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AN INTERPRETIVE STUDY OF TWO EXPERIENCED HIGH SCHOOL PHYSICS TEACHERS' KNOWLEDGE, CONCEPTIONS, AND CLASSROOM TREATMENT OF THE SUBJECT-MATTER

Volume I

By

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ABSTRACT

AN INTERPRETIVE STUDY OF TWO EXPERIENCED HIGH SCHOOL PHYSICS TEACHERS' KNOWLEDGE, CONCEPTIONS, AND CLASSROOM TREATMENT OF THE SUBJECT-MATTER

By

Ribhi Abu-Sneineh

The study described, analyzed, and interpreted two high school physics teachers' knowledge, conceptions, and treatment of the subject-matter they taught.

During a four-month long study, two teachers' physics and physical science classes were observed for three to four hours a day, three days a week. Each teacher was formally interviewed four times, each with a duration of fifty to ninety minutes. Data sources included transcripts of all interviews and recordings of portions of many lessons, fieldnotes, worksheets, and a variety of other handouts. Analyses of data were done in the tradition of interpretive research.

It was found that the teachers' knowledge and conceptions of physics could be conceptualized and described along four major knowledge clusters: vocabulary of physics, higher-order relations, mathematics, and philosophy and history of physics. Analyses of the fourth cluster showed that each teacher held a mixture of incongruent views, both traditional and relativistic, about the nature of physics knowledge. Interpretation of these views called attention to two factors that could have strongly influenced them:

the textbook used, and the teachers' formal education.

The teachers' treatment of the subject-matter was investigated along five major areas: planning, instruction, teachers' decisions, and teachers' characterizations of aspects of that treatment.

Analyses of data in these areas showed how instruction was driven mainly by planning, how abstract knowledge was avoided, and how teachers concretized and destructured the taught physics knowledge in their attempts to achieve their goals if wide content coverage and high enrollment. In so doing, both teachers seemed to have compromised their professional ideals to cope with workplace realities.

To give a comprehensive picture of the setting, other related issues were briefly investigated including the teachers' conceptions of their roles, of their students, and of learning. Teachers' experiential history was also narrated to trace the origins of some of their views.

Implications of this research for the discussion on the nature of teacher knowledge, for teacher education, for curriculum design, and for teacher epistemology were pointed out.

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1988

To: the memory of my father, Abdel-Muhdi;
my mother, Rashideh; my wife, Basimah;
and my children, Basel, Haifa, Abeer,
Adel, Ola, and Rana.

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CHAPTER I

TEACHER KNOWLEDGE AND CONCEPTION OF PHYSICS AND PHYSICS TEACHING

What the Study is About

This is an exploratory study which has two foci. First, it attempts to describe two high school physics teachers' knowledge and conceptions of the subject matter they teach. Second, it describes the teachers' classroom treatment of the subject matter. An attempt is also made to discuss these two research topics both in relation to each other and in relation to the instructional environment and the milieu at large within which the two teachers have been working.

These research issues have evolved in the form of guiding research questions out of some initial inquiries about the subject matter. The process of evolution together with a personal connection with both the research topic and site will be discussed in the rest of this chapter.

Background Knowledge and Information

During the scholastic years 1984 through 1986, I worked for the IRT Secondary School Science Project (SSSP) coordinated by Dr. Gallagher. In my work for the project I used to visit one high school once every week. During each visit I spent about four hours observing various science lessons, chemistry, biology, and physics, or interviewing the science teachers at the school.

Of the different science lessons I observed, the biology one was where I had least interaction with both the teacher and the class. The major reason, on my part, was the fact that my knowledge and experience in the subject matter of biology and its teaching were limited. Had it not been for some of the biology courses I had taken over twenty years ago in a two-year agricultural college, I would have been virtually ignorant of even the basic terms in this vital domain of knowledge, for my latter learning as a physics student was very much focused on physics, mathematics, and a few physical chemistry courses. I would say this is characteristic of many physics graduates.

Why did my modest knowledge of the subject matter of biology limit my interaction with the biology classroom setting? It was so, partly because much of what was going on in that classroom, as well as in the other science classrooms I observed, was related to the subject matter. This is not to say that other classroom matters were not important; it simply meant that the biology teacher I observed, just like his other colleagues at the school, conceived of himself as a 'provider' of a certain specialized body of knowledge, or a 'resource guide' for students trying to learn that body of knowledge (Abu Isneineh, 1986). For that reason, at least partly I would suppose, I was asked, early in my observations, by most of the science teachers I talked to about what I had previously taught. This, to some extent, influenced the way each

teacher conceived of my presence in his classroom, and, consequently, had its impact on the form and content of my interactions with the setting.

While all the science teachers I observed were open to any discussions, not all such discussions could be sustained with interest and seeable relevancy. Teaching issues, for example, appeared more relevant to teachers than learning matters. I once asked one of those teachers about what he thought would happen to students who did not understand the subject matter he was teaching. With the sense that learning was more of a student's responsibility than of a teacher's, I received the following response: "When they grow up they will pay the price!"

When it comes to science teaching at the secondary level, knowledge, particularly its forms and structures that deal with the subject matter becomes very central in the teachers' life. Discussions over topic-related scientific knowledge and the way such knowledge could be represented or modulated for teaching purposes induced much teacher input in such discussions. A teaching 'trick', in itself, appeared of greater relevance and significance to teachers' work than the implications of a certain learning theory or conception.

The centrality of the subject matter knowledge in the classroom events and happenings, and my very limited knowledge of biology, restricted, to some extent, my interactions with the biology setting. It may be argued here

that for a phenomenologically oriented study like this one, unfamiliarity with the setting should be helpful or even required rather than restrictive. It is even suggested that the researcher should suspend his prior assumptions about things in the setting in order to achieve the first step necessary, called 'epoche' (Ihde, 1979). However, while this may be advocated as a theoretical principle in qualitative research, it was not possible for me to literally abide by that in this research for two main reasons. The first was related to the fact that all teachers had already known that I taught physics for several years. This, not only put some restrictions on my questions, but equally well, I would assume, influenced the teachers' responses to my questions or probing. The second reason was the fact that much of the knowledge articulated and discussed in the science classrooms was not created or constructed by the classroom participants. Instead, those participants, teachers and students, were dealing with knowledge structures that had originally been created or constructed by a different group of people, namely the scientific community. Of course, I could have suspended my previous pertinent knowledge and beliefs about scientific knowledge. Under such a hypothetical condition, the relevant question would be: how much could I have gone into making sense of the teachers' knowledge and actions? My answer at this point is that: very little, if anything at all. These issues will be discussed again in Chapter III.

In contrast, my interactions with the physics teachers and classes went on without any serious restrictions. My knowledge and experience of physics and physics teaching were indeed the light by which I navigated through the labyrinth of my research site. Being a foreign student, the possibility of misunderstanding people, or being myself misunderstood by them, loomed over much of my social interactions. But not so much with the physics teachers I observed, especially when we talked physics. And since the subject matter was central in their classroom activities, initiating a purposeful discussion through the subject matter was both accessible and informative.

The common body of knowledge I shared with the two physics teachers facilitated the initiation of several discussions and in various directions of the classroom activities. That did not mean full agreements among our conceptions of physics and physics teaching. Though agreements or disagreements of our conceptions were not principally important for the study, non-convergence of conceptions, even on some conventional physics notions, could be detected in the study. Indeed, that was my starting point in the journey to study the two physics teachers' knowledge and conceptions of physics and its teaching.

The suggestion that each teacher held a set of understandings and conceptions of the subject matter that shaped his teaching practices, was the central idea to be researched. Initially, I termed this set of understandings

and conceptions after a number of researchers' terminology: personal practical knowledge (Abu Isneineh, 1986). The terminology was meant to reflect two essential attributes of such knowledge: its being person-centered, which implied that everything that might go to make up a particular teacher might have an input in that knowledge; and its being practical, which implied that the generation as well as the application of that knowledge were practice-oriented. At the time I wrote my research proposal, two examples from my work for the IRT project were given to elucidate some aspects of this knowledge.

The first example was my observation of a lab experiment in a physics class on the concept of acceleration. The experiment, very well known to high school physics teachers, required that a small cart would be pulled by an unbalanced force along a short path. A strip of paper tape was attached to the rear of this cart and passed through a recording timer which, when vibrated, ticked periodically leaving marked dots on the paper tape. The period of vibration of the recording timer was assumed constant over time. The main idea of the experiment was to calculate the acceleration of the cart from the dots left on the tape (figure 1), after the cart was pulled by a force.

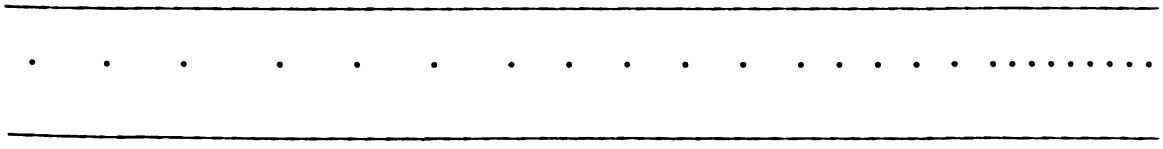


Figure 1. Dotted Tape

In calculating the acceleration of the cart students used the mathematical form: $a = (V_2 - V_1)/\Delta t$, or simply, $a = \frac{\Delta V}{\Delta t}$, where V referred to the change in velocity between different dots, arbitrarily chosen, " " stood for the corresponding time interval, and "a" meant to represent the acceleration to be calculated. In applying this formula to any pairs of dots on the paper tape, students would need the period of vibration of the ticker-timer and measurements of the spacings between two pairs of dots. Spacings between dots could be measured directly by a ruler and that was what the students did. The period of vibration, however, could be measured by an additional very simple exercise in which students would measure the time needed for the timer to make an arbitrary number of dots and then simply divide the time measured over the number of spacings made. The teacher could also have chosen to explain, roughly, how the timer vibrated as related to the main power source and, then, estimate or agree upon that period. Instead, however, the teacher chose the numerical value of the period without any references to any measurement or explanation. He simply explained that the time elapsed between any two consecutive dots was 0.02 second.[1]

After the class had ended their work, we started to talk about the experiment. I asked him why he had chosen

---

[1] In my observation for this research work both teachers used the value 0.01 second.

to give the students the value of 0.02 without referring to its origin, meaning, or how they would calculate it from the data they already had. In his response, the teacher pointed out that if he had attempted to do that students would have got confused. He explained that his main aim had been to teach students how to calculate acceleration using that mathematical formula.

