingly described himself as follows:

> I truly believe, I like discovery. I'm an inquiry guy. My methodologies class came from a guy named _______, a biology teacher over at _____ and I took a methods class when I came back to get certified and he was inquiry, and it's just the way I thought science should be taught. But kids should discover because it builds their curiosity. The act of discovering was *exciting*, compared to somebody up there in front of the room telling me what I'm supposed to know. (initial interview)

In the follow-up interview, Jack's very first comments were again about inquiry and discovery:

> I see effective science teaching as inquiry-based, number one, where kids are still discovering things. (follow-up interview)

He differentiated between the concepts of open-ended discovery and the more guided form of discovery, which he associated with the Modeling Program:

> So myself, I want to be somewhat of a, I guess, more guided discovery is what I would call the difference between ______'s and _____'s. ____'s was *all* discovery. ______'s is somewhat guided toward he knows where your endpoint's

> going to be. And I think this Modeling Program is much more of a *guided* discovery than a really open-ended one like we were doing a lot in biology. So I like the idea of guiding discovery in that way. (initial interview)

Jack was a zoology major in college and almost exclusively a biology teacher before he was convinced to try physics teaching by the creator of the Modeling Program himself. It fit in well with his inquiry orientation. In Jack's words,

> You know what, coming in and only having one year (of physics teaching) experience, I've always kind of been a modeler. So I've taken this along with my like of inquiry and curiosity-building and I've run with this ever since. (initial interview)

Jack also felt that an essential responsibility of an effective teacher is to empower students. One aspect of this empowerment is allowing the students the opportunity to make genuine discoveries, thereby experiencing, to some degree, what it is like to be a scientist. In his words:

> So I guess the word I'm looking for and what I strive for is to give some empowerment back to the kids and I think by allowing them to discover relationships in the laboratory first, that does that. It not only gives them some empowerment but you know as well as I do that they're *doing* the science and they're going to remember it a lot more. (initial interview)

Jack felt this issue of empowerment goes beyond laboratory discovery and that students should have some say in their course of study as well:

> I also see it as, they have some empowerment to where they also have some decision-making on what it is that they might want to study or how they are going to study it, but also in sharing their ideas with each other. (initial interview)

Empowerment can even arise within the details of a laboratory exercise. Jack described a dissection lab in his Anatomy and Physiology course and showed how empowerment can enhance the discovery process:

> First of all, we think the kids should be able to pick what big animal they want to dissect. So right away, as they set up their groups, you can choose whatever animal you want. If it's not a pig, you have to pay for it, we tell them. So if I

> choose a shark, my group chooses a shark, somebody else chooses a turtle, somebody else might choose an eel, somebody else might choose a dove, we allow them to kind of choose different things. And then, when it comes to our dissection, we basically are saying 'Okay, open it up and let's find the digestive tract. Identify the digestive tract.' So the kids have to get in there and they start figuring out what's kind of leading to what and we don't give them any lecture. (initial interview)

Jack felt that an effective teacher should help students identify and confront their misconceptions. One of the conceptual pillars that supports the Modeling Program is the identification and confrontation of student misconceptions. The more recent references in the professional literature to "alternative" conceptions is less judgmental but the participants in this study are more in the habit of hearing and using the term "misconception." After the misconceptions are identified, they are dealt with through a series of "deployment" problems, again using modeling vocabulary. This is what Jack referred to when he told the somewhat humorous story of an exchange with a fellow teacher as he tried to convert him to a "lab first" philosophy:

> Well I would come in and I would erase that lab from Thursday and I would put it Monday on him all the time. I said '______, all you gotta do is do your lab first. Do your lab first.' But they're not gonna do their labs first. They feel more comfortable with the kids knowing a lot going in and making it reinforce it. And that's a valid way to teach, too, I'm not saying that you can't teach that way, but I just truly believe that labs should come first and they should be your first insight as to the relationship. And then the idea of following it with deployment problems that are not just random problems but are based upon misconceptions I think is another really valid thing that we do here. (initial interview)

The focused nature of the deployment problems is what Jack was referring to when he said:

> As I go through my program, I make little notes as to where I know a class discussion is going to occur, and so my kids are whiteboarding and all of a sudden I know it's coming. I just sit back and wait for it. Boom, a certain question comes up, somebody answers it and I say 'Does everybody agree with that?' Somebody else will raise their hand and disagree for some reason and that's right where I know it's coming. Every time. Because every single year that same

> discussion shows up based upon that deployment problem or worksheet. And it's not just a fluke. That question was designed around getting to that misconception. (initial interview)

Misconceptions are such an important part of his planning process that Jack even judges his own performance by them. In describing his effectiveness in teaching chemistry and biology, and recall that biology is his field of certification, Jack said:

> I try to do this when I teach chemistry or biology, too. I'm not quite as good because I haven't sat down and gone through all the misconceptions and put together the deployment problems that go with it, but I do try did come up with discovery labs that I'm after and we identify variables at the beginning. (initial interview)

He repeated the same sentiment when discussing a lower-level chemistry/physics class he also teaches:

> Even when I teach a lower level or a chem-physics, obviously I don't have all the worksheets and I don't have the misconceptions aligned as well but I try to do a lot of the same things. I'm not quite as effective because I haven't really identified all the misconceptions in chemistry, as to what I'm trying to get to, so I'm not quite as effective. Or when I teach biology, again I haven't identified those misconceptions and written questions designed to bring that discussion to the forefront. (follow-up interview)

Jack felt that the effective teacher must facilitate cooperative learning and encourage students to interact, share and learn to express themselves. Many of his comments in this area came out of a discussion which he initiated about Gardner's concept of "multiple intelligences" (Gardner, 1983, 1993). Jack felt that effective teaching involves honoring each of these various types of intelligence:

> I think that's my particular role, too, to help set up assignments that will help them use their different intelligences instead of just always using the same thing, to allow them to express themselves in their different intelligences. And again I think the teacher's role is to set up the lessons to where they can use those and to give them some insight as to how to use those intelligences and how to allow them to come out. (follow-up interview)

During the follow-up interview, while discussing the advantages of block scheduling, his feelings about cooperative grouping and student expression again came through:

> So it gives me a chance to use some of these other methods and techniques and try to get them to express themselves a little bit. And you know cooperative groups are really important, too, and I think the teacher's role in setting up the grouping is almost as important at times. (follow-up interview)

While enumerating which of the specific intelligences are most useful in science learning, Jack said:

> I think interpersonal, which means they are learning to socialize within their own group and becoming more of a committee, you might want to say. Not intrapersonal but interpersonal. I think you have to kind of design some lessons where they can practice that and use those skills of communication and working within groups, because that's what the world's looking for more and more, not just big businesses but areas where kids can work as teams and they have to have those particular skills. (follow-up interview)

He even went so far as to defend the use of music in physics with the intention of finding yet another avenue for students to express themselves:

> Music can actually be a great way to express themselves, too. They may not learn what I'm doing, I can't maybe set it up in a musical way, but they might be able to express themselves and what they've learned in a musical way. (follow-up interview)

Jack has come to see the value in having students present to each other and the whiteboarding process is his technique of choice:

> But even in biology, I would try to do a lot of discovery labs where the kids were graphing patterns in some form or another. When we worked genetic problems, I do not work them out on the board. They get a whiteboard and they do just like we do in physics. I split them up into groups, you're doing these two you're doing these two, they present them to each other. The biggest benefit I see there, actually I see two. One, they're more apt to challenge each other. Boy, do I believe in that now. (initial interview)

In a continuation of his discussion of his dissection lab, he came directly to the point of what he perceived as the value of cooperative learning:

> When it comes to actually seeing it in the dissection, it's a riot. _____ and I are going 'Heck, what *is* this?' You know, we're looking at some things in that eel and going 'All right, let's talk about this. What's the possibilities here? What is this?' And the two of us would have to do that, too, and try to discover what it is. And then we made them kind of teach each other. (initial interview)

Those seem to be the benefits that he saw in the process of group sharing, the opportunity for students to teach each other and the opportunity to challenge each other's ideas.

Jack expressed the unique perception that an effective teacher should create an environment of reflection and reinforcement of ideas. This process builds from his "lab first" philosophy:

> I think that they'll have a better chance to remember it a year from now, two years from now, I think they'll have a better chance to remember even the mathematical model because they'll kind of think back to doing that lab. They'll remember, I hope, doing certain labs and going 'Oh, yeah, I remember when I was doing *this* it affected *this*,' and they're kind of keying back into it. (initial interview)

He viewed his role as a sort of assembler or coordinator of ideas:

> Most of the time, it's kind of like what I did up here, using a little bit of their thoughts and my thoughts, kind of putting things together. . . When they do, I kind of summarize what they were doing up here in some ways. (initial interview)

Jack felt that the effective teacher should interact with students, listen to students, and create an environment of excitement:

> I think the teacher has got to be involved. I think the teacher has got to move with the kids and not isolate themselves. They've got to be a part of listening to the kids' conversation and, at times, participating a little bit with their conversation. . . I don't ever really sit down. (initial interview)

Observations of Jack in the classroom were entirely consistent with this statement.

For Jack, the excitement is embodied in the discovery process itself:

> They're designing their own experiments. The act of discovering is *exciting*, compared to somebody up there in front of the room telling me what I'm supposed to know. (initial interview)

Perceptions of Effective Student Science Learning

Jack's perceptions of effective student science learning concentrated on a small number of strongly-supported issues. These issues can be classified as relating to the individual rather than the social aspects of the learning process.

During the interviews, Jack felt very strongly that active involvement on the part of students is essential for effective student learning. Students must take an active role in designing their activities and their success as students depends upon actually "doing" science. In his first interview, Jack tied these perceptions in with the discovery process:

> They understand more because they're the ones that are really putting together and analyzing their own results. They're designing their own experiments. So I guess the word I'm looking for and what I strive for is to give some empowerment back to the kids and I think by allowing them to discover relationships in the laboratory first, that does that. It not only gives them some empowerment but you know as well as I do that they're *doing* the science and they're going to remember it a lot more. Like that sign of mine says up there, 'I read I forget, I see I remember, I do I understand.' (initial interview)

He began his follow-up interview with a similar sentiment: "Again, they have to do science, they have to actually be actively involved." This active involvement is just the beginning of a more elaborate process which he described as follows:

> I've always thought that the kids, in science, need to be doing the activities and seeing science and doing science and from that asking questions and then either reinvestigating or researching it or, even if it comes out to OK, this is what we've all discovered, what kind of does this mean? (follow-up interview)

This emphasis on student activity is an essential part of the open-ended laboratory exercises he uses in his Anatomy and Physiology classes:

> First they have to go in there, open up, and identify some things. Make some drawings, try to relate it to where it's at, its position, what it's connected to. 'What is this thing? Is this lung, heart, what is it? Where's it at?' (initial interview)

This perception of the importance of active involvement expanded in Jack's mind to the issues of effort and practice. In discussing the importance of homework, Jack referred back to a paraphrased quotation from his physics mentor, the creator of the Modeling Program:

> And like Mac said at one time, I really liked his idea, just because I want to be a great pianist, I can't just watch a pianist play and then think I can play that tune. I've got to practice it, the kids have got to practice it themselves. They got to try to answer the questions whether they can or can't. That's why I still give homework on effort, not on right answers, when I give them these homework packets. I want them to *try,* even though it's wrong. (initial interview)

In the follow-up interview, he restated this perception:

> But kind of getting back to it, the students have to take an active part in their own learning. They can't just watch other kids solve problems. I think that's how kids learn. They have to take an active part in it. I'm not going to be any better in physics by watching my physics teacher solve all these problems on the board. I've got to go home and practice it. And I think kids have to practice it in order to get better at it. Sometimes they're going to get frustrated and they're going to quit but that's OK as long as they have given it some honest attempt and tried to at least think about it. I think that's where their real learning has to start and it's up to them. (follow-up interview)

Jack also felt that if students are to be successful science learners, they must concentrate on searching for patterns and relationships. This was another perception unique to him. Sometimes the pattern may be visual, such as a graph, and other times the pattern may emerge as a mathematical relationship or formula. Again, the process starts with the discovery process:

> So I like the idea of guiding discovery in that way. It builds their critical thinking skills, it helps their formal reasoning skills, they have to analyze data in some form, so looking for patterns with data. That's kind of the whole key when you're trying to look for results is to look for a pattern, a reproducible pattern in data. And by graphing it, they can get a reproducible pattern, therefore their mathematical pattern or equation. (initial interview)

While discussing some of the details of the computer graphing process, Jack revealed how important the visual aspects of graphing are to student understanding:

> I want them to have to physically see what change it caused, not just something giving you that automatic curve fit. You might as well just read it in a book. I think you miss the picture that goes with it, and without that picture burning that hole in there, you're not going to remember that relationship very well. It's just not going to happen. (initial interview)

Regardless of how they are discovered, the search for relationships is still the key goal for student learning in Jack's mind. His final question to the students during the dissection lab is crucial: "Can you put this in larger terms, help us define it as a relationship or something of that nature?"

Jack felt that effective student problem-solving requires the development of a deliberate strategy. The key to this strategy is learning to "categorize" problems. This is a new strategy for Jack, learned during the Modeling Program, and one that he tries to encourage his students to use when faced with a challenging problem. He described it in very personal terms with himself as the student:

> The first thing I do now when I read any open-ended problem is I categorize it. What type of motion is it, I ask myself that question. Is it constant motion, is it accelerating motion, is it circular motion, or does it look like something dealing with either momentum or energy, and right away then I know what math models I can attack it with. So right away, I get rid of all this other stuff and I seem to be able to get right to the point. I *never* did that in the past. I had *no idea* how those guys, a lot of the times they took this question 'How you know where to start?' was my common response in college, too. 'Which equation do I start with? How do you guys *know* that?' You know what, I can do that now, because I can categorize it right away and I know how to start and attack the problem. I know what to look for and so I try and get my students to do that too. (initial interview)

The development of this strategy was an important influence of the Modeling Program on Jack and will be discussed in more detail in the next section.