The second example was related to the other physics teacher at the school. I had observed him teaching a class of 12th grade students, a physics course labeled by the school catalogue as "advanced physics". The teacher was using the well known physics textbook that appeared in the Sixties and had been developed by the Physical Science Study Committee (PSSC). In my attempt to understand his teaching practices within his conceptions of physics and physics teaching, I asked him about what kind of physics teacher he would see himself as. His response came as follows:

> "Humanist! On the side of the student! Both of us are going to explore physics, rather than challenging students to bring themselves to me. My course is for a broad base. We look at things that college don't look at, like the history of an idea. A student taking my course and going to college will have the best of two worlds: breadth, and depth." [Fieldnotes: 2/6/1986]

The PSSC course had been conceived of as a serious and challenging course for both the teacher and the student. The term "humanist" had not been within the vocabulary of the course. The following paragraph from the textbook's preface would, when translated into teaching acts, challenge

both the teacher's teaching skills, and the student's imagination:

> "Throughout, the student is led to realize that physics is a single subject of study. In particular, time, space, and matter cannot be separated. Furthermore, he sees that physics is a developing subject, and that this development is the imaginative work of men and women like him." (p. vi)

So, while the teacher conceived of his role as a 'humanist', 'rather than a physicist', the textbook authors expected that students would be led, presumably by the teacher, to the realization of inseparability of time, space, and matter. In their course of achieving such a realization students were also expected to be imaginative in their work, just like young scientists.

What I saw common about the two examples was that both teachers were autonomous enough to develop their own ways of dealing with their classroom events. Those ways or views would be put into practice even when they did not agree with the curriculum developers' suggestions and recommendations. Furthermore, it seemed as if the teacher's personal beliefs, knowledge, and conceptions were the final determinants of what would be going on in classroom.

What I originally found worth more investigation was twofold. First, the teachers' knowledge and conceptions of the subject matter they taught; and second, their ways of treating the subject of physics in the classroom. I assumed at the time that elucidating these two fundamental issues

would be of significance to curriculum developers who would be better informed on how to communicate with teachers who act on the subject matter while teaching it. Furthermore, focusing on these issues would shed more light on the possible interconnections between them. That, in itself, would be of some significance for it would elucidate the interplay between theory, teachers' knowledge and conceptions of the subject matter, and practice, the teachers' treatment of it.

Dilemmas and Decisions

The guiding research questions for this work had been formulated in terms of one physics teacher's personal practical knowledge of the subject matter he taught. The idea had been to observe the teacher's various lessons, and interview him over a long period of time, one school semester, in order to explore his knowledge and conceptual structures of the subject matter, and the way he dealt with that in the classroom.

As the school year started some changes in both physics teachers' teaching schedules were made. None of them was to teach chemistry as had been the case before. That left them with only three courses to teach: a physical science course, a physics course, and a second "advanced" physics course. Their work schedules overlapped over the physics course which they taught as a team. In practice this meant that both teachers used the same lesson planning and

evaluation for their separate classes. It was consequently impractical on my part to emphasize one teacher and simply ignore the other. I, therefore, had to observe this overlap and thus include both teachers in the study.

As I progressed in my observations, I started to realize the limitations and uncertainties implied in the two adjectives, personal, and practical. Early in the study, I detected some tension in the way one of the two teachers was thinking about their methods of treating the subject matter. As will be explained in later chapters this teacher even 'agonized' on the way some concepts were dealt with. Nevertheless, he persisted in doing just what he 'agonized' over. The other teacher did not go so far in his feelings about how they treated the subject matter. On several occasions, however, he expressed his uncertainties about that. At one point he likened their methods to a 'gamble'. At another point he agreed that by doing what he did he "betrayed" the physics knowledge he was taught at college. But did the teachers know other alternatives to physics teaching? The answer, as will be seen, is yes. They even tried those alternatives; but then settled on what they described as a 'gamble', or what they 'agonized' over. At one point in their history they decided to change, and drastically, from inquiry, problem solving, and discovery techniques, as suggested by the PSSC curriculum to ways that will be explored fully in this work. Let me introduce a quote from an interview of the teacher who seemed to have

engineered that change many years ago.

> "I didn't know then, as I don't know now, whether if I had stayed with that mode and just smoothed it up, and taught better these ideas, and taught more smoothly, developed ideas more carefully, that I could have brought the students along with me, if I stuck with that. But in frustration and desperation I was looking for something, some other direction, some other formula, I guess." [4th Interview: 5/13/87]

First, let us look at the way he described another teaching alternative he did not try: "just smoothed it up, and taught better these ideas, and taught more smoothly, developed ideas more carefully." Would not all these clauses uttered by a very experienced teacher point to what could have been a potentially viable "mode" of teaching of physics? Personally, I believe they would. However, as will be seen in this work both teachers seemed determined to do what they have been doing for several years in spite of their "agonizing" and uncertainties about that. Second, the teachers changed out of "frustration and desperation". This work will inform us much about that.

As I attempted to look at this picture from the perspective of personal knowledge the two perspectives did not square with each other. Researchers who used this concept drew on the work of the philosopher of science Michael Polanyi. In his 1958 work, Polanyi introduced the concept as a way of describing how scientists participate actively in shaping our scientific knowledge. Scientists, according to Polanyi, approach nature with intellectual

passion and with beliefs inherent in these passions. These passions would be theirs though held with the conviction that they would be universal in nature. Scientific passions were thus seen as having logical functions in the construction of scientific knowledge by scientists. So while Polanyi emphasized the personal dimension in our scientific knowledge, he, nevertheless, saw that personal interwined with the scientists' commitment to a universally valid vision or reality. This commitment, according to Polanyi, saves personal knowledge from being merely subjective.

So, while personal knowledge would establish contact with reality and thus would preserve an element of objectivity, it would still be motivated by the knower's intellectual passion, and thus touches upon the knower's subjectivity. Polanyi's conception of personal knowledge has thus assumed an interplay, or a dialectic, between subjectivity and objectivity. Translated into individual actions this mounted to his conclusive assertion that: "The freedom of the subjective person to do as he pleases is overruled by the freedom of the responsible persons to act as he must", (p. 309).

The teacher who "agonized" over what he had been doing for years, and his colleague who saw in his practices a "gamble", could hardly be described as showing passionate commitment to what they had been doing, at least as far as the contexts of those quotes were concerned. Whether the teachers' actions could be described within the framework of

Polanyi's conclusive assertion will be left for the reader to judge. For me, I found that disputable. For all that, the adjective "personal" as had originally been suggested by Polanyi, and re-used later by some educational researchers, appeared too restrictive for my work and, thus, I decided not to use it.

So was the other term 'practical'. As I started to probe into the teachers' knowledge, the idea of looking into what might be practically-oriented understandings became also too restrictive. When talking about knowledge per se, I found that both teachers held, theoretical, philosophical, and technical forms of knowledge which should be brought into the foreground of the study. I, therefore, decided not to exclude such an important dimension of the teachers' knowledge from the study, and for that reason I decided to avoid using the adjective 'practical'. I was, then, left with the two expressions: the teachers' knowledge of the subject matter, and their classroom treatment of it.

Investigating the teachers' knowledge of the subject matter as such without any restrictions on it, appeared for me a formidable, and sometimes undoable, job. What is knowledge anyway, and how can I deal with such an invisible? What to look for? Should I look for their knowledge across various topics? Or, should I focus upon one single topic? What would be the implications of either choice? All these questions, and a host of other similar ones consumed a lot of my energy and thinking. At one point they even

threatened my enthusiasm for the project, or at least the part of it that dealt with knowledge of the subject matter.

Another source of dilemmas was the methodology used in the study. As will be explained in a following chapter, the methodology adopted had anthropological origins. The major dilemma I faced was related to how I could use such a methodology, with its primary emphasis on interaction and communication in social contexts, to look at the teachers' cognitive structures of knowledge. This issue together with the pertinent decisions I made will be discussed in a following chapter.

In response to the first set of dilemmas and problems, I made some simplifying decisions. First, on the general level I started to conceive of this study as an exploratory one. To me, teacher knowledge of the subject matter, particularly at the secondary school level, appeared an unexplored territory in educational research. A topographical, or a natural featural mapping of the region would thus be required. I have, therefore, attempted to travel with the teachers in their journey with the subject matter in order to trace those features.

In my journey with both teachers, I carried a guiding compass made by philosophy of science. But unlike magnetic compasses which tell directions in almost definite ways, mine was more of suggestive nature only. To define my directions and trace my chart, I had to create a dialogue between the guiding suggestive information from the

philosophy of science, and my regional features, which could have been anything but simple, clear, or static. Teachers' knowledge of the subject matter, as well as their ways of dealing with it appeared to me an immense territory which included, among other things, crests and troughs which sometimes resisted or even defied probing, as well as elusive images and mirages. It also included some important teacher conceptions of the subject matter and its teaching which, in a sense, were unique to the setting or the teacher under consideration.

My tracing of what I could possibly synthesize tended to be of extrapolatory nature. Other unexplored areas of the teacher knowledge might possibly be conceptualized in the same way. I also attempted to leave some poles and flags, as visible signs, at some spots where I thought a second exploratory visit would be helpful.

Second, I decided to avoid any philosophical discussions pertinent to the meaning of the word knowledge. The traditional philosophical answer to the meaning of knowledge as a "form of justified true belief" (Dretske, 1982), and any discussions of that were avoided. Knowledge in this work was meant to include the content of the subject matter, such as concepts, relations, laws, and theories, and structuring and organization of this content. I also used the expression 'teacher conceptions', to denote any mental impressions, abstractions, or generalizations the teacher may formulate about a certain idea, practice, or bit of

knowledge he was involved with. These conceptions are assumed to be synthesized by the teacher out of his mental activities over, and interactions with, the idea under consideration.

My plan for the rest of this work will be as follows. In the next chapter I will attempt to put this research in the framework of some pertinent research on teacher thinking and knowledge. Chapter three will discuss the methodology I used in collecting and analyzing my data. The setting will be described in chapter four. Chapters five and six will attempt to describe the teachers' knowledge of the subject matter and their ways of dealing with it. In the final chapter some speculative ideas, implications, and suggestions are discussed.

CHAPTER II

RELATED LITERATURE

Teacher Knowledge of the Subject Matter: Evaded, or Taken for Granted!

A review of research on teaching would show that teacher knowledge of the subject matter has not been on its agenda. If we talk broadly of two research paradigms in education, the positivist paradigm, and the interpretive one, then each appeared to have its own reasons for not researching knowledge of the subject matter. As for the research with a positivistic orientation, knowledge, in itself an invisible entity, was unmanipulable within the tradition of this approach.

The interpretive paradigm with its emphasis on social interactions and socialinguistic matters seemed to distance itself not only from teacher knowledge but from the content of teaching and learning as a whole (Erickson, 1982a). Shulman (1986) referred to the absence of focus on subject matter among the various research paradigms for the study of teaching as the "missing paradigm" problem.

The mother project for this work, the (SSSP), had originally sought an understanding of the nature of interactions among secondary school science teachers, school administrators, and external agents in secondary schools. However, as the project progressed, more emphasis was put on teachers' classroom practices. Though teachers' knowledge of the subject matter as such was not dealt with explicitly

in the project, the teachers' ways of dealing with the instructional contents were often referred to in various interim reports on the project. In his final report on the project, Gallagher (1986) summarized a lot of particular pieces of related information and observations when he stated:

> "Secondary science teachers appear to have made their job easier than it really is. Reliance on target students of high motivation and ability to guide pacing provides teachers with a false sense of accomplishment. Minimizing the diagnostic-remedial component of their teaching role and emphasizing their role as managers of instruction and presenters of information make their work easier. Emphasizing recall and deemphasizing the nurture of higher order thinking skills further reduce the demands of their jobs. Reliance on texts as the basis of organization for instruction and belief that "good students will learn and the rest will not" shifts responsibility from themselves and places the burden on students. All of this add up to a "culture of secondary science teaching" that accepts and justifies little or no planning as well as low standards of expectancy. Moreover, there are no incentives or checks and balances within the organizational structure of schools to move science teaching out of this position. (p. E5)

Three research groups have recently been involved in researching aspects of the subject matter: Smith, E.L. and Anderson, C.W., at Michigan State University, Shulman, L.S., at Stanford; and Leinhardt and her colleagues at the University of Pittsburgh.

For several years Smith and Anderson studied students' misconceptions in science. They suggested instructional strategies and developed curriculum materials to combat those misconceptions. For them, effective science teaching

should focus on the learning problem that would result from such misconceptions or naive theories: called "the problem of conceptual change", (Anderson, C.W., and Smith, E.L., 1986). With an eye on conceptual change as a focus of effective teaching, the researchers described four patterns of science teachers' thought and behavior related to science teaching and learning. These patterns included: activity-driven teaching, didactic teaching, discovery teaching, and conceptual-change teaching. In their description of these patterns, the researchers attempted to trace the influence of the teachers' knowledge of the subject matter on the pattern of thought and behavior they displayed in classroom. For example, teachers who were described as "uncomfortable teaching science", for lack of understanding of some aspects of the subject matter tended to follow the "recommendations of the authors of their textbook", and thus exhibited an orientation toward "activity-driven teaching".

Knowledge of content, according to the two researchers, was one of three components on which effective conceptual-change teaching depends. The other two were knowledge of students, and knowledge of teaching strategies. Failure to provide teachers with such knowledge was very consequential on what they did in classroom.

> "A major cause for the prevalence of didactic science teaching in our schools, and the resultant disappointing student learning, is that our educational system fails to help teachers acquire the knowledge they need for conceptual change teaching." (p. 33)

Working with a wider program of research on "Knowledge Growth in Teaching", the second group, led by Lee Shulman, at Stanford University started to look, among other things, at teachers' knowledge of subject matter and how such knowledge would contribute to teachers' planning and instruction. Of the several studies done, one seemed relevant to this study for it dealt with science teachers. Therefore, I will review this study as an example of the work done by this group.

In his 1985 research work, Hashweh attempted to find out how science teachers' knowledge of their subject matter affect some aspects of their teaching; and likewise how the teachers' conceptions of the learners and of the learning process affect particular aspects of their treatment of the subject matter. To do that, six experienced teachers, three in physics and three in biology, were recruited to participate in the study. To assess the teachers' subject-matter knowledge the researcher used three tasks: summary statements, where the teachers were asked to summarize what they knew about the topic, concept-mapping, where the teachers were asked to draw a map by connecting a number of given concepts to each other, and sorting, which asked the teachers to sort a number of problems into groups. The knowledge structures of each teacher on two topics, one was within the teacher's specialty and the other not, were assessed.

For the assessment of learning, the teachers were

interviewed on questions which focused on concept acquisition, the persistence of preconceptions, and ways of inducing conceptual change. Just like the MSU group, the researcher focused on effective learning as a process of conceptual change. Finally, through the use of thinking aloud and simulated teaching techniques, each teacher simulated preactive and some aspects of interactive teaching of each of the two topics. The topics were on photosynthesis and levers.

Hashweh's findings indicated that teachers tended to have a superior knowledge base and structure within their field of expertise. This knowledge, described in terms of schemata, greatly contributed to the transformation of the written curriculum into an enactive one. This transformation occurred either directly to the content and organization of the subject matter, or indirectly through the use of activities and other representations. He also asserted that teachers with deeper subject-matter knowledge were more flexible in their teaching, and less dependent on the textbook than the other teachers who were less knowledgeable. They could handle various topics more effectively. Thus more and deeper knowledge of the subject matter was seen to contribute to more effective teaching.

As for the teachers' conceptions of learning, the researcher found that two of the six teachers held conceptual change view of learning. These teachers emphasized inducing conceptual change in the learner through

three specific steps: inducing new concept acquisition, confronting misconceptions, and helping cognitive strategies. On a more general level of classification of teachers' conceptions of learning, two viewpoints were pointed out: cognitive and non-cognitive. Four teachers, including the two who held conceptual change viewpoint, were found to hold cognitive viewpoints on learning. These teachers used strategies that emphasized, either totally or partially, the problem of conceptual change. These four teachers emphasized interaction between the learner and the new knowledge. The remaining two teachers who held a non-cognitive viewpoint "emphasized only attention on the part of the learner and the 'proper' presentation of knowledge on the part of the teacher" (p. 262.). Hashweh, like Anderson and Smith, concluded that subject matter knowledge "was a necessary but insufficient condition for confronting student preconceptions." (p. 272); and, therefore, suggested more focusing on conceptual change in order to make science teaching more effective.

Leinhardt and her colleagues at the Learning Research and Development Center, at the University of Pittsburg studied elementary math teachers' knowledge of the subject matter in their attempts to describe the expertise involved in the cognitive aspects of teaching. In their work, Leinhardt and Smith (1985), and Leinhardt and Greeno (1986), the researchers conceptualized this expertise as emerging from two core areas of knowledge: lesson structure and

subject matter. While the lesson structure knowledge included the skills needed to plan and run the lesson smoothly, the subject-matter knowledge included two forms: declarative, facts in a particular domain, and procedural, algorithms and heuristics that operate on those facts. The researchers studied both core areas of knowledge as well as the interplay between the two structures in both novice and expert teachers.

As for the subject matter, these researchers found that experts had more elaborate and deeper categories for math problems than did novices who tended to have more "horizontal", separate category systems. Among the experts some differences were also found. The level of conceptual information as well as the degree to which procedural algorithmic information was presented, were found to vary from one expert to another.

Experts and novices differed also in their lesson structures. Expert teachers used efficient routines in their lesson, each of which consisted of an action agenda; while novice teachers did not work in habitual ways.

Looking for a Wider Perspective

This study has two different, yet related, parts. In its first part the study attempts to delineate the teachers' knowledge and conceptions of the subject matter, physics in this case. This delineation will be inferred from various sources of data as will be discussed in the next chapter.

The second part of the study describes how the teachers went about teaching the subject matter. In their treatment, a multitude of variables were expected to come into play.

Since this is essentially a naturalistic study, I thought that it would be more congruent with the methodology used to call things as they were called by the teachers in the setting without any impositions of external conceptions. Physical concepts and laws like force, velocity, acceleration, Newton's third law, the law of conservation of momentum, and so on, would be called as they had been in the teachers' classroom discourse. In other words, in my description of the teachers' knowledge of the subject matter I attempted to talk subject-matter. This necessitated looking at two sources as a theoretical perspective for the first part of the study: literature on the nature of our scientific knowledge, and the textbooks the teachers used.