In Jack's mind, student interaction is key to effective student learning. This interaction may involve the group whiteboarding process, students presenting their work to others, and students being willing to argue, challenge, defend, and try to convince classmates of their views. While discussing how students can differentiate between good and bad models, Jack said:

> They're only going to find that out sometimes when we get back into a class discussion and the kids are going to start saying 'No, I got this, I got this, I got this and you didn't get that,' or the teacher ends up intervening, but I don't do that very often. Usually the kids can figure out the right answer, which is amazing, actually, and they can convince the other kids in the classroom, even if there's only two or three that actually get it right, especially on some of those good quizzes we give them. But they can convince the class that they're right afterwards, when you go back and whiteboard it. (follow-up interview)

Jack strongly encourages students to challenge each other. Realizing that students are not very likely to challenge the teacher, he sees the whiteboarding process as a way to set up a situation where views are presented by students in a forum that encourages challenge and argument:

> When we worked genetic problems, I do not work them out on the board. They get a whiteboard and they do just like we do in physics. I split them up into groups, you're doing these two you're doing these two, they present them to each other. The biggest benefit I see there, actually I see two. One, they're more apt to challenge each other. Boy do I believe in that now. I almost could say anything up there and even *wrong*, a lot of the information if I wanted to, and most of my kids would nod their head and write it down and accept it because the teacher said so. 'You know, he told me this is the answer and this is how I do it, so I'd just better write it down.' They usually do not challenge the teacher. They've been kind of programmed *not* to challenge teachers. They'll challenge each other, so if a student would do the same thing on a whiteboard and make the same mistake, usually I get a variety of hands going up. 'Wait a minute, I don't think you can do that.' You know, I want to see that challenge. (initial interview)

In order for students to be successful science learners, Jack felt that they need to work at identifying their misconceptions, being willing to let go of those misconceptions, and trying to replace them with conceptions that work more consistently. This is one of the founding principles of the modeling methodology and one that Jack supports quite strongly. Jack stated it most succinctly in the follow-up interview:

> You know, I go back to what we learned a long time ago in that there's all kinds of misconceptions in there and they've got to address their misconceptions that they have in order to really effectively learn, I think. Somewhere along the line they have to address those misconceptions, if it's in discussion groups, small discussion groups, or if the worksheets help them address those, but if they don't really address their misconceptions, they don't really learn. And then, of course, replace them with something that is a little more powerful or a model that works more often, you might want to say, or at least from what they've already discovered. They find out that this other way of doing it just works more consistently. (follow-up interview)

The issues of active involvement, student interaction, and identification of misconceptions all come together in one key comment by Jack:

> The other ones, they like that, they like the openness and the discussion and you know, the poor thing is with a class like this, if you don't participate in the open discussions, I think you miss out on what this class is trying to do, as a student. Without participating in the small little chat of arguing your point of view with another student, you miss out. So if you get frustrated and turn off and want to read a book or just work on your lab report like some students do, they miss on identifying their misconception and then either accepting their own misconception or getting rid of it and accepting the new model. They miss out on that, in my opinion. (initial interview)

Although he does acknowledge the role that social interaction plays in the learning process, Jack's major concern is on the individual's confrontation of misconceptions and creation of patterns, relationships, and strategies. This would place him more at the individual end of the individual-social continuum discussed in Chapter 1.

Perceptions of the Influence of the Modeling Program

The intensity of Jack's experience in the Modeling Program is unquestionable. Comments such as "It was unbelievable what I learned in that summer" and "So that summer was eye-opening to the max" and "It turned me on, I'm going 'You're kidding'" and "My eyes did *this* when I took that summer class that first year" attest to the excitement he associated with the experience. Jack fully admitted the weakness in his formal physics background prior to modeling:

> I didn’t have much understanding of physics prior to modeling at all. I taught what I read in the book. I stayed in front of the kids. (initial interview)

He felt that the first major influence the program had on him was to show him how the formulas in physics actually were arrived at:

> And, you know, I wasn’t real strong in physics, I’d only had a couple of classes, maybe eight hours, when I taught my first year and then it was my second year that I came into modeling, and I still remember doing our first couple of labs and watching this graph come out and watching this formula come out and this light bulb just jumping out in my head and said ‘So *that’s* how that formula came about.’ I didn’t know that. I’ve been reading this in the book for a year and I’ve been teaching it to the kids but I never knew how it was developed. (follow-up interview)

That comment was almost an exact copy of his thoughts from the first interview:

> When I did physics, in my opinion for the very first time, was during that modeling summer and all of a sudden I started to collect data and I was amazed when all of a sudden I put it in a graph and wrote a math equation, first time I’d ever done that. I said ‘So *this* is how those equations came about?’ (initial interview)

This ability to see where the formulas came from is important to Jack. It empowers him to be able to demystify these formulas for his students. His excitement at this newfound enlightenment leaps from his words:

> All of a sudden I go, ‘You know what, I can write relationships and write mathematical models, too, that are real models that work. They weren’t just reading them in the book.’ It was neat to me that I was able to do it, discover them and see how it was done in the first place. It was a big ‘Holy mackerel, are you kidding?’ (follow-up interview)

Another influence of the Modeling Program on Jack was to give him a problem-solving strategy and methodology that he could, in turn, pass on to his students. This strategy is based on “categorizing” problems and then attacking them:

> I remembered force diagrams, a little bit from my college day. Obviously no motion maps, but force diagrams I remembered a little bit, but you know what, I couldn't take a problem and the first thing I do now when I read any open-ended problem is I categorize it. 'What type of motion is it?' I ask myself that question. 'Is it constant motion, is it accelerating motion, is it circular motion, or does it look like something dealing with either momentum or energy?' and right away then I know what math models I can attack it with. So right away, I get rid of all this other stuff and I seem to be able to get right to the point. I *never* did that in the past. (initial interview)

He provided a similar description in the follow-up interview:

> I used to memorize a lot of equations and then try to identify the variables and look for an equation where I could find other unknowns that might suit my problem-solving needs. I didn't know how to categorize the problems or attack the problems so it was more of random trial-and-error, in the past. I would not have felt very comfortable with a student walking up to me and just handing me a problem and saying 'Can you solve this for me?' I'd rather go into a hole because my physics background was so weak but now I really can look at that problem and I'll tell the kid 'Sure,' and we'll sit down and the first thing I do is I try to categorize that problem. (initial interview)

He credited this directly to the Modeling Program:

> So then when I learned the modeling method, it gave me a much stronger tool, a methodology, you could say, to attack the real problems in physics. (initial interview)

The third influence of modeling on Jack was to sensitize him to the issue of student misconceptions, an issue only he verbalized. These misconceptions first came to his attention during his participation in the workshop and he described his surprise at the fact that some of the other participants in the workshop seemed to have them as well:

> I worked a lot with the teacher over at _____. His eyes were opened almost as much as mine, which was very surprising because I kind of knew him so it was easy to gravitate towards him, in the groups, so a lot of times ended up whiteboarding with him or collecting data with him because, again, it was safer, you could say. But here was a teacher who had been teaching physics for almost as long as Malcolm and *he* was opened a lot by, 'You're kidding, this is . . .' I was amazed when we were solving problems and I could kind of get to his misconceptions at times. I was solving it right and he *wasn't*. This was a teacher that's been teaching physics and I'm going, and we got in this discussion 'Oh, yeah, right, because of this not being the net force because of the . . .,' All of a

> sudden we start seeing kind of what Mac was trying to get to on some of those. (initial interview)

Jack seems to have thoroughly integrated this process of identifying misconceptions into his inquiry methodology:

> I was an inquiry teacher but my inquiry was pretty open-ended. I wanted kids to discover things so, yes, I was an inquiry teacher but the modeling kind of gave me a stronger method of how to do it plus it helped me identify the misconceptions that I was really trying to get to. (initial interview)

The final influence of modeling on Jack was to introduce him to a new array of teaching strategies that he believes have made him more effective. These strategies involve increased group work, use of the whiteboarding process, and new questioning strategies. The key for Jack is student empowerment:

> I was always an inquiry teacher in the first place. I was always kind of do the labs first, and hands-on. What the modeling did is it helped me to give more empowerment to my students, because I used to get as frustrated as anybody before I took modeling and I'd be like screaming, working all these problems on the board, some kids sleeping, some kids not paying any attention, 'What am I *doing* up here?' So the whiteboarding and the group work and how to effectively ask questions of them were tremendous changes for me when it came to teaching. The questioning strategies of getting the kids to try to answer their own questions and to get them to not just give an answer but to give a why, give a concept that it applies to that they're using in terms of physics. (follow-up interview)

He echoed the value of student empowerment later in the interview:

> It just kind of opened my eyes to a lot of empowerment for the kids. I thought I was a good inquiry teacher but I didn't know how to really empower the kids so they took control of a lot of their learning in the classroom and they have a lot more fun. (follow-up interview)

Jack is certainly much more excited about his own understanding of physics since participating in the Modeling workshop and he seems thoroughly focused on transferring this excitement to his students. His newfound problem-solving skills and array of teaching strategies have certainly made his effectiveness more likely.

Sarah -- the Multitasker

Sarah is a fifty-two year old chemistry and physics teacher in an urban/suburban high school located in a major southwestern metropolitan area. She has taught high school science for thirty years, the last twenty at her current school. She taught science for ten years in the eastern part of the United States until personal events led to her relocation to the southwest.

Sarah earned her B.S. degree in Comprehensive Science at a midwestern university in 1972 and later earned her M.A. in Physical Science in 1988 at a southwestern state university. She currently has miscellaneous graduate credits of more than one hundred hours beyond the master's degree. She is certified to teach biology, chemistry, and physics in grades seven through twelve. She participated in the Modeling Program in 1992 and 1993 and has been a Modeling Workshop leader during the summers of 1996 through 2000. In addition, Sarah is the science department chairperson, tennis coach, National Honor Society sponsor, and she sponsors a student teacher and conducts teacher workshops across the country for Casio calculators. She also teaches chemistry and physics classes at the local community colleges during the evening.

Sarah's school has an enrollment of approximately 1600 students, 47% of whom are White, 37% Hispanic, and the remainder Black and Asian. Over 40% of the students are classified as lower income and the school is currently a Title I school.

Sarah's classroom is very cramped and crowded with linoleum floors, low, dropped ceilings, and a narrow strip of windows to the outside across the very top of the right side wall. The room was intended to be a science room because of the large demonstration bench but Sarah has chosen to arrange the room so that the demonstration bench is at the back of the room. Fifteen two-person biology-style tables are jammed into a rather random arrangement which makes moving from front to back an obstacle course of sorts. A separate laboratory room is shared with another classroom on the other side. The storage and prep rooms are accessed from the lab room.

The front wall, as defined by the direction the student desks face, has, from left to right, a large periodic table, a whiteboard, and two bulletin boards. A television on a cart stands in front of the whiteboard. One of the bulletin boards contains spreadsheet printouts of student grades and the other has samples of student work and photographs of students engaged in lab activities. There is barely three feet between the front row of student tables and the front wall. Above all of these is a continuous row of scenic photographs intermixed with physics formulas. Below the bulletin board in the front right corner is a handcrafted bin of standard student whiteboards (24x32) and a separate bin of smaller individual whiteboards (12x16), an idea Sarah came up with on her own. The bins were made by a cooperative industrial arts teacher in her building.

The door to the outside is very close to the front right corner of the room, leaving only enough wall space for two posters above the bins. To the right of the door, below the windows, is a row of four file cabinets, a table with a telephone and a microwave oven, a large, three-door, closed storage cabinet, and a small bulletin board with a variety of Sarah’s personal awards and plaques. The back wall has two large whiteboards straddling a structural pillar and a bulletin board containing more student work. Above all of these is a continuous row of motivational posters. Class assignments are written on the whiteboards. Two computers stand on the demonstration bench, a PC for administrative use and a Macintosh for physics purposes. Sarah’s teacher desk is located to the left of the demonstration bench and a cluttered table stands to the right, currently being used by a student teacher. The left side wall consists of a door to the laboratory area, a long wall-mounted whiteboard, and a wooden bookcase all the way in the front corner of the room. More motivational posters adorn the area above the door and whiteboards. An easel stands in the front left corner of the room for student use during whiteboarding sessions.

Trying to keep up with Sarah during the observations of her classes was physically exhausting. She only engaged in whole-class discussion with one group, a class preparing for a district writing examination in science. The class was involved in a role-playing scenario about an imaginary lake that had become polluted with an unknown toxin and they had to come up with a plan to identify and find the source of the toxin. This exercise was similar to the question on a previous year's test and Sarah was modeling how to structure their writing. The role-playing took place at the front of the room while Sarah stood at the back and simultaneously fired questions at the students, took attendance, critiqued her student teacher, and filled me in on what the class was doing. One of the students asked her a question while she was in mid-sentence talking to me and she turned and redirected the question to another student without missing a beat.

Her physics classes were engaged in a study of projectile motion. The students were to videotape themselves outside throwing a ball, play the video back on the class TV/VCR, advance the video one frame at a time and mark the location of the ball on a sheet of plastic taped over the television screen, lay the plastic over a grid and measure the horizontal and vertical coordinates of the ball at each location, graph the behavior of the ball versus time in both directions, write a group lab report, and prepare a whiteboard showing their conclusions. The class immediately separated and went all different directions with different groups already at different points in the process. Sarah took attendance by trying to remember who she had seen and the student teacher reported it by computer. While trying to talk with me, Sarah darted from her room to the laboratory room to the prep room to the baseball bleachers outside her door where students were videotaping their projectiles. One moment she was troubleshooting a computer hookup, the next she was helping with the camcorder, the next she was giving a make-up assignment, the next she was explaining how to take the grid measurements to a lab group who were struggling with the purpose of the lab. When a messenger from the main office came looking for a particular student, Sarah just laughed and pointed to the chaos and said “Good luck.” She apologized to the student teacher several times for being so neglectful. The student teacher just shrugged and said she was used to it.

In spite of the chaotic appearance of her classes, the students were clearly on task and knew that they could get her attention and help when they needed it. Sarah showed total patience with her students even when she was explaining something for the third or fourth time. She was very friendly and nurturing and they responded by calling her Ms. _____, the first syllable of her three-syllable German last name. Her student teacher volunteered to me how supportive Sarah is and how grateful she was to have such a talented sponsoring teacher.

Perceptions of Effective Science Teaching

Sarah’s perceptions of effective science teaching were all highly student-centered. From questioning to presenting to cooperative learning to learning styles, Sarah is completely focused on her students.