The two sources, however, were strongly related. The two courses the teachers taught, Physics, and Physical Science, were among the various science courses developed during the Sixties when the views about the structure of the discipline were very popular among science educators. What I had expected, then, at the beginning of this research was a body of teacher knowledge shaped after Schwab's (1962) famous description of the structure of our scientific knowledge which influenced the organization and presentation of the subject matter in the two textbooks used. This description talked about two structures in such knowledge:

substantive, and syntactic structures. The substantive structure referred to the conceptions, laws, and principles that would guide the inquiry process; while the syntactic structure referred to the methods used in scientific inquiry and validation of our scientific knowledge. Both textbooks seemed to be influenced by this perspective on scientific knowledge in their discussions of various physics topics. I will give a brief description of the contents and structure of each textbook in chapter five as a prelude to my description of the teachers' knowledge and conceptions of the subject matter.

I should emphasize here that apart from the domain of these ideas, I had had no expectations of where the description of teachers' knowledge might lead me. As will be seen in chapter five this conceptual framework turned out to be of limited utility in my attempts to analyze the teachers' knowledge and conceptions of physics. I, therefore, invoked a wider analytical perspective against which the pertinent findings could be discussed. This wider perspective included a range of fundamentally different ideas on the contents and nature of our scientific knowledge coming from different philosophers of science. A brief description of these ideas was evoked in the analytical comments made over the depiction of teachers' knowledge and conceptions of physics presented in chapter five.

The second part of this research dealt with the teachers' treatment of the subject matter. Here, not only

teacher knowledge would come into the picture, but, equally well, his attitudes, beliefs, feelings, assumptions, and interests. Within this picture, the teacher would become central in deciding not only how the subject matter would be treated in classroom, but also how the whole classroom environment and experiences would be shaped. The study of all that would, therefore, be, and to a good extent, the study of teacher thinking. For that reason I thought that research on teacher thinking, or part of it, would be the wider context within which a good part of this research would mesh. Since research on teacher thinking is a relatively new enterprise for educational researchers, I will give a brief description of its beginning before I review some works pertinent to this study in some way or another.

Historical Beginnings of Research on Teacher Thinking

While various related studies refer to Jackson's (1968) book Life in Classrooms, as one of the first studies on teacher thinking and its relation to behavior, the official initiation of this new field of research came at the 1974 conference of the National Institute of Education NIE (Clark & Peterson, 1984; Halkes, 1986). One of the panels in that conference suggested a research program on teachers' thought processes. In their report to NIE the panelists stated:

> "It is obvious that what teachers do is directed in no small measure by what they think. Moreover, it will be necessary for any innovations

> in the content, practices and technology of teaching to be mediated through the minds and motives of teachers. To the extent that observed or intended teacher behavior is "thoughtless," it makes no use of the human teacher's most unique attributes. In so doing it becomes mechanical and might well be done by a machine. If, however, teaching is done and, in all likelihood, will continue to be done by human teachers, the question of relationships between thought and action becomes crucial." (NIE 1975, quoted in Clark and Peterson 1984).

It is important to note here that the perspective adopted by panelists on teaching was that of information processing. Their view of the teacher was congruent with this orientation. In this regard their report stated:

> "The panel was oriented toward the teacher as clinician, not only in the sense of someone diagnosing specific forms of remedies, but more broadly as an individual responsible for (a) aggregating and making sense out of an incredible diversity of information sources about individual students and the class collectively; (b) bringing to bear on a growing body of empirical and theoretical work constituting the research literature of education; somehow (c) combining all that information with the teacher's own expectations, attitudes, beliefs, purposes. . . and (d) having to respond, make judgments, render decisions, reflect, and regroup to begin again" (National Institute of Education 1975, quoted in Clark and Peterson 1984).

Other important related events activated the process of formation of research on teachers' thinking. The first was the establishment of the Institute for Research on Teaching (IRT) at Michigan State University in 1976. A large body of research on teachers' thinking has been carried out at this institute since that date. In 1983 another related development took place. Two organizations were founded to

enhance research in this field: the AERA Special Interest Group "Teacher and Student Cognitions," on the American continent, and the European based "International Study Association on Teaching Thinking" (ISATT). The ISATT held its first symposium in 1983 which was followed by a conference in 1985 both at Tilburg University in the Netherlands.

Research on Teacher Thinking and Knowledge

During those formative years a large and diversified body of related research was done. Several reviews summarized the emerging literature (e.g., Clark and Yinger, 1979; Shavelson and Stern, 1981; and Clark and Peterson, 1984). In this review a high degree of selectivity will be exercised; only some related research is cited.

In their review of the research literature on teachers' thought processes, Clark and Peterson (1984) organized it under four major headings: Teacher Planning, Teachers' Interactive Thoughts and Decisions, Teachers' Attributions, and Teachers' Implicit Theories. Of all these fields of research, "Teachers' Implicit Theories" consists of the smallest and youngest part of the literature. The inadequacy of research in this field was realized by Shavelson and Stern (1981). They stated:

> "Unfortunately the sequence of elements considered (in a teacher's planning a task) and the compromises that have to be made are, as yet, unknown." (p. 478).

A decade earlier, Postman and Weingartner (1971) had emphasized the need to study teachers' beliefs and assumptions in order to improve the learning environment. In their words:

> "There can be no significant innovation in education that does not have at its center the attitudes of teachers and it is an illusion to think otherwise. The beliefs, feelings and assumptions of teachers are the air of learning environment; they determine the quality of life within it."

Munby (1982) shared with them their concern of the need to know more about teachers' beliefs and implicit theories in order to understand teacher decision making and teacher thinking in general. These theories and beliefs were assumed to be kept partially in tacit forms and one purpose of research on teachers' implicit theories is to make them explicit in order to examine how teachers process information.

Several studies on teachers' implicit theories or related topics have been reported in dissertations or published in books. Elbaz's (1983) is one of these studies. This study attempted to examine various particular aspects of the practical knowledge of a junior high school English teacher. To elucidate what she meant by practical knowledge Elbaz stated:

> "In carrying out his work, the teacher exhibits wide-ranging knowledge which grows as experience increases. This knowledge encompasses first hand experience of students' learning styles, interest, needs, strengths and difficulties, and a

> repertoire of instructional techniques and classroom management skills. The teacher knows the social structure of the school and what it requires, of teacher and students, for survival and for success, she knows the community of which the school is a part, and has a sense of what it will and will not accept. This experiential knowledge is informed by the teacher's theoretical knowledge of subject matter, and of areas such as child development, learning and social theory. All of these kinds of knowledge, as integrated by the individual teachers in terms of personal values and beliefs and as oriented to her practical situation, will be referred to here as practical knowledge (p. 5).

Elbaz reported five content areas of teacher practical knowledge: knowledge of the self, the milieu of teaching, subject matter, curriculum development, and instruction. She also identified five orientations (ways that practical knowledge is held and used) to this knowledge: situational, personal, social, experiential, and theoretical. The internal structure of this knowledge is reported to be organized in somewhat hierarchical manner: "rules of practice," which are specific, "practical principles," less specific, and "images," which tend to be broad and of some metaphoric nature.

A point of interest to this study was the teacher's practical knowledge of the subject matter. Elbaz's study dealt with a wide variety of issues pertinent to practical knowledge. The discussion of the teacher's practical knowledge of the subject matter was, consequently, brief for it was not the central question in the study. However, some interesting findings were reported. The teacher's view of the subject matter of English were summarized in two

distinct forms: English as an academic discipline based on a valuing of the inherent aesthetic qualities of literary work as object, and the view of English as a medium for the expression and clarification of experiences, feeling, and value.

More interesting, I think, is the process of transformation or modification in the teacher's knowledge of the subject matter as she, the teacher, was developing a new course in reading skills. Elbaz reported those transformations as changes that took place in terms of general imagery or metaphoric expressions of the teacher. Though Elbaz's study was principally a study of teacher knowledge, it, however, did not attempt to probe into the technical or theoretical aspects of the teacher's knowledge, either in general or particular forms, related to the subject matter or any other dimension. A possible reason for that could be the various assertions made by researchers such as Lortie (1975), about teachers' lack of professional knowledge.

Munby (1986) emphasized the importance of unraveling or understanding the metaphorical content of teachers' speech. In his study which included analysis of transcribed interviews of five junior high school teachers, Munby identified two metaphors in one of those teachers' speech: "lesson as a moving object," and "missing." The first metaphor would explain how the teacher constructed her professional reality: the beginning and continuation of a

lesson, and the teacher's as well as the students' journey with the lesson. If the lesson was metaphorically described as a moving object with students and teacher moving along with that object then "missing" that moving object might convey failure to interact or perceive that object which in turn may mean a failure on the part of some students to learn. This was the metaphorical picture implied in the "missing" metaphor. To relate the two metaphors to each other in a meaningful way Munby concluded:

> "There is a clue here that learning is perhaps a matter of taking up the information as the moving object travels by or through, which suggests that the movement metaphor is related to a conduit metaphor for learning." (p. 205)

Literature on curriculum innovations has revealed much about the influence of teachers' thought processes on the way they apply or use curriculum developers' ideas and suggestions. According to Connelly (1972) this literature showed that only in rare cases the curriculum developers' recommendations and intentions were achieved in significant measure. Supportive of this view were the findings of some evaluative reports of the 1960's science curriculum innovations. Connelly cited as examples Robinson and Toman (1970), Heron (1971), Gallagher (1966), and Rosenshine (1970).

Doyle and Ponder (1978) echoed this concern when they stated that:

> The life histories of innovation projects are, more often than not, records of disappointment and failure. Indeed, it seems that few authors of strategies for innovation can point to solid evidence that their particular set of procedures has in fact produced fundamental changes in the regularities of schooling (p. 1).

According to them many procedural recommendations for the classroom made by curriculum developers lack "ecological validity." They, therefore, suggested that we should learn more about the work environment of teachers in order to be able to predict successfully what impact a particular change in curriculum will have on teaching conditions. They also argued that teachers appear to use three general criteria to determine the practicality of a suggestion or recommendation about classroom procedures. These criteria included instrumentality (description of a procedural recommendation in terms which depict classroom contingencies), congruence (match, as seen by the teacher, between proposed procedures and previaling conditions), and cost (the ease with which a procedure can be implemented).

Several related studies added further to the importance of teachers' beliefs to the success of implementation of curriculum innovations. Three works that dealt with science curriculum will be briefly reviewed: (Roberts 1980, Olson 1981, and Munby 1984). Roberts (1980) used the expression "theory-practice inferface" to explain what he called "mismatch" in science curriculum implementation. The word mismatch was meant to refer to the difference between what the curriculum developer had in mind and what really went on

in the classroom. Roberts' idea was that the "interface" was the point where two distinct perspectives or understandings meet: the perspective of the curriculum developer with all his theoretical conceptions and understanding of classroom setting, and that of the teacher which is influenced by the realities of his classroom. The teacher, according to the paper, would interpret the curriculum materials in his own way which would undoubtedly take into consideration his own beliefs and knowledge. Consequently, curriculum materials will become "modulated", as Roberts put it.

Olson (1981) studied eight British science teachers who were involved with the implementation of the English School Council Integrated Science Project (SCISP). Using the Repertory Grid Technique of Kelly (1955), Olson found that teachers' main personal construct was classroom strong or high influence. They deliberately, even when they were not required to, exhibited high or strong involvement in classroom interactions, like lecturing, note giving; and tended to maintain firm control over the point and direction of their lesson. The SCISP program, on the other hand, had called for a low teacher's influence in classroom events. Indeed a major underlying conception of the program is its call for the teacher to be only a guide in inquiry. The teachers, in their attempts to resolve this dilemma made several changes and distorted the curriculum materials in order to match them with their beliefs and personal

constructs. In Olson's words:

> "The dilemma was resolved in favor of familiar, reliable methods. A host of project domestications occurred as the project language was translated into familiar terms. The project language was given new meaning in terms of the existing vocabulary of teachers. For example: discussions become lectures or recitations; intellectual skill development was translated as content memorization and examination rehearsal; the integrated design was translated as a patch work of specialized content to be unravelled and resewn; criterion referenced assessment was translated as norm based. In short, after a period of experimentation during which they saw their influence declining, the teachers re-established influence through the varied domestications of the project doctrine." (p. 265)

Munby (1984) examined a junior high school science teacher's thinking. He used the Repertory Grid Technique to analyze two interviews he conducted with the teacher. During the first interview an introduction was read to the teacher in order to elicit "elements" for one axis of the grid. "Elements" were then grouped on cards and the teacher was next asked about the grouping process in order to find out his "constructs," the second axis on the grid. "Constructs" were meant to be ways in which the teacher thought about "elements". "Elements" and "constructs" were then laid out on a grid and the teacher was asked to rate the associations of each element with every construct on the grid. Analysis of those associations resulted in phrases that were then presented to the teacher in order to probe for what might underlie them. After such probing, the researcher identified six personal constructs:

a) student success at curriculum content and their subsequent confidence,

b) making them think,

c) daily life information,

d) application and transfer making factual information more real,

e) successful use of resource material, and

f) group work and social learning.

There are two fundamental issues which have been emphasized by the findings of the studies in teacher thinking reviewed here. The first is the personal dimension in the implications and consequences of this thinking. Each teacher had his own way of interpreting events and constructing his knowledge and actions. Second, teachers' thinking, beliefs and knowledge tend to be practical or pragmatic. Munby spoke clearly about them both:

> "In summary, Ellen's (the teacher who participated in the study) dominant concerns are for the students' confidence and increasing ability to handle information independently. She appears to strive toward meeting these by invoking instructional principles that arise, for her, from her own experiences but evidently not from formal course work, as she sees it. On the contrary, the origin of her principles seems clearly pragmatic rather than theoretical. There is no hint of a well developed theoretical psychology of learning, for example. (Why should there be?) Instead Ellen talks in pragmatic terms, such as "making learning fun," and "a different way of learning." Also her view of the earth science curriculum she teaches is pragmatic: some general ideas will be remembered (if they are "seen"), but the specific information will soon be forgotten, at least that is what her experience seem to have shown her." (p. 37)

These two dimensions were made explicitly central in some other studies. Drawing on previous philosophical works of Polanyi (1958) and MacIntyre (1981), and Elbaz's 1983 study of practical knowledge, Clandinin (1983, 1985) examined one first grade teacher's images of the classroom. In a six-month ethnographic study Clandinin did participant observation in the teacher's classes where she took the role of a teacher assistant and colleague. Fieldnotes, two structured interviews, and narrative accounts of the researcher's interpretation of classroom events were the source of data of the study. Analysis of the data showed that the teacher conceptualized the image of "classroom as home." It also explained how that image, a form of personal practical knowledge, embodied the teacher's personal and professional experience. Clandinin stated:

> "Personal practical knowledge is, furthermore, intimately connected with the personal and professional narratives of our lives. It is not something which has an independent and objective standing apart from our personal histories. Readers have seen how the image of "classroom as home" originates in both the personal and the professional spheres of Stephanie's life; binds the two together in a narrative unity, and are reflected back upon each as the image is expressed in Stephanie's home and school activities." (Clandinin 1985, p. 283).

In another study Connelly and Clandinin (1983) studied a junior school principal's personal practical knowledge as stated by the principal in a form of "personal philosophy." The study focused on one school event, a professional development day, where the principal of the school gave a

speech in a general meeting with the school teachers in which he summarized his own philosophy as related to his profession. The researchers, using ethnographic methodology, collected fieldnotes during that event. Analysis of fieldnotes showed how the principal's personal philosophy was related not only to the rituals found throughout the setting, but also to the physical environment of the school. The principal used to state his personal philosophy on various important and related occasions which were not necessarily limited to general meetings like the one observed. The construction of a mural and its placement on a wall was also interpreted as a clear physical expression of the principal's personal philosophy. The study attempted also to explain how, on the basis of conceptualizing teachers' practical knowledge, we can understand these teachers' construct their classroom practices.

In the same vain, yet drawing theoretically more on Kuhn's concept of "paradigm" among scientists, Lantz and Kass (1985) studied what they called "functional paradigms" of chemistry teachers in Alberta, Canada. Using both qualitative and quantitative approaches for data collection, the researchers studied a sample of high school chemistry teachers from 50 high schools who were using the ALCHEM curriculum materials.

Using Schwab's four curriculum commonplaces to organize their findings, the researchers described four sets of

elements that constituted the teachers' functional paradigms. These sets of elements or categories were: perception of high school chemistry, perception of teaching, percpetion of students, and perception of school setting. Influences of various elements on the interpretation of curriculum materials were also discussed. For example, the belief that the program was limited to topics listed in curriculum guide, an element in the teachers' perception of high school chemistry, influenced the way the teachers selected the topics for classroom discussion. Summarizing these findings the researchers asserted, among other things:

> "Training in chemistry and experience in teaching chemistry seem to have the most influence on teacher interpretation of curriculum materials." (p. 10)

In another high school science study, Aikenhead (1984) attempted to portray science teaching of "Prairie High" with an emphasis on the viewpoints held by the five science teachers at the school. The researcher observed various classroom events and interviewed the teachers about the decisions that had led to those events in an attempt to inquire about the reasons the teacher had for those decisions and the teachers' beliefs upon which those reasons were based. Among other things the researcher found that the teachers' preactive decisions served various personal, curricular, and social functions. He saw in these decisions a form of personal knowledge that defied the assumption that teachers would automatically implement the suggestions of

others. In his own words:

> "The Prairie High teachers held strong beliefs in their academic discipline, essentially defined by their university science experiences. The integration of these beliefs with practical classroom knowledge - including the socialization of students - created a stable and reliable set of 'theories-in-use' for preactive decision making; a robust framework resilient to influences from curriculum innovators and education researchers." (p. 184).

A note should also be made in this review about Stake and Easley's (1978) case studies in science education. In their discussions of science education at a national level, these researchers occasionally talked about the subject matter and how it was dealt with by science teachers. They found, for example, that often teachers used the subject matter to demonstrate their personal competence. They also found, however, that teachers in their decisions about the subject matter lived a struggle between what is personal, like their value systems, and the teaching of the body of established knowledge and procedures to be taught. Eventually, teachers treat the subject matter in a way that secures their survival in the social system.

> "Teachers are fixed into the social system that places demands to be met in order to avoid extreme social discomfort - demands which are incompatible with the demands of the scholarship system. Scientists and other intelligentsia have little effects, parents and other teachers have much. What teachers do with subject matter is determined by how it sustains and protects them in the social system." (p. 16:23)

Just like most other related studies, Stake and Easley did not describe teachers' knowledge of the subject matter. Neither did they go into specific details about how some specific topics or domains of knowledge were dealt with by science teachers.

Several remarks can be drawn from this review. First, the three groups researching various aspects of the subject matter approached their research issues from a cognitive psychological perspective and with a predefined conception of effective teaching and learning. Effective learning, for both the MSU and Stanford groups, was defined as a process of conceptual change; and effective teaching was, consequently, seen as the teacher practices that would emphasize inducing conceptual change. Leinhardt and her group, on the other hand, approached the issue through their analyses of knowledge structures of experts and novices. The three groups seemed to tacitly agree on accepting a direct, and perhaps strong, connection between a teacher's knowledge and his classroom practices. A teacher who had learned and known how to induce conceptual change through instruction would be assumed to do that in his daily classroom practices. Contextual and other societal factors as well as teacher intentions and purposes that may fundamentally change teacher knowledge and practices seemed well beyond the realm of these groups' research.