During the interviews, Sarah expressed the perception that effective science teaching involves focusing on a small number of central concepts which the students themselves derive from laboratory work. In reference to her original participation in the Modeling Program, she said:

> It taught me how to motivate students and how to teach them central methods, central models, really, that they then could do any, solve any kind of problem without just using an equation. . . They build on their own concepts and they start every unit with an experiment and they build from there. (initial interview)

She continued:

> The main reason I think it works is all the centrally focused ideas that are essential through every unit, they are through the core of every unit. Everything is based on the lab so everything you can relate back to that lab, remember when *you* did this in the lab, when *you* did this, not just when Newton did such and such or some other physicists. We don't give them equations, they derive them and that's the difference. (initial interview)

For Sarah, these "centrally focused ideas" are the goal but the only access to them is through laboratory experimentation. Labs are the key:

> My teaching is all based on their original laboratory experiment and experience, and they don't just prove what I've already taught them but they *derive* it and then we go from there. And if they say 'Well how do we know?', I say 'Well you're the one who got that equation in the lab so how did *you* know?' . . . I always start units with experiments. They learn and form the equations versus my giving them to them. I never stand up there and put an equation on the board. They derive their equations from the lab and then we solve some problems with those equations. (initial interview)

During the follow-up interview, she emphasized again the importance of labs by saying "It's the lab itself that establishes the content I'm then going to teach. So once they have the experimental background, I can keep relating everything I teach to it."

Sarah also felt that effective science teachers constantly question their students to check for understanding and do not move on to new topics or units until they are satisfied that virtually all students understand the material. This may require covering less material but this is an acceptable trade-off for covering the material in more depth. At the beginning of the first interview, she said “I think as a teacher I have never been totally clueless about my students and their not understanding something. I know when they don't understand something.” She then commented:

> I can ask them questions and they have to be able to respond and I keep asking them until I get everything out of them I possibly can about that problem. . . That way I know who understands and who doesn't. It's very obvious. (initial interview)

For Sarah, checking on student understanding is important because she clearly differentiates between teaching and learning:

> I think I’m totally aware of where my students are in their understanding at all times. I do not move on until the majority of the students do understand it. I don’t think ‘OK, I’ve taught this material so the kids understand it.’ To me that’s the big difference in teaching and the students learning is, yeah, you may have taught it but did the students learn it? (initial interview)

While describing her use of easels for students to display whiteboards, she said:

> You know which ones [don’t understand] because you know who can’t answer your questions when they’re up there and you know who to ask questions because they’re the ones hiding behind the whiteboard. And that’s why I’ve gotten an easel because there’s no one behind the whiteboard holding it. They all have to be at the sides and they’re all equal, evenly open to questions. (initial interview)

Over and over again, she expressed her reluctance to move ahead until she felt that almost all the students understood the previous lesson: “I don’t leave a unit until I know the majority of the class understands it. . . . If I don’t feel the majority have it, I won’t move on. . . . If twenty kids answer, that’s not enough. I want *everyone* to understand the meaning. . .” She admitted that, before modeling, she didn’t always operate that way: “The whole point of teaching is to make sure that every single kid, or as close as you can get to that, understands the material, and I wasn’t doing that. . . . Quite often we would move on even if only half the kids understood it which is not how I like to teach." During the follow-up interview, she even explained why she almost always gives tests on Friday so that she has the weekend to grade papers: "I can't exactly move on until they have the results of their test."

Sarah is somewhat concerned about never "covering" the entire curriculum but feels that this is a fair trade for deeper understanding of the key "underlying" concepts. She expressed her feelings through a pair of rhetorical questions:

> You have to ask yourself 'What is your goal?' To get through the material to say 'Yes, I taught it. I got through the book?' You can't say they learned the book because you're simply guessing. Or to have a more narrow river that is deep and you know they understand the concepts and there's serious retention because you've taken the time to make sure that there is depth there and not just a shallow understanding of a concept so you can move on? (initial interview)

She described the ramifications of both of the above approaches through a pair of anecdotes. In the first, two former students came back to visit and described their experiences in advanced physics at the state university:

> These were kids that I didn't get past that [mechanics] with and they said 'Oh, yeah, we're doing electricity. No problem. It's the same concepts, Ms. _______. It's the same idea, it all is the same idea as what you taught us,' which they just didn't put a word to it, mechanics. (initial interview)

In spite of the "no problem" comment, she admitted she "felt terrible only getting through mechanics" and finished mechanics by January of the following year so that she could cover waves, light, and electricity. She came to regret it:

> Well, I ended up not doing circular motion at all, going right into waves, light, and electricity, and I did Castle and that stuff. It was good but I think that their understanding was not deep because I stopped before the units were completed. Their understanding of each unit was completed. I stopped my unit. So I don't think that all of them understood, I don't think they had the retention nor do they understand the depth. (initial interview)

The second anecdote shows the lesson she learned from this. She discussed some other students who had returned to visit her:

> I mean they're taking third and fourth year physics and they're still saying 'No, I didn't have any trouble from the very beginning' and that's because they have all the underlying concepts so well ingrained in them that the rest just follow through. They have no trouble with them. Where if they skip any of the underlying because you went too fast and wanted to get through everything in one year, then they don't get it, they don't retain it and so they have just as much problem in college and they go back to the plug-and-chug method. (initial interview)

Sarah felt that effective science teachers require their students to verbalize and otherwise express their understandings and make frequent presentations in front of their peers. Her first comment came as she described how she checks on student understanding:

> When they get up in front of the class to help each other understand, it is so obvious when they don't understand it, but it's kind of an oral thing versus just written and we don't do very much multiple choice at all because they have to, like on tests and everything, they express by paragraphs, by diagrams, by motion maps, etc., their understanding. (initial interview)

Having brought up the subject of testing, she continued: "They also have to express their understanding [on tests], just like they do when they are in front of the class doing whiteboarding."

Sarah clearly stated her feelings about the importance of verbalizing in the following comments:

> Everybody expresses their learning when they get up in front of the class. . . . They have to explain everything. They explain it to each other, they explain it to the class and in my opinion when you learn and then you have to verbalize it and explain it and answer questions then you *really* have to learn it. . . . I do know how much they understand now because they're in front of the class *telling* me. They're expressing their learning and when they do that and then on the tests they answer essays you know how much they learn. (initial interview)

One of her favorite forums for having students present to each other is an exercise she calls "circle whiteboarding," where students solve a problem or write up a post-lab conclusion on a whiteboard and then they sit in a circle and take turns defending what they have written. During the follow-up interview, she described a typical post-lab circle whiteboarding session:

> So they do all this in the lab and it takes them about three days. Then they write it up and we sit in a circle, they write it on whiteboards, we sit in a circle and we ask each other 'Why does your graph look different than his? What does the slope represent?' which of course is going to be velocity. 'How can you have a negative slope in this case?' and that takes them to the fact that velocity can be negative just because of direction. So we do all that in a circle, then once I feel they totally understand it, I give them another day to write it up, write their conclusion, and then turn in the lab. (follow-up interview)

As for dealing with students who may not be comfortable presenting to the class, she explained:

> I always let every kid from the group up there even though that causes a little disturbance. It helps them not to be so insecure up there. Even though they may be the ones talking, there are three that aren't but they're all there and I let them ask each other, but I'll still come back and ask that same one that maybe couldn't verbalize in a different way. (initial interview)

She gives credit to the Modeling Program for showing her the importance of having students verbalize: "Modeling helped me know *how* to pull it out of them and to put them in charge of their own learning and responsible for their own learning and able to verbalize their own learning."

Sarah felt that effective science teachers create a student-centered classroom environment in which students spend a great deal of time in front of the class and the teacher's presence at the front of the room is greatly reduced. In describing her normal classroom routine, she said:

> I'm not at the board hardly at all. The kids are up there. I'll introduce a lab but from then on the whole unit, they're working. They're working in their groups, they're working in front of the class, and I'm not in front of the class all the time, which is really nice. It really takes the pressure off of me. I'm in the back of the room putting pressure on *them* to really explain the concepts. So that part's really much better, that I'm not the one in front all the time, all the time. (initial interview)

In commenting on the Modeling Program, she said:

> So it kind of taught me to build on models, to make it student centered versus me at the board all the time and me on task all the time or at the center. . . . The students are the ones, it's student centered. It's not text centered, material centered, teacher centered, it’s student centered. . . . And that’s something I did not do before modeling. I did not have kids in front of the class like that. (initial interview)

Sarah felt that effective science teachers promote the use of cooperative learning techniques and group work. She did not make an overly strong point of this but it did work its way into both interviews in a number of places. For instance, she said “And they do work a lot in groups where before they’d do their problems but more in pairs.” And again: “But they do a whole lot of group work.” And again: “When they do these worksheets, they do them in groups.” Twice, once in each interview, while describing what effective science teaching would look like, she added on: “And a lot of cooperative learning.”

Sarah felt that effective science teachers teach in such a way as to take advantage of many different student learning styles or learning modalities. She only addressed this issue once, during the follow-up interview, but she went into it in considerable depth:

> And I try to hit all of them [the different learning modalities] because if you don’t, they don’t learn. Most kids are very visual and if you give them a lot of hands-on, to me they have to have the hands-on or it will not stick. . . . It’s all hands-on. If all I do is lecture, forget it. They’re lost. Even in college, even when I teach my college classes. That’s part of why modeling works, because we use so many facets, so many modes. I mean, I’ll *run* across the room to show them a graph or they’ll be up front and I’ll say ‘Walk that motion.’ Some of the kids don’t understand it visually until they actually themselves walk it. And so I do a program where they make their graphs by walking them and it comes up on the computer because we use motion detectors. So in a way you are trying to build on that, you’re trying to pull in those things that usually work in gym class, because you’re having them walk it and they are seeing that motion across the front of the room versus just on a graph on the board, or just as a video. . . . We’re trying to build and grab all those different ways of learning. . . . To take all these

> different intelligences and bring them into my classroom, but I'll tell you I go to workshops and everything all the time to try to learn different ways because these kids were brought up a whole different way than you and I were. . . . They want it changed, they want every different thing changed, they want some visual and then they want some auditory, then they want some moving around. I don't limit my kids on moving around. They don't have to ask my permission or anything. If they aren't understanding from one side of the room then they can move to the other side. They can sit on their desk if they have to, within reason. (follow-up interview)

My observation of her classes was consistent with the above statement. There was a high degree of student movement in her classroom without any thought given to asking permission.

Finally, Sarah felt that an effective science teacher should expend whatever energy is required to create an environment of fun and excitement in the classroom. The level of excitement in her classroom is one of her indicators of successful teaching:

> I look for the excitement, number one. If they're excited about coming into class, then I know they're finding success. And if they're having success, because I don't play with them, I'm not just there to play, if they're actually coming in because it is a learning environment, excited, then I know they have found success. (follow-up interview)

She feels that the techniques she picked up from modeling are significantly responsible for this excitement:

> And plus they're excited about it because it is so much hands on, so much group work. I don't think I did as much group work [before modeling]. I did pairs. . . . I mean they border on excited like they're in an amusement park. And it's because we do let them talk, we do let them work with their neighbors, we do everything hands on, and it's fun for them and the period goes by so fast. You'll hear comments like 'Oh, my gosh, there's no way that was the bell. Is that the bell? Is that really the bell?' And I didn't get that before I started modeling. (initial interview)

In a way, she uses this excitement as a marketing tool: "And now if I was to ask a student which they had a better time in, if they hadn't taken physics yet they'd say chem but once they take physics their answer is always ‘Oh, physics.’ And they tell their friends ‘Take physics.’”

She does acknowledge that creating this level of excitement requires a lot of energy and planning on the part of the teacher. She said “You really have to expend a lot of energy to keep them on task, and the less you do and the less you work at it, you’re going to lose kids.” On the other hand, if you are willing to expend the energy:

> Just the excitement. So I think it has added excitement to my classroom. Kids come in my room and go ‘Oh, Ms. ____, this is just my favorite class. Sometimes I never think I’ll get here,’ you know, if I have them seventh hour. Finally it’s seventh hour and I go ‘Oh, I know it’s been a long day.’ ‘No, Ms. ____, I just never feel like I can get to physics soon enough.’ And when you hear those things, that keeps you alive, it keeps you excited about teaching, but it takes a lot of work to do that. Energy, energy and planning. (follow-up interview)

Sarah’s energy and excitement overlay everything she does. She is so student-centered that I had a difficult time getting her to talk about anything else. As far as she is concerned, effective teaching is effective student learning.

Perceptions of Effective Student Science Learning

Ironically, Sarah had less to say about effective student learning. Her perceptions of effective student science learning seemed to center on issues of involvement and peer teaching with some almost obligatory comments about students taking responsibility for their learning.

During the interviews, Sarah expressed the perception that effective student science learning is characterized by active involvement and participation on the part of the students. She stated her feelings quite clearly at the beginning of the follow-up interview:

> I think, whether it’s effective science teaching or any kind of teaching, it’s keeping the kids active and involved and keeping them all on task so you’re

> looking at teaching to one objective at a time but keeping all the kids active all the time. I don't see science as more than about fifteen percent lecture. (follow-up interview)

Later on in the same interview, I asked her to assume the role of student and describe the behaviors she would need to have to be an effective learner. She said:

> I have to participate and be part of the group and be a peer learner as well as a tutor. I have to pay attention during the whiteboarding sessions when the other students are presenting to me. I have to complete my work and ask questions when I don't understand. (follow-up interview)

The willingness to ask questions is part of active participation. During a discussion of whiteboarding, she commented: "So when *they* have to put it on a whiteboard, they're active and that's why this method works. They're active all the time." Continuing on the same topic, she said:

> That's why I have them go up front and explain the problem because the kids will come up with questions I can't even think of and then the kid has to think, and that's how they learn. (follow-up interview)

Still on the topic of whiteboarding, she said:

> We'll sit in a circle, everybody can see everybody else's whiteboard and they can ask each other questions . . . And you'll hear them asking each other things like that and I got that from modeling, from physics. I didn't do that before I went to modeling physics. And so I love the circle after a lab. (initial interview)

Sarah also felt that effective student science learners take advantage of peer learning and peer teaching opportunities to increase their understanding of the material under study. This theme popped up many times in both interviews in comments such as: "Whatever it takes, they start helping each other and when you learn from other students as well as the teacher you learn the material" and "They're not just learning from me, they have a hundred teachers. Whoever's in the class is a teacher for each other" and

"And they peer teach each other which is another method of learning" and "I'm not just teaching it, they're teaching each other."