Second, much of the research reviewed on teacher thinking was originally guided by one of two models used in

educational research: the decision making model, and the cognitive information processing model, Clark (1980). Munby (1982) explained how such research had had seveal problems like the assumption of a shared perception between the researchers and the teachers and the imposition of coding systems by researchers. He suggested different research techniques in which the teachers' own perspectives would be portrayed. However, the Kelly's Repertory Grid Technique which he used was not without serious problems as he himself pointed out.

Third, some studies did attempt to portray teachers' beliefs and knowledge from the perseptctive of teachers: Elbaz (1983), and Clandinin (1985). However, these studies limited their investigations to what they termed as practical or personal practical knowledge. Limitations of these expressions were discussed.

Fourth, with the exception of the last three studies, the research reviewed, as well as most of the research done on teacher thinking in general, was carried out on elementary school teachers.

Fifth, no where in this research work was there any attempts on the part of researchers to make any connections between teacher knowledge of the subject matter and the way it would be treated in classroom on the first hand, and other societal events, or factors on the second. The only study that hinted toward that, without giving any specific information, was the national study of Stake and Easley.

CHAPTER III

BACK TO HOWARD HIGH FOR A NEW RESEARCH[1]

By the end of summer 1986, I had spent two years visiting Howard High School at the rate of once every school week. I had then become a familiar face at the school, especially for the five science teachers working there. In this chapter I will briefly describe the research site, introduce the two physics teachers I worked with, and then discuss how I did this research.

The School

Howard High School is located on the boundary between a pleasant upper middle-class neighborhood and a large automobile assembly plant in a midwest city of a population around 150,000. The school draws a varied population of students, over 2,000 in number, representing a range of socio-economic and racial backgrounds with approximately 40% of the students population Black and 15% Hispanic. The school incorporates grades 9-12. There are over 100 staff members including seven full time science teachers. Prior to my beginning of this research, no science courses were required for graduation. However, as I started this second phase of work two more science teachers were hired in order to meet the new regulations that required one year of

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[1] All names of site, teachers, and students used in this dissertation are pseudonyms.

science for graduation. The number of science teachers thus rose from five to seven.

The Teachers

Two physics teachers were observed and interviewed for this study: Mr. Stewart, and Mr. Davis. What follows is a collection of biographical information about each teacher's education, professional experience and employment, honors and awards, and self-conception.

Mr. Stewart

Mr. Stewart's college education started in an engineering school at a major university thirty-five years ago. He had spent three years as an engineering student before he moved to another university to spend another three years before he got his Bachelor of Science with a major in physics and a minor in chemistry and mathematics. Soon after graduation, Mr. Stewart started his career as a physics teacher at Howard High School. He spent fifteen years before he obtained his second degree, a Master of Science with emphasis on general science, while still working at Howard High. Parts of his formal learning for both degrees included courses in education. During those fifteen years, Mr. Stewart attended four Summer Institutes focusing mainly on the science curriculua introduced in the late fifties and sixties: mainly the Physical Science Committee (PSSC), and Harvard Project Phyics (HPP)

curricula.

Mr. Stewart's employment at Howard High has continued up to the present date. In the late sixties and seventies, he became more actively involved in the Summer Institutes and other related activities. He worked as a consultant to the HPP for about one-and-a-half years. He also worked as a Summer Institute instructor for about six consecutive summers. In one of these summer institutes he met Mr. Davis and seemed to have encouraged him to apply for work at Howard High. Mr. Davis did that, and both of them had been working together ever since 1972.

As for his professional readings, Mr. Stewart included Physics Teacher, Physics Today, Science Teacher, and to a less extent High Technology and Popular Science. However he only "browsed" them for articles of interest to him which were not many anyway. As for his professional affiliation Mr. Stewart is a member of both the American Association of Physics Teachers (AAPT), and the National Science Teachers Association (NSTA).

During his career Mr. Stewart wrote one article for the Physics Teacher magazine, which was a series of interviews he did with a famous living physicist. He also presented what he described as "a major paper" at an AAPT convention and was elected president for the local section of that association. He also served on several related committees and was a chairman of one of them that dealt with professional concerns. Based on the AAPT observations of

his physics teaching, the association awarded him in 1973 the "Innovative Science Teaching Award" which he shared with Mr Davis.[1] Mr. Stewart was also honored by Sigma Xi, a science honorary fraternity at a major local university as a runner up for a "teacher-of-the-year" title in his school district. Mr. Stewart was the head of the science department at the school.

Mr. Stewart described himself as a liberal, work oriented person. He likes to keep busy doing things, enjoys puttering around the house, rebuilding and finishing furniture, and collecting antiques.

Apart from this information about Mr. Stewart which he provided me with, I, on three separate occasions, heard high praise of Mr. Stewart and his achievements as a physics teacher. In a general meeting of the board of education in his school district Mr. Stewart was described by the superintendent as an "excellent" physics teacher. In another gathering of some science educators, he was described by a science education professor as a "leader" in science education. Finally, during the annual meeting of the State section of the AAPT, Mr. Stewart was referred to by two other people, whom I guessed to be physics teachers, as a "superior" or "excellent" physics teacher.

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[1] In Mr. Davis's recollection about the award, he mentioned that it was awarded by the NSTA division in their state.

One final note about Mr. Stewart. This time it is mine. The impression I formed about him agrees with his self-description as somebody who keeps busy doing things. Except during some short breaks when he used to have a cup of coffee, I never saw him relax at school. He always appeared busy doing something related to his classroom activities. Furthermore, he appeared to me an open, outgoing, and conscientious individual. Above all, he was always friendly, cooperative and willing to discuss anything with me.

Mr. Davis

Mr. Davis is nine years younger than Mr. Stewart. His education started at a community college. He then moved to a small local state college where he got his Bachelor of Science with a major in chemistry, a major in biology, and a minor in physics. Soon after graduation he worked as a science teacher in a small town. He then got a grant and went to college again, earned his Master of Science with emphasis on physics and physics teaching. After graduation he went to work in another small town but only for a short time before he became a science teacher at Howard High in 1972. Since then, he has been working closely with Mr. Stewart.

As for his professional readings Mr. Davis mentioned Scientific American, Physics Teacher, and Science Teacher. Professional affiliations included membership in both the

AAPT and NSTA. He shared with Mr. Stewart the presentation given to one of these associations as well as the Innovative Science Teacher Award.

Mr. Davis described himself as "pretty low-keyed." In an interview he told me: "I don't like to get in front of groups and tell them what I've done. Sometimes I feel what I am doing is not very important for people to know about." On another occasion he spoke of himself as: "a person that is not demanding, very quiet. I like to be near people, but not leading people or demanding on them. I don't really enjoy prestige". He likes to fish and to hunt. He enjoys working with his hands and puttering around "from automobiles to plumbing."

My own impression of Mr. Davis was that of a conservative individual. At times he was a bit reserved, but always very friendly, and polite.

Methodology

The nature of the research questions in this study were thought to be best answered by using fieldwork research methods. Other terms used by other researchers, using similar methods, include ethnographic, qualitative, participant observational, case study, and symbolic interactionist. According to Erickson (1985) fieldwork research involves:

> "(a) intensive, long-term participation in a field setting; (b) careful recording of what happens in the setting by writing field notes and collecting

> other kinds of documentary evidence (e.g. memos, records, examples of student work, audiotapes, videotapes; (c) subsequent analytic reflection on the documentary record obtained in the field; and (d) reporting by means of detailed description using narrative vignettes and direct quotes from interviews" (p. 6).

In the rest of this chapter the first three steps will be discussed in details, but first a word about re-entry negotiations.

Re-entry Negotiations

My first entry to the site goes back to August 1984 when I started to work as a research assistant for the IRT Secondary School Science Project. Prior entry negotiations had been conducted by the coordinator of the project Dr. J. Gallagher. The IRT project lasted for two years during which I observed and interviewed four science teachers (one chemistry teacher, one biology teacher, and two physics teachers). As the IRT project was approaching its final stages I was developing my own research proposal but in a different direction from that of the IRT project. The two physics teachers, from the four observed, were originally thought to be promising subjects for the study. However because the original proposal for this research was intended to be a case study of one physics teacher's knowledge of subject matter, only one of the two was to be chosen. I consequently talked about my future project with one of those two teachers who, without any hesitation, welcomed the idea and expressed his readiness to cooperate with me on

this research. However, because the the work of the two teachers overlapped over a physics course they both taught, and because they taught it in a sort of team work, I thought that it would be prudent to talk to the other physics teacher about the project. Just like the first one, the second physics teacher appeared enthusiastic about the work and expressed his willingness to cooperate as well. As it turned out later it was practically difficult to study one teacher in isolation from the other one, and so the decision made to talk about the project with the two teachers turned out to be a very helpful one. These negotiations took place as early as February 1986.

By the end of the school year in June 1986 I gained acquaintance not only with the science teachers in the school but with the administration, including the principal, as well. When I talked to the principal's assistant about my research project, he too approved of the renewed entry to the science classes for this study.

Data Collection

Fieldwork research methods require the researcher to spend much time in the natural setting under study because his or her primary concern is the context. The setting is the direct source of data and the researcher is the key instrument in the study (Bogdan and Biklen, 1982). The researcher, an outsider, can be more sensitive to experiences and perspectives of the people in the setting

than the insiders themselves who may tend to be unaware of the recurrent happenings or interactions in their setting (Schatzman and Strauss, 1973). The specific methods I used in this study included: participant observation, indepth interviewing, and documents analysis. Each will be explained separately. However, because I, like many qualitative researchers, reflect a phenomenological perspective or orientation in this study a very brief description of some pertinent phenomenological ideas seems necessary.

Phenomenology

Phenomenology, or more precisely in this case phenomenological sociology has been influenced by the philosophers Edmund Husserl, Martin Heidegger, and Alfred Schutz (Bogdan and Biklen, 1982; Ihde, 1979). Phenomenologists emphasize the interpretive understanding of human actions. They emphasize the subjective aspects of people's behavior in order to understand what meanings they construct in the setting. They attempt to gain entry into the conceptual world of their subjects (Greetz in Bogdan and Biklen, 1982). To achieve that, phenomenologists follow certain rules. Ihde (1979) call them hermenutical rules. They could be summarized as follows:

a) Attend to the the phenomena of experiences as they appear. In this initial phase it is required that the researcher would suspend or step back from his ordinary way of looking in order to set aside his knowledge and

assumptions about things. This step is called epoche' (Ihde, 1979), or phenomenological reduction (Ihde, 1979; Schutz, 1973).

b) Having done the required phenomenological reduction, the researcher should be able to describe the phenomena he attended to. Explanation should be avoided or suspended at this stage.

c) Horizontalize or equalize all immediate phenomena. Here the researcher should deal with all phenomena without the imposition of any hierarchical order among them. Any judgements should be suspended.

d) The fourth rule is to seek some structure or invariant features of the phenomena. Examples that might be necessary to discover the structural features will be sought. What is implied here is to look for a general character, or a universal attribute which is possessed by a number of things.

e) Phenomenology examines experience that deal with and is limited by whatever falls within the correlation of experienced-experiencing. The term used for this correlation is intentionality (Ihde, 1979; Schutz, 1973). This means two things. First, if we experience at all, we experience something and in some way. Or there is a correlation between what is experienced (object) and mode of experiencing. Second, any experience is always an experience of something. To paraphrase Schutz (1973), there is not such a thing as

fear. There is fear of something. This is what is usually called the intentionality character of our thinking and experience.

From this brief description of phenomenology it is clear that though phenomenology emphasizes the interpretation of subjective experience, it is nevertheless both empirical and scientific. It is empirical because its rules emphasize observation. It is scientific because eventually it seeks structures of phenomena. So while the steps followed include empirical and scientific orientations, the theoretical context of any conclusions arrived at would be interpretive or hermeneutical, for as stated before, what phenomenologists are after is an interpretation of the subjective aspects of people's behavior.

Participant Observation

Participant observation is the process in which an observer participates in the daily life and interactions of a group of people under study: observing the things that happen in the setting, listening to what members of the group say, participating with them in their natural life setting, and gathering data (Becker and Geer, 1957; McCall and Simmons, 1969). The observer, therefore, comes to the social setting with two purposes: to engage in activities appropriate to the situation, and to observe the activities, people, and physical aspects of the situation. Spradley

(1980) spoke of six functions of a participant observer should do that would allow him or her to achieve those purposes. The participant observer usually has a heightened sense of awareness that would allow him to observe the familiar and very ordinary things in the setting. He or she should approach social life with a wide-angle lens. The participant observer usually experiences simultaneously being both an insider and outsider to the setting. He should learn how to use himself as a research instrument. He should enhance his introspectiveness. And finally he should keep a detailed record of both objective observations and subjective feelings.

This dual nature of the role of participant observer is fundamental in this kind of research. While the observer tries to get involved into the setting in order to understand or have some feeling of the subjective experience of people in the setting, he, at the same time, constantly attempts to detach himself from that setting or to "objectify himself" (McCall and Simmons, 1969).

This mix of involvement and observation in the role of participant observer may vary from one setting to the other depending upon the nature of the setting, the experience of the researcher, and the nature of the study to be carried out. Generally speaking there is a continuum of possible roles for observers to play. This spectrum of roles ranges from complete participation or involvement in the site to non-participation at all (Gold in Bagdan and Biklen, 1982;

McCall and Simmons, 1969; Spradley, 1980; Goetz and LeCompte, 1984).

My role as a participant observer in the school dates back to August 1984. During the whole year I used to observe three science teachers at the rate of one hour per week for each teacher. One of them, Mr. Stewart, was observed in his "Advanced Physics" course. A fourth teacher, Mr. Davis, was observed but with less frequency. As pointed out before, these two physics teachers became the subjects of this study. I had started my observation with practically no involvement in the setting whatsoever. I was a complete stranger to the setting but with one exception. The subject matter the teacher and the students talked about was familiar to me. In retrospect, I would say had it not been for my acquaintance and familiarity with the subject matter, it would have taken much longer time, and perhaps more frustrations on my part, before developing a rapport with the teachers and thus increase my involvement in the setting. The subject matter was the small opening through which I was able to get into the wider picture of what was going on in the setting.

During the next year, 1985-86, a friendly rapport was developing among us: teachers and researcher. During that year, with the same frequency of observation, I became more at ease with the setting. My involvement increased. I interacted with the teachers as well as with the students: asked questions, answered their questions, made some

suggestions, and frequently offered my help when it was needed. Toward the end of that year, I interviewed those teachers mainly about their role conceptions.

Though the subject matter, science, was for me an ideal starting point for more probing into the setting and in various directions, it was not the focus of the IRT project. During those two years I gained a wide-angle perspective on the setting. Due to the low frequency of my observations and the fact of being a foreign student the problem of "over-rapport" (Miller in McCall and Simmons, 1969), or "going native" (Bogdan and Biklen, 1982) did not arise in my situation. I always felt that there was a lot to know about in that setting.

My participant observation for this study started with the opening of the school. My first classroom observation was conducted on September 2, 1986. As planned in the research proposal, I started to participant-observe one teacher whom I had thought before would be teaching physics, chemistry, and physical sciences. However due to some changes in the schedule he taught two subjects only, physics and physical sciences. His daily schedule included two hours of physical science (1st and 2nd), and three hours of physics (3rd, 5th, and 6th). I decided to participant-observe the teacher for four hours daily from nine in the morning until one o'clock in the afternoon and for the first three or four consecutive days of the week depending upon the activities to be carried out. This schedule allowed me

to observe one physical science class (2nd hour), and two physics classes (3rd and 5th hours) plus a free hour during which I would be able to talk with the teacher about various issues.

Though I realized right from the beginning of my observation that the two physics teachers planned for their physics classes together, it took me practically until the end of September to realize that it was not practical to focus on one teacher only. The other teacher had to be included in some way or another since what I was observing in the classroom was really the product of the two teachers working as a team. So by the end of September I changed my observation schedule to include one hour observation of a physics class taught by the second teacher. I chose not to observe his advanced physics class since I had done that in the past. Consequently, my new observation schedule included four hours: a physical science hour, two physics hours, one for each teacher, and a free hour. The new physics hour that was included made me drop a physics class (5th hour). However on certain occasions, especially toward the end of my observations I used to drop the physical science hour (2nd hour) in order to observe a physics class for the second teacher. These changes were made whenever I did not expect anything new or important to my research to take place in the physical science class. The participant observation process lasted until the end of the school semester, in the middle of January 1987.

Right from the beginning of my participant observation I explained to the two teachers, in general terms, that I was planning to look at their knowledge and conceptions of the subject matter and the way they would go about teaching it. I also expressed both my willingness and desire to participate in whatever activities the teachers might be planning to do. At the time I had two goals to achieve. The first was to get as much involved in the setting as possible in order to live some of their experiences with the subject matter, and hence fulfill my role as a participant observer -- try to look at the things through their eyes and minds. The second goal was to offer them something in partial return of my "using them," as one of them put it on one occasion. Indeed, I was always ready to offer any help needed in the classroom. However, in my persistent attempts to do that I was faced with a problem. Both teachers appeared to me very reluctant to accept me as somebody who simply wanted to understand what was going on there, as far as the subject matter was concerned. I believe that three factors influenced their conception of my role: my being a foreign student, an experienced physics teacher, and a university man. While it is extremely difficult to assess how these factors, whether separately or interactantly, influenced the way they interacted with me, one aspect of that influence was felt. Both of them, each in his own way, conceived of me as somebody who would eventually judge what they were doing. While Mr. Davis asked, on several

occasions, for my opinion on what he was doing, Mr. Stewart spoke explicitly, sometimes without asking him about that, about criticisms raised against his teaching by some people.

In my observation, I hypothesized another possible consequence of their conception of my role. But first I should say that I was given the full liberty of moving around interacting with students, teacher, and materials. I was never denied any answers to any questions I raised with them. I helped in passing handouts, answering students' questions during seatwork, setting equipment and collecting them back after work. Both teachers were very friendly and cooperative. However, they again and indirectly, left me with the feeling that they would not allow me to go beyond a certain line with my involvement into their work. More than once I expressed my readiness to assume partial or full responsibility of teaching certain topics under their supervision and attendance or otherwise. Nevertheless, they never asked me to do that. Not even on the day or days when they were absent and a substitute teacher, who confessed to me that he did not know science, was taking their place in class. These observations made me more sensitive to their concerns and more careful in the way I interact with them lest I sound critical and evaluative in my approach.

During my participant observations I wrote field notes, collected samples of all handouts and documents used in the class, and partially or totally recorded some lessons. I will talk about each of these techniques separately.