She commented on what she has observed in some of her colleagues' classes:

> I sit around and I look at these kids who are sitting at individual desks doing individual work. They aren't getting each other's ideas on anything. I think 'Oh, my gosh, what a long school day for those kids.' (initial interview)

Again playing the role of student, she said "I have to be there to learn and hear and have lots of discussion with my peers about the material."

Sarah felt that effective student science learners take a significant degree of responsibility for their own learning. All of her comments on this theme relate to her use of modeling. For instance, she said "But they do a whole lot of group work. They're much more in charge of the learning than I am." She commented that, since her adoption of modeling, "it's kind of different because everyone is responsible for understanding the material." She directly credits modeling in this quotation from the follow-up interview: "Modeling helped me know *how* to pull it out of them and to put them in charge of their own learning and responsible for their own learning . . ."

Finally, in a perception only she verbalized, Sarah felt that effective student science learners make the effort to be in class and take responsibility for completing their work. When I asked her what she looks for in effective student science learners, she said:

> Are they on task in their groups, do they complete their work or are they lethargic and just not really interested? I listen to their comments about the class and if you watch their behaviors you can tell if they're actually understanding it and if they are then they're on task, they're learning. They do their work, they complete it. (follow-up interview)

Attendance is also an issue with her. When I asked her to assume the role of a student and describe effective student learning, she said:

> I have to complete my work and ask questions when I don't understand. . . . But I definitely have to do my work and I have to be there. If I miss very much, I can't be a good student. I have to be there to learn. . . . (follow-up interview)

It strikes me that Sarah's sparser comments on effective student learning as compared to her perceptions of effective teaching might indicate that she feels that the teacher bears the greater burden. That would be consistent with the intensity of her work ethic and the multitude of commitments she has made to her students and her school.

Perceptions of the Influence of the Modeling Program

Sarah's perceptions of the influence of the Modeling Program seemed to be focused on making her feel as confident and competent in her physics teaching as she was in her biology and chemistry teaching. This, in turn, led to the return of the enthusiasm that she felt made her effective.

During the interviews, Sarah expressed the perception that her participation in the Modeling Program had essentially taught her physics. Instead of a multitude of disconnected topics, she felt that she now sees more structure, coherence, and connection between them. This is one of the most pervasive themes in both interviews. Almost immediately in the initial interview, she said: "The main difference before modeling and after is I didn't really understand physics, before I went to a modeling class one summer for six or seven weeks and learned physics." Sarah was a converted biology and chemistry teacher who had been assigned to teach physics because of the retirement of the only physics teacher. She continued: "I never really understand the depth of physics and how all the things connect or anything until I took modeling and that's when I really learned physics."

When I asked her what had motivated her to attend the Modeling Program, she said:

> I knew there had to be a better method of teaching physics when I taught every other subject I've ever taught without a book and all of a sudden I'm relying on a textbook. I knew there had to be a better method of teaching physics plus I needed to *learn* physics. (initial interview)

The Modeling Program turned out to meet both those needs:

> So when I saw *this* offered, that it was being taught right in _____ so I didn't have to leave my home for the summer and it would be other physics teachers and we were all in it together it was awesome and I knew that my goal was not, the goal of the workshop was not to teach *us* physics but now I have taught modeling for three summers and I know from the teachers' comments that fifty percent of the teachers at least that come to these workshops feel they really learned physics for the first time even though that isn't the goal of the workshop. (initial interview)

Since she has become an instructor for the Modeling Program, Sarah has become much more aware of how many other physics teachers are trying to actually learn physics during the workshops:

> But every year, in our modeling workshops, you can tell that there are about thirty percent that really are trying to learn physics at the same time they are learning a new way of teaching and they keep wanting us to slow down, slow down . . . (initial interview)

She administers a survey after each workshop to find out how many teachers actually feel they learned physics during the session: "About a third say I never really understood physics and now I do." She even had her own student teacher as a student during one of the workshops:

> I find that every time I teach the first of modeling, there are other people in the room that were just like me. My student teacher told me the same thing. She said 'You know, I'm a physics major and I would not have known how to teach physics any more than fly if I had not taken modeling and then student taught under a modeler.' . . . She said 'It opened my eyes so much and even though I was a physics major I did the stuff but I never connected it and now I really understand the physics material.' (initial interview)

When I asked her to be more specific about what modeling had done for her understanding of physics, she said:

> When I actually learned physics material, I could see how they built on one another and I could see the end of the tunnel from the beginning where I never knew where the end was, as far as where do I really want to take these kids. . . . It all connects. I never saw it as connecting until I went to the modeling workshop. And so now because I have the content behind me and understand how it connects, I can help the kids understand the connections and how one piece builds on another. (initial interview)

When I pressed her to be even more specific, she said:

> I used to think of physics as OK, that's linear motion, that's done and this is accel, all right, that's a separate unit, that's done, I never thought of it as building on itself where once I went to modeling I could see where one built on the other. . . . And all of Newton's Laws. I thought they were separate entities. Teach his first, teach his second, teach his third. All right, I've taught Newton's Laws. Now, let's go on to projectile motion. I taught everything so separate that it was like pieces of a puzzle that didn't even touch other pieces and now I teach it where they're all parts of one puzzle. They all fit together. (initial interview)

Sarah uniquely felt that her participation in the Modeling Program has given her a sense of confidence in her physics teaching and the knowledge that it is acceptable not to know the answers to all student questions. Prior to modeling, she felt: "I was very insecure about it, very unsettled. . . . I never felt they understood the whole concept but part of it was that *I* didn't."

She admitted that, prior to modeling, she felt pressured to have an answer to student questions. Now, she tells them:

> Why don't *you* look it up and find it? I've never been one to do that. When they ask me I want to tell them. I've gotten better about asking them questions back if I know it's something they can answer like if it's part of our content. But if it's something way off that we're never going to get to, nuclear physics or something like that, I'll give them the knowledge I can and then try to promote their going further with that. (initial interview)

Her eyes were opened during her first Modeling Workshop when the instructor was asked some probing questions and

> he had to say ‘I don’t know. Let’s do what we can and see what we can get with it.’ And we couldn’t always get a bottom line but we could sure use models and stuff to get an idea about what we thought. Whether it was right or wrong we didn’t know. But there are questions in physics that go unanswered. And I didn’t know that. (initial interview)

This experience gave her a great deal of confidence in dealing with student questions:

> So even in areas where I maybe didn’t learn much more content, I felt better. And when you feel more confident, I think you’re more eager to let the kid learn on their own, too, just by leading them, leading them, instead of just answering them and moving on because you don’t want to look like you don’t know the answer. (initial interview)

Sarah felt that her participation in the Modeling Program has given her techniques and methods to use for checking on student understanding. Early in the initial interview, she said: “With modeling, I know now how to get them to understand it. . . . And with modeling you know whether they’ve learned it.”

The primary tool she has picked up from modeling is whiteboarding, which she has modified into circle whiteboarding. During a circle session, she can assess their understanding:

> So we do all that in a circle, then once I feel they totally understand it, I give them another day to write it up, write their conclusion, and then turn in the lab. . . . I didn’t do that before I went to modeling physics. And so I love the circle after a lab. I love getting into a circle . . . (initial interview)

She also sees tests as another way of assessing understanding:

> And the test, it comes from the lab and then problems off the worksheet and then an extension of those problems that they’ve never seen but if they understand the content they can transfer their learning to that. (follow-up interview)

Sarah felt that her participation in the Modeling Program has made her less reliant on textbooks, an issue that was only hers. This is another issue she addressed only once but in considerable detail. When she was assigned to teach physics for the first time, she had to try to teach herself through textbooks:

> I was told to teach physics when the physics teacher retired and I was teaching chem and bio so all of a sudden I had one summer to prepare and no one to help me or anything so I got books out and I learned by textbooks and that again tells me kids can't learn that way because I never really understood the depth of physics and how all the things connect. . . . (initial interview)

Things are considerably different since modeling:

> So I think before I took modeling I taught from a textbook and it's the only subject I've ever taught from a textbook. I don't use a textbook in any class I ever teach, even my college class. But I taught that one year I taught physics. Now there were two years, I taught physics two years before I took modeling and in both of those years I had to rely on a textbook because I couldn't really rely on my knowledge base or my worksheets that I created. (initial interview)

Sarah felt that her participation in the Modeling Program has changed her perception of physics as formulas, applied mathematics, and problem-solving to a view which involves the systematic application of just a few critical concepts. In a continuation of the discussion of what she had learned from modeling about motion and Newton's Laws, she broadened her comments to the very nature of physics itself:

> It opened my eyes as far as learning. It opened my eyes to what physics was all about and it isn't just equations. I think that that's all I thought of physics as a math-science. That's all. A science that was totally math-oriented and I could teach physics now without a bit of math if I needed to. (initial interview)

She continued, shifting the emphasis to concepts:

> Once I went to modeling I realized that physics isn't just a bunch of equations that you fill in with numbers to find an acceleration. Its real-life stuff. It's everyday motion, everything, light, sound, everything, it's what we use and see and happens to us or that we visualize on a day-to-day basis. But I think I moved away from the idea of physics as equations to physics as concepts and an

> understanding of the concepts versus a solving of equations and problems. (initial interview)

Finally, Sarah was alone in expressing the perception that her participation in the Modeling Program had helped her find and pass on to her students the excitement she felt in her other areas of teaching and, in turn, had enabled her to retain virtually all of her students in an elective course with a traditionally high dropout rate. Her newfound passion for physics is undeniable:

> I guess when I went into it, I kind of figured ‘OK, if I bide my time, I can just teach physics a year or two and then they’ll take me out of it.’ Now if they take me out of it, I’d kill them, because I love it. (initial interview)

And again:

> Now of course, if I had to choose between any other science and physics, I would choose physics and modeling did that for me. (initial interview)

And yet again:

> So I feel I have been much more successful, especially in physics, after taking modeling and I love it, I’m a firm believer in it. (follow-up interview)

Another example of the excitement she has instilled in her students comes from this comment:

> The main difference, pre-modeling and post, is now when kids come in the class, instead of one or two kids at their desk always talking physics, physics and the rest of them not just coming in and sitting down, they’re *all* talking physics. They’re all talking to each other. They’re all into it and they’re excited and they don’t say ‘Are you dropping at semester?’ (initial interview)

This issue of students dropping the course is very important to Sarah. She judges herself by her dropout rate. Since modeling, she has seen a big difference:

> And so the biggest thing is I’m retaining my students, and I’m not just retaining them, they’re excited, they’re coming in here excited about physics. If my parents call, it isn’t ‘Why are you assigning so much homework or they can’t this or that,’ it’s ‘My kid likes your class. This is cool. My kid’s excited about physics.’ (initial interview)

She uses her high retention rate as a selling point in her own summer workshops. Referring to some of the teachers who attend the workshop, she said:

> The ones that already know they don't know how to teach it are the easiest to convert. The ones that believe they have the answers and have taught it all these years whether they've seen retention or success, their success was, OK, forty percent learn and I'm happy. Well I think the modeling workshops improve that because they're hearing us say we don't lose students, we don't have students drop. (initial interview)

The teachers she finds hardest to convert to modeling are the ones who adhere to the "old philosophy":

> The old philosophy was if you could retain half your class and of those half if half understood it then that was good. It was an elitist club. You're in it or you're out of it. They didn't care if you were out of it. They liked it. The fewer that were in it, the better they felt about themselves. And that's the people we tried to change in the modeling workshops. (initial interview)

She feels that she is successful with the vast majority of the workshop participants:

> There are a few that we never convert in those modeling workshops. We never convert them and they go back and they do their own thing, but I think they're very few and far between because even the teachers that have taught for twenty years, physics majors, think they have all the answers, actually listen to some of us and our success stories and how we don't lose kids and they're excited about physics and they're understanding it. (initial interview)

Sarah is very critical of her own teaching and holds herself to very high standards. When she was moved into physics teaching, her self-esteem suffered and she felt she did not meet her own standards. Her perceptions of the influence of the Modeling Program show that she credits the program with giving her the tools and understanding she felt she needed to once again meet those standards.

Janet – from Medical Technologist to Physics Teacher

Janet is a fifty-one year old physics teacher at an urban high school in a moderate-sized southeastern city. She has taught high school science for nine years, all at her current school. Before that, she taught Medical Technology for seven years at a local state university.

Janet earned her B.S. degree in microbiology in 1972 at a state university in a neighboring state and then took a job in medical technology. She earned an M.A. degree in Health Care Administration in 1987 and, after moving into high school teaching, completed her Ed.S. degree in Science Education in 1995. She is currently certified in General Science. She participated in the Modeling Program in the summers of 1998 and 1999 in the northeast. She has completed her portfolio for National Board Certification and, as of this writing, is waiting to hear whether she has passed. In her spare time, she teaches ballroom dancing.

Janet's school enrollment is approximately 1200 students, primarily middle class. Half the students are Black, 40% are White, and the rest are Asian and Hispanic. Approximately 17% are eligible for free or reduced lunch. The school uses a "four by four" block schedule design and Janet is currently teaching two sections of college prep physics and one class of Advanced Placement Physics.

Janet has a lecture room and a separate laboratory to herself. Her rooms are of an older style with high ceilings and one long wall in each containing wall-to-wall large, double-hung windows starting less than three feet from the floor and extending to the ceiling. The lecture room is small and nearly square with twenty-five individual student desks and separate chairs arranged roughly in a five-by-five pattern. The front of the room has a large demonstration bench that doubles as the teacher desk. The front wall has a large, green chalkboard above which Janet has mounted framed certificates she earned as Teacher-of-the-Year. To the right of the front board is a large, closed storage cabinet and to the left is a large television on a tall cart. Farther to the left, behind the classroom door, is a large pile of whiteboards for student use.

The left side wall contains another large, green chalkboard with class assignments written on it and a small bulletin board filled with a variety of notices. Near the front of the room is the door to the hallway. The remainder of the wall is bare. The back wall of the room is actually a supposedly moveable divider that no longer moves. It contains the door to the lab room and the remainder of the divider displays a variety of posters on Einstein, the physics of sports, the space shuttle, Nobel Prize winners, and astronomy. The only other decorations in the room are a variety of cut-out paper stars and snowflakes hanging from the dropped ceiling.

The laboratory was clearly designed as a chemistry lab with two narrow, free-standing, room-length, fixed lab benches containing sinks and gas jets down the middle and a third, narrower bench running the length of the long wall opposite the windows. As a result, there is little flat, unobstructed surface area for doing physics experiments. In addition, there are six Macintosh computers, four sitting at either end of the two free-standing lab benches and two on carts. A fume hood at one end of the laboratory is flanked by glassware storage cabinets while the divider at the other end, shared with the classroom, is bare. The wall surface above the lab bench on the long wall is also bare.

Janet has a very soft, slow, and deliberate speaking style that promotes a very calm and respectful atmosphere in her classroom. She is very dignified and well-dressed and exudes an aura of professionalism. During my observations, her classes were all involved in a study of the behavior of pendulums. After a brief pre-lab discussion in which she called on students to verbalize the purpose for the lab and their hypotheses about its outcome, she set the students loose to set up the equipment however they wished. When students tried to make her tell them how to collect the data, she just referred them back to their purpose statements and suggested they work it out within their groups. She remained very calm and restrained throughout the lab, moving slowly from group to group and asking how they might improve what they were doing. The majority of students were completely self-sufficient and all were on task. They all graphed their data extremely rapidly and confidently.

Janet is very supportive of her students. She made an effort to point out to certain groups that she had never seen students use the available equipment the way they were using it but that she felt it was very clever and creative. She mentioned it again to the whole class during the post-lab whiteboarding session. She also complimented each group on their quality work at the end of each whiteboard presentation and made a special point to compliment two groups who had shown extra attention to detail.

Perceptions of Effective Science Teaching

Janet's perceptions of effective science teaching involve comparatively more comments on issues relating to teacher conduct and behaviors then were expressed by the other participants. Although she was very much concerned with inquiry teaching and reducing the visible role of the teacher, she was also concerned with teacher excitement, time commitment, use of assessments, and sensitivity to learning styles.

During the interviews, Janet expressed the perception that effective science teachers use inquiry-based teaching strategies emphasizing the central role of laboratory experimentation. She compared her current feelings on the subject with the way she did it earlier in her career:

> I think what I like best about it is starting every unit with a lab that *they* have to design and that *they* develop the equation and they remember it longer because *they've* developed it and I haven't just stood up here and said 'OK, here's the equation that goes with this concept.' And throughout the entire unit I can always say 'OK, lets think back to the lab. What did you do, what to do come up with?' And that just provides the background, the floor for everything else that we do during the unit, and what I did in the past was 'OK, here's the lecture material, here's the equation, now let's go do a lab and prove what we just did, what we just said.' And that served no purpose at all. Maybe to teach them how to use the equipment. (initial interview)

When I asked her what she would see in an effective teacher's classroom, she said "There's a lot of hands-on experience, a lot of questions, a lot of discovery with themselves." When I asked specifically about laboratory work, she added:

> To me, the laboratory has to be what starts a conceptual unit and is used as a discovery tool so that they can establish the concepts for themselves . . . If they can discover it for themselves then it becomes part of them. (initial interview)

Janet also felt that effective science teachers promote the use of student presentations and student interactions and reduce the visible role of the teacher. When I asked her to describe effective science teaching, her first comment was:

> I describe it as the teacher is not the sage on the stage, they are the guide on the side. They have a lot of student-student interaction, a lot of student-teacher interaction but less student-teacher interaction than student-student. (follow-up interview)

During the initial interview, she had made a similar comment on her changing role in the classroom:

> I used to think it was a matter of dispensing the knowledge. I am the well of knowledge, now let me tell you everything that I can and it's your job to just soak it up. Now, I think that effective physics teaching is letting them see what the problem is. This problem has already been solved by hundreds of people before but now it's *your* problem. How are *you* going to solve it? And what results do *you* get out of it? So it becomes more inquiry-based rather than dispenser of knowledge. I think I heard somebody say we quit becoming the dispenser of knowledge and become the facilitator of knowledge. And I truly believe that's the difference. (initial interview)

She feels that this reduced visibility may have been in part responsible for her having been selected as the county Teacher-of-the-Year. Referring to the committee that came and observed her during the selection process, she said:

> They were so impressed that this is what happens every day in the classroom, that students were brainstorming among themselves and could figure out problems without the teacher being present and that what they needed was guidance in the direction rather than being told ‘This is the way it’s done.’ (initial interview)

She feels that the purpose of focusing on student presentations is to shift the learning responsibility to the students:

> The whiteboarding process and the Socratic questioning I think is just invaluable in the way that they learn because all of a sudden they’re the ones that are putting together, maybe synthesizing the facts, if that would be the correct term, rather than the teacher synthesizing. (initial interview)

Janet felt that effective science teachers should be willing to commit the necessary time and energy to do their job the way they know they should or to re-evaluate and change their methodology. She presented the dilemma faced by many teachers:

> I think too many teachers get set in their ways. I’ve done it this way and it sure is a whole lot easier to keep doing it this way rather than to change because I don’t want do anything at night to prepare for the next day and if I change anything, the way I teach, then I have to redo everything. And perhaps what made it easier for me is I’ve only got one child who’s going away at college so I didn’t have little ones at home that I was having to deal with so I could put the time and effort into it that needed to be put into it to make that change. (initial interview)

Once a teacher makes a change, it can still be difficult to summon the energy to carry it through. Janet told a story of a student who complained to her of “having to think” for the first time in Janet’s class but then came back from college to thank her:

> I knew she would, but it still puts a lot of pressure on you and you do start second-guessing yourself and thinking ‘Maybe I shouldn’t be doing it this way. Maybe I should go back to, like, because it sure would be easier to stand up here and lecture and then give them the problems and it would be a whole lot easier.’ It looks like, when you’re sitting back there in the back of the room and they’re up here presenting and asking the questions, it looks like you’re not doing

> anything. But it’s a whole lot harder to do the modeling than it is to just stand and lecture and hand out the problems. (initial interview)

Janet felt that effective science teachers use a variety of techniques to monitor their students’ understanding. She explained how, during whiteboarding sessions, it may look “like you’re not doing anything” but how difficult it is in reality:

> Because you have to be on top of everything that’s going on and make sure they’re staying in the line where they need to be. And so every class is different, and to watch the faces and to see the one that’s frowning and going, they don’t have to say anything, you just know that they’re going ‘I really don’t understand what they’re talking about,’ but you have to be aware of what’s going on in the room and every person as to whether they’re understanding or not. (initial interview)

Another technique she uses for checking on student understanding is the lab practicum, which she schedules shortly before major tests:

> For me, a lot of the evaluation comes from the practicum, seeing whether they can use the concepts they’ve learned in another situation. I think that’s when I know that they really have a grasp of the concepts. If they can apply it to a different situation, similar but different. (follow-up interview)

Janet felt that effective science teaching requires teachers to display a sense of excitement about and love for their subject and their profession. She is so happy in her job that she has resisted the call to become an administrator like her husband:

> They’ve tried to talk me into going into administration and I’ve just said ‘I’m where the fun is.’ And as far as I’m concerned, this is the apex of the career, not the administration. (initial interview)

She considers teaching to be her personal calling. This is the source of the excitement she feels for her work:

> And I think that’s the primary reason that I’m good at it, because I know I’m where I ought to be. And therefore I’m happy where I ought to be, and I think if you’re happy in your job, that *excitement* just has to spill over to everybody else. I may not like physics, I may have to endure this year, as far as the students are concerned, but you know what, she’s excited about it and there must be something to do it that’s worthwhile if she’s excited about it. So I think it’s just a

> matter of excitement, excitement about your subject and I love to learn. That's the pleasure of teaching these students, they love to learn, too. (initial interview)

Janet felt that effective science teachers use cooperative grouping to encourage students to constructively interact. Right at the beginning of the initial interview, she described her normal classroom procedure: "We do a lot of group work. The time as far as when we're doing problem-solving, not laboratory time, we work in groups ninety-five percent of the time."

During both interviews, she told the story of her son, a gifted student, and how he and his friends had resisted the cooperative groups that she attempted to create in her physics class. They felt that "they were always having to carry the load" and Janet gave in. She came to regret it:

> I'm just *convinced* that I was absolutely wrong in delaying as long as I did. And the gifted students do not complain about doing it this way and maybe that's because I'm not their mother and they feel like they can't cry to me like my son did. (Laughter) But it seems to work very well, very well. (initial interview)

Finally, Janet felt that effective science teaching attempts to meet the needs of students with a variety of learning styles. During the follow-up interview, she showed her awareness of the issue by describing a personal revelation:

> I think the first thing is to figure out what kind of learner you are as a student or as a teacher, either way, because I didn't realize how much of a visual learner I was until I started dancing, and kept finding myself saying 'Show me. Don't describe it to me, show me.' And how old am I before I learned what type of a learner I am? I need to see things. I think it's important for the teacher to provide opportunities for all of those different things. For people who are the visual learner to actually be able to see things. Maybe they don't want to get their hands on it. Maybe they just need to see the graph that's the result. And then you've got those, the kinesthetic ones, who are going to be the kids who are going to jump in there into the group and they're going to be the ones that are putting everything together in order to get that graph developed. (follow-up interview)

Later in the same interview, she said:

> I’ve got to be real sensitive to how fast the students pick up on things, that some people need reiteration, they maybe need to get their hands on it, then they need to hear it in discussion and then they need to hear it perhaps in a lecture whereas the gifted students are ready to go directly from a lab to a practicum. (follow-up interview)

Janet’s perceptions of effective science teaching seem much more focused on teacher behaviors than most of the participants. This is very much consistent with her very ordered and controlled teaching style and might well be a factor in why she was chosen as her district’s Teacher-of-the-Year.

Perceptions of Effective Student Science Learning

Janet’s perceptions of effective student science learning seemed to concentrate on student involvement, open-mindedness, and interaction. These are issues that are clearly the responsibility of the individual students and, coupled with the issues raised in the previous question, signify a clear separation of the duties of teacher and student.

During the interviews, Janet expressed the perception that effective student learners are active and involved. When I asked her to tell me what a student needs to do to become an effective learner, the first words out of her mouth were “They can be involved.” During a description of whiteboarding and why she finds it so effective, she said: “They are an active participant in what they are doing, is what it boils down to, rather than just being passive.” She had a personal revelation about the importance of being an involved learner during her experience as a student in the Modeling Workshop:

> The first two weeks I was in that modeling workshop I said ‘No way. This is ridiculous, what they’re doing here.’ And it took me about two weeks to begin to get the ‘ah-hah’s’ myself by working through it and just to realize that *I* wasn’t used to thinking in class. I was used to sitting in college classes where they dispensed the knowledge to me and I could just be passive and I think that’s what I was reacting to initially is I had to be active in this thing. I was actually in a workshop where I was having to *do* something. (initial interview)

Of course, she has since become a strong supporter of the program and even recently applied for a grant to teach a summer session of modeling.

Janet also felt that that effective student learners maintain an open mind and are willing to change their mind when presented with sufficient evidence. When I asked her to tell me what a student needs to do to become an effective learner, the *second* set of words out of her mouth were:

> They can keep an open mind to re-evaluate something that they *think* is true, and I'll see that happening so often where they go 'No, that can't be true because I've seen it in the movies and it happens *this* way.' But to keep an open mind about things. I guess just a willingness to change and that open mind comes in there, involvement and an open mind. (follow-up interview)

This issue of keeping an open mind applies to relationships within the social structure of the classroom as well:

> And if they've got suggestions for you, not criticisms but suggestions for you, that you take it and go 'Oh, maybe I could do that like that.' But also again that you keep an open mind that if somebody did their experiment different, that doesn't mean they're wrong, it means they did it differently, and that you can learn something from both ways. (follow-up interview)

Janet felt that that effective student learners interact willingly and comfortably with others in the manner of "pure scientists." She described the necessity of learning to work cooperatively with others:

> When they're out in the real world, they're going to have to work with all kinds of folks, they're going to have to work with that person who has no idea what's going on as well as that person who is much better at stuff than they are. And I think part of the education process is simply learning how to get along with folks so I think it's important that they learn to work with different kinds of people. (follow-up interview)

She also described what the classroom of an effective teacher might look like:

> It's a situation in which the teacher, maybe, not lays out the questions before them but lays out the situations on which the questions will be asked, and then they find

> out the answers from there. They become more of pure scientists, interacting with each other. (initial interview)

When I pursued what she meant by a “pure scientist,” she compared it to what students do when they get back together to whiteboard their conclusions after a lab:

> When they come back and present their work, and I guess this is where we get into the pure scientist thing, you’re presenting it to other scientists who are going to evaluate your work, they’re going to ask you questions as real scientists would do, and you’ve got to support what you came up with, why your graphs look like they do, why you decided to go at your lab the way that you did. . . . And I think that’s what we see scientists do when they get together at conventions and everything else. That’s the whole purpose for it is to share research. (follow-up interview)

Later in the interview, she related the notion of pure scientist to the assignment of students in lab groups:

> I guess, both as a teacher and a learner, it’s important to have groups where you don’t have all the visual learners in one place and all the kinesthetics in another place. It needs to be a give and take, and I guess that goes back to the pure scientist kind of thing where you are working as a group. (follow-up interview)

Even when she is not using the modeling methodology, such as during the second semester of A.P. Physics, she claims that her students still benefit from the cooperative group skills they learned during modeling:

> We still have similar type activities and I find it interesting, when we switch over and I don’t have the worksheets that have been made up and all that, we begin to use problems out of the book and so forth, that the kids will go ‘Can we whiteboard that? Can we work in a group on that? Could we do one problem and they do another problem and then show each other what we’re doing?’ They love those skills they learned in working as a team. (initial interview)

Finally, Janet expressed the unique perception that effective student learners accept the risk of being wrong or making mistakes. This is not something that she thinks the students are immediately comfortable with:

> We whiteboard the problems that we work and the students do the presentations. I have found that initially they are afraid, in the presentations again, because

> they're afraid of making mistakes, and the kids who are listening, their peers, are afraid to ask a question initially because they are going 'Well, gee, they know what that was. I probably should know and I'm afraid,' again the kind of students I've got, 'I won't let anybody know that I don't know that,' and to finally get them over that to where they can go 'Well, what about this?' and then to see the discussion start bouncing back and forth and I'm just sitting back here going 'Cool. This is good, this is good.' (initial interview)

This is an important issue to Janet which she related back to how real scientists make discoveries:

> I think if we could get that across in other courses, not just physics, to let the students get up there and make some mistakes. That's one of the things that I've really developed with this modeling, to tell the students It's OK to make a mistake. If you're up here presenting, its OK to be wrong. I don't want to be wrong on a *test*, but it's OK to be wrong. If you have designed your experiment wrong and you come up with some kind of screwy results, if we can figure out, if *you* can figure out why it came out like that and you can give me a good explanation of what you would do different the next time, then, you know what, scientists learn a whole lot by mistakes. Some real exciting things by mistakes. (initial interview)

Occasionally, she will catch a mistake on a student whiteboard before they present to the class and she will tell the group to leave it and see if any one else catches the mistake:

> And all of a sudden they go 'Oh, wow,' so now even if they made the mistake, they say that Ms. _____ said to leave it on there. And it's just a way again to be able to make a mistake with ease and be able to laugh about it. I think that's important in life, too, not just in physics. (initial interview)

That important life lesson is another lesson that she had to learn first-hand during the Modeling Workshop:

> When I got past the fear of being wrong and just went 'You know, I am learning something here and I'm learning it real fast and it's staying with me when I learn it.' Just that realization made me realize how important it was to have the kids experience the same thing. (initial interview)

The support she showed for her students in class and the avoidance of criticism when they were wrong is consistent with this valuable life lesson.

Perceptions of the Influence of the Modeling Program

Janet's perceptions of the influence of the Modeling Program all center on how it has changed her and her personal understanding of physics and its formulas. This is in many ways consistent with her focus on teacher behaviors as she discussed effective science teaching.

During the interviews, Janet expressed the perception that her participation in the Modeling Program has strengthened her understanding of physics itself. When I asked her to be specific, she immediately said:

> Of course the electricity. Not having had a physics major, and having to kind of teach myself along because it had been several years since I had had physics, but seeing the relationships in graphical models where you can see if you check voltage and you check resistance or whatever then you can figure out the current from those two relationships from a laboratory experiment that, this is where the equation came from. It's not something that was magically pulled out of the air, but it really came from data that you develop yourself. I think that was the major thing that I saw. (initial interview)

Along similar lines, Janet felt that her participation in the Modeling Program has given her an understanding of how the physics formulas and relationships can be obtained directly from experimentation and analysis of graphs. When I asked her how she had been influenced by modeling, she went on to generalize from the specific example of electricity cited above:

> I really think that any of it from mechanics through to modern, it's just the thought that all this stuff, all of these formulas that I have been up here putting on the board, are really things have been developed through experiments. It's not somebody who sat there and all of a sudden went 'OK, I think force equals mass times acceleration,' that *came* from somewhere. And where did it come from? How do we get from the experiment to this formula that looks so simple? Where did it come from? Just stopping to think about it, and maybe I knew that that's where it came from but I never really put it together in a way to show the students. (initial interview)

After being introduced to the way in which the modeling methodology relies on graphical interpretation, she felt enlightened:

> Something so simple, and once you start thinking that way, it just opens the doors to so many different things. What does this slope mean? And the kids have a real hard time with that, going from their math, well, it's four. Yeah, but four *what*? Oh, it means it moves four meters in one second. And you can just see the light come on, go 'Oh, that's what it means,' and so their math becomes real and I don't know if that's even connected with the question that you asked but I think that's the kind of thing that I was seeing, too, and that I became excited about. You know, this slope really *does* mean something, this intercept really *does* mean something, it's not just a number here on the page with the unit that goes with it. But it really *means* something. (initial interview)

Making the connection to calculus was almost inevitable:

> And then to see how that kind of works in and then figuring it in with calculus, of course, it makes sense. And some of the kids can understand that and some of them can't because of their math levels that those who don't know why we're doing it can just go ahead and kind of do it because we've been told to do this. But the others who understand their calculus understand why we're doing what we're doing. (initial interview)

Finally, Janet also felt that her participation in the Modeling Program has helped her appreciate the fact that there are multiple ways to solve problems. Early in the initial interview, she described what she had absorbed from the modeling methodology:

> To have them observe a particular motion and then be able to design an experiment for themselves and to look around and to say 'Well, my experiment's as good as yours. It may not be the same thing but we're still working toward the same end.' And to watch the different ways that they solve problems so that then I begin to see them gain confidence to solve other kinds of problems. So I think it goes beyond physics. It's OK to solve a problem in a different way than somebody else does. It doesn't have to be the way it's always been done. (initial interview)

She said that modeling has totally changed her, even at the personal level:

> It just changed it so much I'm not even the same teacher that I used to be. It made me look at things differently, not just in physics-related situations but at home, maybe a problem, I don't know, maybe arranging furniture, to be able to step back and say 'You know, there is more than one way to do this.' (follow-up interview)

She continued:

> And that was the emphasis that I changed with the students, where there's not just one way to do something. That what learning is all about is problem-solving and going from one layer of knowledge to the next layer or level to the next one simply because you're looking at the problem in a more mature way each time because you have more background each time. So it really changed me from a situation where I was telling the kids 'Here's the problem, here's the solution, memorize it' to 'Here's the problem, how many ways can we figure it out to come to a solution?' (follow-up interview)

Modeling has certainly had a major influence on Janet. From her understanding of electricity to formulas and graphs to multiple methods of problem-solving, she feels much more comfortable with physics than she felt before modeling. When I asked her how much credit she gives the Modeling Program for her selection as Teacher-of-the-Year, she said, without hesitation, "One hundred percent."

Cross-Case Analysis

In this section, I will identify the various themes that ran through the comments of multiple participants, consolidating where reasonable and necessary. This task is complicated by the fact that each participant used unique terminology in the course of their interviews, but the themes will be merged where the underlying focus of the comments appears to be fundamentally similar. The overall organizing scheme will be to introduce each theme in decreasing order of popularity, that is to say with the themes with the broadest support coming first. This analysis will also be organized separately by research question, with the issue of perceptions of effective science teaching coming first, perceptions of effective student science learning coming second, and perceptions of the influence of participation in the Modeling Program coming last. The section will end with a table summarizing the results of the cross-case analysis.

Perceptions of Effective Science Teaching

The perception of effective science teaching held by the largest number of participants was the perception that reducing the visible role of the teacher at the front of the classroom is important in effective science teaching. This theme was specifically identified by five of the six participants, with Jack the only one who did not bring up the issue. Robert referred to it as becoming less “didactic” while Diane called it being less “lecture-based.” Mike described effective science teachers more in terms of their supporting roles while Sarah emphasized her physical presence at the back of the room. Janet talked about moving from “dispenser” of knowledge to “facilitator.” All five of them either compared this reduced role to their own previous physics instructors or to themselves at earlier points in their careers. Mike, Diane, Robert, and Sarah all compared this reduced role to what they perceived as “traditional” science teaching.

Four of those same five participants also identified the creation of a “student-centered” classroom environment as an important factor in effective science teaching. Robert, Mike, Diane, and Sarah all tied this in with the previous perception of the reduced role of the teacher as an important factor in effective science teaching. Both of these perceptions relate to the issue of classroom focus and it is reasonable that talking about the reduction in one kind of focus would be linked to talking about a corresponding increase in a different focus to take its place. Jack did not specifically discuss the creation of a student-centered teaching environment but he did strongly support his perception that “empowering” students is another important factor in effective science teaching. If creating a student-centered classroom environment and empowering students can be thought of as variations on each other then all but Janet verbalized this theme.

Therefore, across the two themes of reduction of the teacher role and an increase in the student role, all six of the participants appear to share in some version of that perception.

Three of the six participants, Robert , Jack, and Janet, made a strong point of including their perception that inquiry-based teaching is an important factor in effective science teaching. In addition, four of the participants, Robert, Diane, Sarah, and Janet, included the perception that beginning each conceptual unit with a laboratory experiment with which to discover concepts and build understanding is also a crucial factor in effective science teaching. Since laboratory work is the key to the inquiry process, it is reasonable to consider these as two manifestations of a single, larger perception. If those two are merged, then all the participants but Mike appear to share that perception. Mike did, in fact, describe his usual rhythm of classroom instruction as beginning each unit with a "paradigm" lab but did not choose to make a point of it when describing effective science teaching.

Four of the participants, Diane, Jack, Sarah, and Janet, expressed the perception that having students verbalize their understandings in front of their classmates during formal presentations or whiteboarding sessions was also an important factor in effective science teaching. Diane and Janet specifically promoted the use of presentations while Jack and Sarah were more concerned with students expressing or verbalizing their understandings. Another closely related theme was the perception held by Jack, Sarah, and Janet that encouraging student-student interactions through the use of cooperative grouping is another important factor in effective science teaching. Jack included this with the importance of verbalizing under the term "sharing."

Robert, Mike, and Sarah shared the perception that effective science teaching should focus on a few key concepts. Mike called them “primary” concepts while Sarah called them “central” concepts. Both Robert and Sarah tied these concepts to the discovery process associated with the “lab first” philosophy.

The perception that effective science teaching requires teachers to show excitement for their subject was expressed by three of the participants, Robert, Sarah, and Janet. The same three participants also expressed the perception that effective science teachers should show a sensitivity to students with different learning styles and attempt to teach in a way that takes advantage of a variety of different learning modalities.

There are four perceptions of what constitutes effective science teaching that are held by only two participants each. Mike and Jack expressed the perception that effective science teaching should include making students “identify” their misconceptions, in Mike’s words, or “confront” their misconceptions, in Jack’s words. Sarah and Janet expressed the perception that effective science teaching requires that teachers develop a number of different techniques to monitor student understanding. The same two participants also felt that science teachers need to commit a sizeable amount of time and energy into their teaching in order to be effective. Mike felt that effective science teaching should include as many “real world” examples and experiences as possible while Diane expressed the importance of “authentic” experiences in effective science teaching.

Perceptions of Effective Student Science Learning

The participants in this study expressed a wide variety of perceptions as to what constitutes effective student science learning.

The perception of what constitutes effective student science learning expressed by the greatest number of participants was the perception that effective student science learners need to engage in a large variety of student-student interactions. All of the participants except Jack expressed this perception in one way or another. Janet felt that effective student science learners “interact willingly” while Diane and Sarah talked about effective student science learners taking advantage of peer learning and peer teaching opportunities. Mike and Diane expressed the perception that effective student science learners should be willing to defend their viewpoints during class presentations.

Four of the participants, Robert, Jack, Sarah, and Janet, expressed the perception that effective student science learners learn best when they are active and involved in the learning process. “Active involvement” was a phrase used repeatedly by Jack and Diane and Robert expressed a similar idea by saying that “students learn best by doing.”

Three of the participants, Robert, Mike, and Janet, expressed the perception that effective student science learners need to have an open mind and a willingness to change their minds. Robert phrased it as being “coachable” while Mike said that they need to demonstrate open-mindedness and a willingness to shift their “paradigm.”

Robert, Mike, and Jack all expressed the perception that effective student science learners should concentrate on developing a set of core concepts and a set of problem-solving strategies to apply in new situations. Jack used the term “deliberate strategies” while Robert emphasized the importance of concepts over memorizing a set of steps to be used to solve problems.

Robert and Sarah both expressed the perception that effective student science learners take a significant degree of responsibility for their own learning. Robert phrased it in terms of taking “ownership” of what they learn and how they learn it.

Perceptions of the Influence of the Modeling Program

The participants in this study expressed a wide variety of perceptions as to the influence of participation in the Modeling Program on their views of what constitutes effective science teaching and on their views of what constitutes effective student science learning.

Four of the participants expressed the perception that their participation in the Modeling Program had given them a new understanding of the importance of helping students develop multiple ways to solve problems, starting with and reinforcing a set of critical concepts. Diane and Janet emphasized the use of multiple representations and “ways to solve problems” while Sarah emphasized the systematic application of “critical concepts.” Jack, on the other hand, made a stronger point of passing on to his students a set of specific problem-solving “strategies.”

Three of the participants, Robert, Sarah, and Janet, strongly expressed the perception that their participation in the Modeling Program had greatly impacted their understanding of physics itself. Robert specifically emphasized his newfound understanding of Newton’s Third Law and the impact of that understanding on other areas of physics while Janet singled out electricity as an area she now understood much better. Sarah could not really single out any one area, repeating several times instead that her participation had essentially “taught her physics.”

Diane, Jack, and Janet expressed the perception that their participation in the Modeling Program had greatly influenced their understanding of how to obtain the formulas of physics from graphical analysis of laboratory data. Diane emphasized her discovery of how to use graphs as learning and teaching tools while Jack and Janet emphasized their amazement at suddenly understanding the origin of the formulas for which physics is so famous.

Three participants expressed the perception that their participation in the Modeling Program had helped them discover a new array of strategies for effective science teaching and checking on student understanding. Mike specifically referred to a set of new insights, tools, and strategies while Jack again emphasized the term "strategies." Sarah was more concerned with the new techniques she had learned for "checking" on student understanding.

Both Mike and Diane expressed the perception that their participation in the Modeling Program had provided their teaching with more of a sense of "organization and coherence," in Diane's words, and "structure," to use Mike's term.

Summary of the Cross-Case Analysis

Presented below is a table summarizing the perceptions of each participant on each of the research questions of this study:

Theme	Robert	Mike	Diane	Jack	Sarah	Janet
Q. 1 – Perceptions of Effective Science Teaching						
Inquiry-based teaching	x			x		x
Labs first	x		x		x	x
Student presentations/verbalizing			x	x	x	x
Reduced role of the teacher	x	x	x		x	x
Focus on central concepts	x	x			x	
Student-centered classroom	x	x	x	x	x	
Excitement on the part of the teacher	x				x	x

Establishment of cooperative grouping				x	x	x
Sensitivity to student learning styles	x				x	x
Devotion of time and energy					x	x
Techniques to monitor performance					x	x
Authentic, “real world” experiences		x	x			
Identification of misconceptions		x		x		
Q. 2 – Perceptions of Effective Student Science Learning						
Student-student interactions/communication	x	x	x		x	x
Active involvement	x			x	x	x
Open-mindedness/willing to change	x	x				x
Development of problem-solving strategies	x	x		x		
Responsibility for own learning	x				x	
Q. 3 – Perceptions of the Influence of the Modeling Program						
Improved understanding of physics	x				x	x
Development of formulas from graphs			x	x		x
Problem-solving/critical concepts			x	x	x	
New teaching strategies		x		x	x	
Improved organization, coherence, structure		x	x			

CHAPTER 5

DISCUSSION

In this chapter, I will discuss the findings reported in Chapter 4 and attempt to find the broader themes that underlie the participants' comments. I will draw whatever conclusions I feel are justified by the data and compare those conclusions to other literature relating to my study. I will then discuss the potential significance of the study and suggest some implications for future study.

Discussion

This is a study of six veteran physics teachers who have all shared a common professional development experience – participation in an intensive constructivist in-service program designed to increase their effectiveness in teaching high school physics. These teachers were selected for the study as a result of having been identified by the administrators of the Modeling Program as exemplary modelers. Two of them, in fact, are instructors in the Modeling Program.

The Dominant Theme

The most prevalent single perception of what constitutes effective science teaching in this study was reducing the visible role of the teacher at the front of the classroom and the most prevalent single perception of what constitutes effective student learning was engagement in a large variety of student-student interactions. Coupled with the second most prevalent perception of effective science teaching which was the creation of a more student-centered classroom, this paints an unmistakable picture of a shift in the control of the learning process from teacher to student. This strikes me as the strongest single message the participants tried to get across to me during this study.

The social constructivist approach to science teaching, as described by Driver et al. (1994) and Ernest (1995), places great stock in the “persons in conversation” metaphor. The social construction of knowledge seems to be the very purpose of the post-lab discussions and whiteboarding exercises that are such an integral part of the modeling methodology. That the participants in this study seem to have come to perceive that this shift from a teacher-centered classroom to a student-centered environment with a great deal of student-student interaction is effective science teaching attests to how far they have moved toward a social constructivist orientation.

Although the teaching styles of these participants have become distinctly social constructivist, this has not come to be as a result of a study of the literature. Their perceptions have come from careers spent practicing their craft and reflecting on what methods seem to be most effective. Their experiences and instincts led to their willingness to adopt and become exemplars of the modeling methodology. These six participants may be some of the best examples of the types of teachers von Glasersfeld (1989) was talking about when he said:

> Good teachers, as I have said before, have practised much of what is suggested here, without the benefit of an explicit theory of knowing. Their approach was intuitive and successful, and this exposition will not present anything to change their ways. But by supplying a theoretical foundation that seems compatible with what has worked in the past, constructivism may provide the thousands of less intuitive educators an accessible way to improve their methods of instruction. (p. 138)

Three of the participants did not recall even hearing the term “constructivism” and yet all of them willingly absorbed the modeling philosophy. Mike may have summed it up best when he said “it (participation in the Modeling Program) gave me some research to validate what I was doing and thinking about.”

Silences in the Data

The Modeling Program was extensively described in Chapter 1 and has three conceptual pillars giving it structure – constructivism, teaching for conceptual change, and explicit awareness of student alternative conceptions. From my own personal experience with the Modeling Program, I can assert that all three of these conceptual pillars are discussed at length during the introductory phase of modeling instruction and the issue of alternative conceptions, usually referred to as misconceptions, is discussed throughout the program. In spite of this emphasis on the theoretical foundations of modeling, I was struck by the scarcity of comments by the participants about any of the three. For instance, the only mention of the terms “constructivism” or “constructivist” was made by Robert and then only during a discussion of his own personal background and preparation for teaching. He did not use the term in any way to refer to his own teaching or what he perceived to be effective teaching. The story is exactly the same for any reference to the term “conceptual change.” Robert again was the only participant to use the term and then only in regard to his own professional preparation.

Two of the participants in this study made explicit reference to the concept of addressing student misconceptions during discussions of effective science teaching. Mike mentioned the term four times but quickly evolved into using the phrase “reshifting their paradigms,” which was the way he referred to teaching for conceptual change. Jack, on the other hand, made a very strong point of addressing student misconceptions and it was one of the dominant themes in his discussion of effective science teaching. By actual count, he used the term “misconception” twenty-three times. None of the other participants used the term at all.

There are a number of possible explanations for why references to the theoretical foundations of modeling have apparently had so little impact on the participants’ perceptions of what constitutes effective science teaching. The first explanation has to do with the nature of the themes on which the participants focused. The dominant themes expressed by the participants were decreasing the visible role of the teacher, making the instructional process more student-centered, using inquiry-based teaching techniques including beginning each unit with a laboratory experiment, and finding ways to have students verbalize their understandings. It strikes me that all of these themes have one thing in common: they all deal with issues that can be loosely categorized as management issues. In some cases, making a classroom less teacher-centered and more student-centered comes down to issues as simple as moving the teacher desk away from the front of the room, as Robert, Sarah and Diane did, or eliminating the front demonstration bench altogether, as Robert also did. In other cases, it involves the increased use of whiteboarding, a technique they *all* adopted, or an increase in Socratic questioning. Choosing to begin each unit with a lab experiment, another technique they all adopted, is certainly an essential element in inquiry-based teaching, a term used by Diane, Jack, and Janet, but can be considered just another science teaching technique to those teachers not as familiar with inquiry teaching. Having students verbalize their understandings through group presentations and whiteboarding is another technique that is linked to making the classroom more student-centered and less teacher-centered.

What all these themes have in common is that they are all relatively easily implemented classroom management techniques, all under the control of the teacher and all of which can be observed. The issues of constructivism, conceptual change, and addressing student misconceptions, in contrast, are much broader issues relating to what is happening inside each student's head and, as such, are much less observable or controllable. A teacher can never know the exact nature of the knowledge a student has constructed or whether they have truly identified and confronted their "misconceptions" or whether there has been any significant change in a student's conceptions. Teaching for these types of changes or confrontations are overarching goals of effective science teaching but are difficult to plan for or witness. All the teacher can do is create the situations, such as labs and whiteboard discussions, that can lead to the possible achievement of these goals and then supervise the experience using techniques such as Socratic questioning to try and keep the learning process in motion. When asked to identify what constitutes effective teaching, teachers seem to focus on these situations and techniques and seem to skip over the broader goals as if they are understood. They tend to want to discuss the management issues they can control.

Another possible explanation for why references to the theoretical foundations of modeling have apparently had so little impact on the participants' perceptions of what constitutes effective science teaching is that many of the participants may not have completely "bought into" these theoretical foundations. Although Robert, the constructivist, certainly made a strong point of what he perceived as the tentative nature of his understanding and the resulting intellectual "humility" he felt and tried to instill in his students, he also enjoyed standing center-stage and attempted to answer a large variety of student science questions, even those outside his area of expertise. Diane, Jack, and Mike made repeated references throughout their interviews to solving problems the “right” way, finding the “right” answer, keeping discussions moving in the “right” direction, and having students confront their misconceptions in order to discover the “right” concepts. Although it is possible that some or even many of these uses of the word “right” were used as casual substitutes for methods or concepts that could be referred to as more “generally accepted,” I think the frequent use of the term betrays a lack of a thorough acceptance of the foundation of the modeling philosophy, at least not as outlined by the creators of the Modeling Program. It is possible that we have a constructivist program being taught and promoted by instructors that may not have thoroughly adopted constructivism. Even the use of the term “misconceptions” by the creators of the program and two of the participants hints at their belief in certain conceptions as correct while others are not. This stands in contrast to more recent views (Champagne & Klopfer, 1983; Clough & Driver, 1986; Klammer, 1988) of differing conceptions as being “alternative” or “naïve” conceptions.

A third possible explanation for the lack of references to constructivism, conceptual change, and alternative conceptions might be that it is merely an issue of terminology. These terms should be very familiar to students in science education programs or teachers in graduate programs but are not part of the everyday vocabulary of practicing teachers not currently or recently in such programs. My own familiarity and comfort level with these terms came as a result of my doctoral study, even though I am currently in my twenty-eighth year of teaching. It may well be that these teachers are expressing the same ideas in more commonplace language and in a more long-winded fashion that involves talking around the use of these terms. Even if they are, in fact, familiar with these terms, frequent use is required to make them part of everyday vocabulary and they would not reasonably be expected to have sufficient opportunity for frequent use.

I find it somewhat surprising that the issue of the use of technology did not arise in the comments of any of the participants. Actually, Mike did mention technology but only to point out that he was already using it before modeling. The use of computers was strongly promoted by the creators of the Modeling Program and was considered a key component of the instructional methodology. They were to be used as both data-gathering and data-processing tools. Interfacing software was used to connect photogates, sonic rangers, light sensors, sound sensors, radiation counters, and force probes to computers for direct data collection and then computer graphing software was to be used to find the formulas for the relationships between variables. Printouts of the graphs were to be pasted directly into student lab reports. Those of us in the original pilot group had to obtain funding from our school districts to match money provided by the National Science Foundation for the purchase of Apple IIGS computers, printers, software, and interfacing accessories.

The reason for the emphasis on computer data-collection and computer graphing was tied directly to the inquiry-based “lab first” philosophy of modeling. If each conceptual unit was to begin with and build on the discovery of a mathematical relationship from one of the “paradigm” lab experiments, the process had to be both quick and convincingly accurate. The use of photogates as timers in the kinematics and mechanics labs is far more precise than the use of hand-held stopwatches and the use of sonic rangers is virtually the only way to simultaneously collect data on displacement, velocity, and acceleration. Coupled with computer-interfaced force probes, relationships such as Newton's Second Law literally leap off the computer screen. By making these relationships quickly available from student-collected lab data, adequate time would remain to properly "deploy" the concepts in other situations and allow students to interact in whiteboarding sessions. The fact that the formulas used during the deployment stage were formulas obtained directly from experiment rather than taught from a textbook was intended by the creators of the program to increase student buy-in to their legitimacy.

For most of us in the pilot group, the Modeling Program was our first exposure to the use of computers as either data-collection or data-processing devices. I can say from my own point of view that the use of computers in the lab is now an absolutely essential component of my teaching. I have relocated twice since my participation in the Modeling Program and I have convinced the science departments in both schools to purchase the necessary computers, software, and peripherals to implement this methodology. I have also convinced all of the physics teachers and many of the chemistry teachers, as well as a few stray biology teachers, to use the equipment in a modeling-like fashion.

Given the fact that the six participants in this study have all been identified by the administrators of the program as exemplary modelers and two of them are, in fact, modeling instructors, I was surprised that none of them even so much as mentioned computers or technology when discussing their perceptions of effective science teaching. One possible explanation might be that the use of computers and technology in the laboratory has finally become so widespread and universally accepted that it is no longer an issue, no longer something that even grabs our attention. In effect, it has become part of the wallpaper. In just slightly over ten years, it seems as if computers in science labs have gone from being budget-busting luxuries that had to be fought and sacrificed for to being so omnipresent that we take them for granted and no longer even take their notice. I would like to think that that is the case.

A Somewhat Discrepant Case

During the development of the cross-case analysis, I gradually began to recognize that one participant, Mike, seemed to hold views that frequently stood in significant contrast to the others. He was, for instance, the only participant to discuss hypothesis formation and he made by far the strongest point of the importance of using “real-world” examples and experiences. He was the only participant who did not make a point of listing inquiry teaching in his discussion of effective science teaching and one of only two who didn’t mention cooperative grouping. He also specifically downplayed the impact of modeling on his teaching and on his understanding of physics in sharp contrast with all of the others. I became curious as to what it was about Mike that might be responsible for these differences.

Mike’s professional background is the first factor that struck me as differentiating him from the rest of the participants. Although Janet had had a career as a medical technologist before teaching, all of the other participants except Mike could be considered as having always been career teachers. Robert spent two years in the Peace Corps, but he spent it teaching. Mike, on the other hand, spent eight years in the Navy and then four years as a computer consultant before he began teaching. His years in the Navy seemed to give him a tremendous variety of experiences, judging by the length of time he spent talking about them during the interviews. All of the “real-life” experiences he talked about using with his students seemed to come from those eight years. Looking back at the interviews, I am somewhat surprised that he had nothing to say about his years as a computer consultant.

Mike’s outside experience seems to have given him somewhat of a sense of superiority and seems to have fed into this sense of being different from other teachers. While describing his Navy experience, he commented that “it gives them [his students] an extra flavor they normally wouldn’t get if I just was only a teacher, never had any real world experience.” I remember instinctively bristling at the phrase “only a teacher” because of the demeaning way it is frequently used by non-teachers, but that momentary feeling passed when I thought harder about the point Mike was trying to make. I am certain it was not intended as demeaning, especially at me, because I know that he was aware of my own experiences as an engineer in private industry. It did, however, hint at how he views himself differently from teachers who have had no outside career experiences.

Throughout both interviews, Mike made a number of comments, all individually quite innocent and defensible, which, taken together, paint a picture of a teacher who considers himself as thinking quite differently from his colleagues on a number of issues. He expressed his disagreement with what he felt was a common belief that it was not important for students to memorize facts: “I kind of disagree with some of the things I’ve heard before where you don’t have to know masses, you don’t have to know numbers, ‘g’, you don’t need to know ‘g’, you just have to know how to use it.” Continuing in a similar vein, he said: “ I hear a lot of teachers today say science shouldn’t include rote.

Well, I'm sorry but there is a lot of rote stuff, I mean you gotta know . . ." After commenting on how he had enjoyed hearing the way other teachers thought about topics like energy, he seemed compelled to add: "Not that I necessarily agree with everything I hear." After describing how he expands classroom discussions to include social or engineering or environmental concerns, he added: "You don't see a lot of that in science classes." On the topic of textbooks, he said: "There's a lot of teachers at a lot of universities and colleges saying you shouldn't use textbooks and I say 'Yeah, but there's a lot of stuff you learn from reading . . .'"

From these comments, it seems to me that Mike has come to feel very different and almost isolated from his colleagues. This isolation has come to manifest itself in an attitude of superiority and self-confidence which he seems to wear proudly. Very possibly this is due to his perception of his strong and broad-based educational background and his extensive "outside" experiences prior to becoming a teacher. It seems entirely consistent to me that he would use every opportunity to downplay the effects of the Modeling Program by making comments such as: "I think a lot of it had already come to me before I was gone to the modeling project," and "I think the modeling enhanced what I was already doing." When he commented "Before I got to modeling, I was already teaching physics on the calculus-based level," my first thought was "So was I, but modeling is about methodology, not content."

New Understandings of Physics Itself

Another issue that caught my attention was the number of participants who perceived that the modeling program had taught them significant quantities of physics. I had expected that some of the participants might mention that they had somewhat strengthened their understanding of certain aspects of physics, as I had when I participated in the program, but I was startled by the intensity of their comments. I was even more surprised by which of the participants were the ones that made the strongest point of their newfound understanding.

Robert, Sarah, and Janet strongly expressed the perception that their participation in the Modeling Program had greatly impacted their understanding of physics itself. With an undergraduate degree in microbiology and years of experience teaching medical technology, I find it quite reasonable that Janet would express this perception. Having been impressed into service by the retirement of a colleague, she admitted to feeling uncomfortable at first teaching physics. Her strength was clearly in the biological sciences and she did not feel that she had a firm grasp on the origin or uses of the physics formulas that she felt compelled to teach. The Modeling Program helped her tie together algebra and calculus skills, graphing skills, and the role of experimentation in the development of relationships in physics.

Sarah, on the other hand, had a master’s degree in Physical Science and was certified to teach any of the three high school sciences before she ever thought of participating in the Modeling Program. Like Janet, she was impressed into service teaching physics by the retirement of a colleague and she had to prepare for her new teaching assignment over one summer. Like Janet, she found her first year of physics teaching to be less than satisfying and knew that there had to be a better way. What she perceived as her success in chemistry teaching made her that much more unhappy with her uncharacteristic reliance on textbooks. In spite of her stronger educational background in physics, she found modeling’s ability to connect experimentation and graphical analysis with physical concepts to be extremely gratifying.

The participant that truly astounded me, however, was Robert. Robert has by far the strongest formal background in physics of all the participants with an undergraduate major in physics from a prestigious technical university. I fully expected that he might find some of the modeling methodology enlightening but that the level of physics discussed would pale in comparison to his level of understanding and intellectual sophistication. I was totally taken by surprise by the excitement he exuded as he talked about his newfound understanding of Newton’s Third Law and how it related to force diagram analysis and problem-solving. It was only through modeling that he “finally understood” and “really grasped completely” this fundamental concept of classical mechanics. He confessed that it had been a humbling experience. He said “I'm not saying I’m a genius but I don't think I'm dumb either. Why should it take me that long to learn that stuff?”

Something in the modeling approach had altered his understanding. He had certainly not learned Newton’s Third Law for the first time. He had instead re-learned it in an entirely new context. He was now learning its relevance from an instructional perspective rather than the academic, undergraduate viewpoint. It is quite possible that he was restructuring his understanding as pedagogical content knowledge (Shulman, 1987), something that the other participants may have done earlier in their careers, prior to their modeling experience. As one of the two least experienced participants, this restructuring might have been a relatively new and dramatic experience for him whereas it would not have the same perceived impact on the more veteran teachers. More will be said about the possible role of experience in the final section of this chapter.

Comparison to Related Literature

The results of this study meaningfully compare to several of the sources cited in Chapter 2. Specifically, sixteen of these studies are worthy of comment in relation to the results of my study.

Hand & Treagust (1994) investigated the changes in junior secondary science teacher thinking as a result of participation in an extended constructivist in-service program and reported changes which included a change in control of the teaching process from teacher to student, increased valuing of student knowledge, and increased involvement of students in the learning process. Their findings are in very close agreement with the dominant theme I reported earlier in this chapter. Harrison & Treagust's (2000) recommendation of the use of multiple models in science lessons and the promotion of the social negotiation of their meanings is certainly supported by the comments of virtually all of the participants in my study.

Oakes (1997) conducted a study which defended the use of graphing as a teaching and conceptualizing tool and found its primary strength to be the ability to make the discovery process quantitative. The results of my study seem to indicate that several of my participants explicitly agree with this assessment and the remainder appear to implicitly agree as well. All of them are using computer graphing as the primary tool for developing the mathematical models (formulas) of physics.

Kahle & Boone's (2000) survey of Ohio science teachers and principals found that the two most important factors in improving science teacher professional development are availability of support materials and the duration of the professional development experience itself. Although my study did not deal in any way with the issue of the duration of the in-service experience, several of my participants did make mention of the completeness of the materials (tests, quizzes, worksheets, recommended labs) they received as a result of participating in the Modeling Program and Diane and Jack explicitly stated how lost they felt in subject areas where they did not have modeling materials available to them.

As previously mentioned, Lederman & Zeidler (1987) reported that programs designed to improve science teachers' conceptions of the nature of science did not appear to influence their teaching behaviors. On the other hand, Brickhouse (1989) conducted a study of the philosophies of science held by three science teachers and found that their views of science were indeed consistent with their classroom instruction and that their philosophies greatly influenced their use of demonstrations, laboratory time, vocabulary, and their choice of instructional goals. Although the issue of the relationship between conceptions and behaviors was not part of my study, I feel that the conceptions of my participants, as evidenced by their interview comments, and their behaviors, as evidenced by my observations of their teaching, would tend to strongly support Brickhouse's view.

The results of my study are in at least casual agreement with several previously cited studies (Lawrenz, 1986; Crawley & Arditzoglou, 1988; Berg & Brouwer, 1991; Heller & Finley, 1992; Trumper, 1998) that suggested the presence and persistence of certain alternative conceptions in experienced science teachers. Robert and Jack's comments on Newton's Third Law and Mike and Janet's comments on electricity seem to modestly support those studies.

Although the purpose of my study was to investigate the conceptions of physics teachers, their comments on their perceptions of the understandings of their students tended to support the findings of two studies (Linn & Songer, 1991; Windschitl & Andre, 1998) of the effects of constructivist teaching techniques on student science learning.

Three studies previously cited (Etchberger & Shaw, 1992; Condon et al., 1993; Jones et al., 1998) studied the effects of constructivist techniques in teacher training and reported changes in the perceptions of student learning, a distinct role redefinition, and significant increases in content and pedagogical knowledge. The comments of the six participants of my study over twelve interviews strongly support all of the effects reported in those studies.

Implications of the Study

By no stretch of the imagination can this group of six participants be thought of as typical high school physics teachers. They were selected for this study precisely because they were judged as exemplary modelers by the creators and administrators of the Modeling Program. Two of them, in fact, have become instructors in the program. The Modeling Program itself has demonstrated its effectiveness in physics teaching through a great deal of rigorous pre- and post-testing (Halloun & Hestenes, 1987; Hestenes, Wells & Swackhamer, 1992). I feel that these six instructors represent some of the very best and most effective physics instruction I have ever witnessed.

The techniques used by these instructors are very constructivist, involving multiple representations (models) of physical phenomena, multiple learning modalities, and requiring the expression of student understanding through graphing, graph interpretation, mathematical modeling, physical demonstration, and verbal description.

These techniques can further be described as social constructivist, involving extensive small group work, group lab reports, and extensive use of whiteboarding. The whiteboarding process encourages student discussion, interaction, critiquing of each other's work, and occasionally spirited argument. The key concepts of the course emerge from these discussions and post-lab analysis and are verbalized and agreed upon by the students themselves.

To what extent this constructivist turn in their teaching philosophy and pedagogy was influenced by their participation in the Modeling Program is very hard to determine. All but one of them, Robert, totally shied away from using the term "constructivism" in spite of the fact that it was used extensively during the modeling instruction in which they all participated. Mike, Jack, and Sarah all claimed to have been using inquiry-based, small-group work with emphasis on student verbalization of understanding before ever being involved in the Modeling Program. These same three participants all were instructors of biology or chemistry and only sought out the Modeling Program after moving, or being moved, into physics instruction.

I could not help but notice that the three participants who showed the strongest constructivist orientation before their exposure to modeling were also the three most experienced high school instructors of the six. I also find it interesting that Robert, the least experienced instructor of the group, was the one most attuned to the constructivist vocabulary and most verbal about its philosophy. He and Diane, the next least experienced instructor, were also the two participants who lamented the loss of "control," in Diane's case, or the loss of your "didactic self," in Robert's case, as they adopted more constructivist teaching styles.

All of these observations lead me to a curious thought. At the risk of sounding somewhat deterministic, I have begun to wonder whether a social constructivist approach to science instruction may be almost the inevitable destination for any instructor who is reflective about his or her craft and maintains a student-centered orientation. As science teachers gain more and more experience and search harder and longer for ways to be effective, perhaps becoming social constructivists is almost unavoidable. As the illusion of control, the Holy Grail of novice teachers, fades and the fixation on perfecting teacher presentations gives way to a focus on effective student learning, perhaps social constructivism provides not only the best but in fact the only currently available techniques for achieving that learning.

The role of experience in this discussion seems very striking to me. In light of the above speculation, if experience seems to lead to a drift toward social constructivism then it seems reasonable to me that less experienced teachers must approach it from a more studied and intellectual orientation. In other words, less experienced teachers might have to be formally taught the same social constructivist precepts that more experienced teachers find on their own without benefit of direct instruction. Once again, von Glasersfeld's (1989) words ring in my ears: "Good teachers, as I have said before, have practised much of what is suggested here, without the benefit of an explicit theory of knowing (p. 138)." To von Glasersfeld's words, I might have the hubris to insert "and experienced" before the word "teachers."

This might make Robert's adoption of the constructivist philosophy and vocabulary seem more reasonable compared to the less overtly constructivist descriptions used by the three most experienced participants to portray their teaching philosophies and methodologies both before and after participating in the Modeling Workshop. It also might make the lamenting of the two least experienced participants seem more reasonable. Perhaps they are now experiencing what their more veteran colleagues experienced years ago and have long since forgotten as social constructivism has become so thoroughly assimilated into their teaching as to have become virtually transparent.

One possible implication of this speculation might be that designers of professional staff development for physics teachers should pay more attention to the level of experience of participants and gear their approach accordingly. It might be wise to include more emphasis on the constructivist theory underlying a particular program if the participants are relatively new to teaching while emphasizing more of the functional aspects when dealing with experienced veterans. This might require establishing separate programs for the two groups, sort of a Modeling I and Modeling II approach, but not necessarily making one a prerequisite for the other. Just as we have different expectations for undergraduates and graduate students, so we might have different expectations for science teachers in professional development courses with widely divergent levels of experience.

Another possible implication is that programs designed for relatively new teachers who are gaining their first exposure to this “explicit theory of knowing (von Glasersfeld, 1989, p. 138)” might need to include more extensive follow-up and monitoring to minimize recidivism. There might also need to be a formal component of such programs that involves observing veteran teachers who have already fully assimilated social constructivism so that the less experienced teachers can see the learned theory and the observed practice supporting each other.

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APPENDICES

APPENDIX A

INTERVIEW PROTOCOL

1. Tell me about your high school physics experience.

2. Describe for me a typical class or unit in your physics teaching.

3. Describe to me your perception of effective science teaching.

4. Describe to me your perception of effective student learning.

5. What motivated you to participate in the Modeling Program?

6. How has your participation in the Modeling Program influenced your views on effective science teaching?

7. How has your participation in the Modeling Program influenced your views on effective student learning?

8. How has your participation in the Modeling Program influenced your understanding of physics?

APPENDIX B

PARTICIPANT CONSENT FORM

Walter R. Snow
Berkmar High School
405 Pleasant Hill Road
Lilburn, Georgia 30047

(Date)

Consent Form

I, (____________), agree to participate in the research titled "Case Study of Teachers Who Participated in an Intensive Conceptual Change Professional Development Experience", which is being conducted by Walter R. Snow, Science Education Department, University of Georgia, 770-921-3636, under the direction of Dr. David Jackson, Science Education Department, 706-542-4600. I understand that this participation is entirely voluntary; I can withdraw my consent at any time without penalty and have the results of the participation, to the extent that it can be identified as mine, returned to me, removed from the research records, or destroyed.

The purpose of this study is to examine the characteristics and attitudes of physics teachers who responded enthusiastically to an intensive, summer-long conceptual-change professional development experience and have integrated it into their teaching. The researcher hopes to be able to identify some factors that might make it possible to predict which teachers are more likely to benefit from this type of experience and possibly develop some criteria for pre-screening teachers so that these programs can have the maximum possible impact on students.

I understand that the only benefit to me will be an opportunity to read the research findings, reflect critically upon my own teaching, and build a relationship with a colleague. Hopefully, this study and the dissertation to follow will help planners of professional development programs to better understand which teachers are more likely to benefit from intensive conceptual-change professional development opportunities and improve their selection procedures, thereby maximizing the positive impact on student learning. I understand that I have been offered no specific incentive or compensation other than the fact that I will be allowed to read the results of the research when completed.

I have been told that this will be a multiple case study of physics teacher who claim to be adherents to an innovative methodology of physics teaching learned during an intensive, summer-long professional development experience. I will be visited by the researcher and observed teaching classes for at least one day. I will be audiotaped and extensive notes on my teaching style and procedures will be taken by the researcher. I will participate in a semi-structured interview which will be audiotaped and transcribed. Finally, I will allow photographs of my classroom to be taken (without students) and will supply the researcher with photocopies of some of my recent lesson plans, tests, quizzes, or worksheets. I will also supply anonymous photocopies of some recent student lab reports. Finally, I will participate in an ongoing e-mail conversation to clarify any questions that may arise during data analysis.

I have been told that there are no forseeable risks involved in participating in this study. I have also been told that there is no deception involved in this study. I have further been told the results of this participation will be confidential, and will not be released in any individually identifiable form without my prior consent unless otherwise required by law. The researcher will not discuss my participation in this study with anyone else. He will not attach my name to any of the materials such as notes, audiotapes, or any of the archival materials previously listed. He will use a pseudonym during the entire data analysis process. He will destroy (by recording over) the audiotapes after his dissertation is accepted and approved. He will offer me the photographs he took of my classroom and will offer to destroy them if I do not want them.

The researcher will answer any further questions about the research, now or during the course of the project, and can be reached by telephone at 770-921-3636.

Please sign both copies of this form. Keep one and return the other to the investigator.

____

Signature of Researcher Date

____

Signature of Participant Date

Research at the University of Georgia that involves human participants is overseen by the Institutional Review Board. Questions or problems regarding your rights as a participant should be addressed to Julia D. Alexander, M.A., Institutional Review Board, Office of the Vice President for Research, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-6514; E-Mail Address: IRB@uga.edu.