Field Notes

I used an ordinary notebook for this purpose; wrote on one side of each sheet and left the other for my own memos, notes, and later reflections on my field notes. In class I used to station within the teacher's territory but in a non-imposing manner. I used to occupy a space near one corner of the classroom to the right hand or left hand side of the teacher's usual posture in front of the class. That space proved to be effective not only for field notes taking but for recording, good hearing and seeing of what the teacher was saying or doing, and for being always ready to get involved into the activities or simply offering a quick help for the teacher when the need for that emerged. In my field notes I used to focus upon the segments of the lesson when the teacher was in some way or another articulating the subject matter. Usually these segments often occurred during the first ten to fifteen minutes of the lesson, or before or after an activity. When the teacher used the lecture mode in his instruction the whole hour was focused upon for notes taking.

On some other occasions when I felt that it was not appropriate to take notes I relied upon my memory, but only for a short period of time. In my informal discussions with the teacher, whether before, or after, or during the lesson I used to store in my memory what I deemed relevant information until the time would come when I would be able to jot down what I remembered from our conversations. On

some occasions, when I felt that I accidentally got what I judged to be a too important bit of information to be kept in memory for minutes, I simply withdrew from the conversation or site, went to my notebook, and jotted down my notes.

Since I did not go to school every day of the week I used to inquire about the activities done during my absence. Some brief notes about those lessons were documented. These days were usually Fridays and Thursdays which were very often used for quizzes or simply seatwork to solve some bonus points on various chapters. That instructional rhythm minimized, but of course did not eliminate, the discontinuity in my observations and field notes.

Recording

I used a very sensitive cassette recording equipment: Sony TCM 5000 EV. Its high sensitivity allowed me to set it wherever I wanted in the classroom and thus minimized the intrusive nature of recording devices. I simply kept it beside me in order to manipulate it whenever and however I judged needed. I always kept it just ready to work particularly at the beginnings or ends of lessons, during the introductions to some demonstrations or lab experiments. In summary, I was always on the alert to know when the teacher was going to express something related to the subject matter. When such a segment of the lesson would come, I would instantly start the recording. These segments

ranged in duration from two minutes up to practically the whole lesson, just about fifty minutes. Through this process I compiled sixteen hours of cassette recordings. These cassettes were filed chronologically with brief information on the ideas and topics discussed, and the teacher who carried out the discussion.

Work Sheets, Handouts, Plans, And Charts

Literally, there had been no lessons that were not preceded by some sort of a handout. This continual stream of papers constituted the instructional references and plans for the teacher, and I suspect the major learning milieu for the students. These papers included dittos of handwritten units and lesson plans, problem sets, quiz papers, and scientific charts. Teachers' own terms which they used to talk about them were: handout, work sheet, homework, unit plan or schedule plan, lesson plan, bonus points, quizzes, tests, and final examination. I have collected a sample of each paper distributed during the semester in both courses, physics and physical science.

Interviewing

Interviewing is an excellent means of getting into peoples' subjective orientations or mental contents -- beliefs, perspectives, knowledge, values, etc. (Gordon, 1980). Both informal and formal interviews were used in this research.

Informal Interviews

This type of interviews consisted of the numerous conversations that took place during my participant observation. Most of those conversations were spontaneous with no prior planning, but very relevant to what was going on in the classroom. They were not always related to the research topic. However, within this type of interview there were certain questions which I thought of them in advance and wanted to get answers for them through conversations without resorting to a formal interview. The reason for that varied form one situation to another. Sometimes I wanted a quick answer for an emergent question which I thought shouldn't be postponed. On another occasion I thought that an informal interview would elicit a more candid answer for certain questions than a formal interview would. However, during a number of conversations when I realized that the teacher was articulating an important issue, I stopped from any further probing into that issue in order to raise the point again at some other time during formal interviewing. This occured at least three times during my observations. It had the advantage of obtaining literal answers for important questions. Relevant information collected through those informal discussions were incorporated into the body of the field notes.

Formal Interviewing

In formal interviews, the time and place of the interview was decided in advance. When I negotiated the time and place of the first interview I practically left it open for the teachers to choose the convenient time and place. They both preferred the school as for the place and their free hours as for the time. The interviews were planned to go in conjunction with the field notes. This allowed for the discussions of some topics, ideas, issues, metaphors etc., reasonably concurrently with what was going on in the classroom. Eight interviews, four with each teacher, were conducted at the rate of one interview each month's observation. The fourth interview, however, was carried out four months after I left the site. Each single interview with each teacher took fifty to ninety minutes; and all interviews were tape recorded.

Each interview focused around a few topics that were encountered during observation or informal discussions and were in need of more elucidation and probing to know more from the point of view of the teacher. For that purpose I used to prepare in advance a set of topics to be discussed with each teacher on each interview.

Although there was no intention on my part to compare between the two teachers, there was some overlap over the topics discussed. This overlap was due to two reasons. The first was the overlap in the subject matter they taught and the lesson plans they both used. The second reason was

attritubed to my choice of some topics for discussion which were only indirectly related to what was going on in their classes, (e.g. their background and experiences, some specific topics they both deleted, and their perspectives on some aspects of physics knowledge which were not explicitly articulated in the classroom).

This set of topics which I used to prepare for each interview was a sort of interview guide whose use was explained by Gordon (1980):

> "The interview guide in contrast to an interview schedule, provides only an outline or a checklist of the topics and subtopics to be covered but does not specify a sequence. In some cases it might also include several ways of working questions or various probes which might be useful in pursuing the subject. The interviewer is not only free to vary the sequence of topics and subtopics to fit the particular situation but he may also return to a topic more than once. He is free to omit questions suggested by the guide if he feels that the information was already obtained indirectly. He is free to add questions and reword others when this help conveys the meaning" (p. 60).

In my actual interviews and on several occasions I did omit some questions, reworded others, and returned to some topics more than once. According to Gordon's (1980) classification of interviews, all interviews conducted in this study were "independent non-standardized" interviews. There was some variations in the way I adapted the structure of the interview with the two teachers. Originally I was in favor of more open-ended, free-flowing style of interviewing. I wanted to exert as little control as

possible on the content of the interview in order to probe deep into the teachers' ideas and perspective. In that sense I was thinking of a minimally structured type of interview. Right during the first interview I realized that was problematic for at least two reasons. The first was the frame of time I had. Each interview with each separate teacher was to be done within an hour's time; and it was under no circumstances possible to go beyond ninety minutes. With the several topics I had each time it was not practical to leave the interviewee going on without any control. This was very clear at least with one of the two teachers who was very articulate.

The second reason for not maintaining a complete open-ended style had to do with the nature of the face to face interaction that was going on between me, the interviewer, and him the interviewee. I had my own research interests. He in turn, and undoubtedly, had his own interests in the process. These interests would converge, diverge, or overlap. The interviewee, therefore, may, consciously or otherwise, interpret the interviewer's questions in ways that would allow him to give self-serving responses, or simply give lengthy responses on side issues or digressions. I am not saying that those side issues and digressions are unimportant. In fact, on some occasions, they were very revealing. What I wanted to emphasize is that few research projects can have the luxury of letting the interviewee go on without any control. At one point or another the

interviewer has to make a decision about that and consequently accept the approximation he attains through his approach. For these reasons all interviews conducted for this study were semi-structured. The interview guides prepared prior to the interviews were flexible enough to give me the possibility of pursuing a range of subtopics. At the same time I deliberately offered the teachers a good chance to practically shape the content of the interview.

What I have said about structuring the interview did not apply equally to both teachers. As may be expected people vary in their abilities or willingness to articulate their ideas. In this study there was a substantial difference between the two teachers in the way they articulated their views. While Mr. Davis tended, generally speaking, to give his answers in short, concise terms, Mr. Stewart was always ready to give more intensive descriptions of not only the topic under discussion but other subtopics which he found or interpreted relevant. While I, occasionally, tried to discuss the same topic from various angles with the first teacher in order to get more information from him, I, occasionally had sometimes, to circumvent some digressions or very lengthy answers by Mr. Stewart which I judged, at the moment, to be unnecessary.

A serious mistake which I made during the first interview should be documented. Several times during the interview I interrupted the teachers. The discontinuities in the flow of information was clear in the transcripts.

While it may be necessary sometimes to ask for certain explanations during the interview, interruptions may render some answers incomplete or incoherent. It would be more effective to ask for these explanations either at the end of the question or interview, or simply be left to another chance during another interview or conversation.

The topics discussed in the interviews would come under one of the following groups:

1) Specific Subject-Matter Topics

   A number of interview questions dealt with specific subject-matter topics discussed in the classroom. The aim was to know more about various aspects related to that topic and the way it was taught. Other questions dealt with some topics discussed in the textbook but were absent from the teachers' discussions. The aim here was mainly to know the reasons for the omission of those topics.

2) Issues Raised in Informal Discussions

   These included a variety of ideas and topics ranging from views and conceptions about specific issues to metaphors that expressed important pedagogical perspectives or principles.

3) Metaphors

   Both teachers used metaphors that were very telling. A number of questions were tailored to understand the teachers' detailed interpretations of these metaphors.

4) Clarifications For Past Issues

Some interview questions sought teachers' clarifications of certain words or statements they uttered either in class or in previous interviews.

5) Teachers' Perspectives

Teachers' perspectives on certain issues were sought explicitly including the courses taught, the students, scientific knowledge or physics knowledge, their perceptions of their role, and science teaching.

6) Hypothesis Confirmation and Refutation

Some working hypotheses emerged in the course of the study. A number of questions were designed to seek more confirmatory evidence. On other instances the objective was to examine whether we, the researcher and the teachers, shared the same perceptions of certain meanings or interpretations of some classroom utterances which appeared central in the research.

Data Analysis

This was a study of and about the knowledge of subject matter of physics or science that teachers held not only in explicit forms but in tacit ones as well. It was a study that dealt with an important aspect of curriculum in both its obvious or direct manifestations: scientific concepts, principles, laws, skill, etc. deliberately taught to students, and its less obvious, hidden or latent forms, teachers' perspectives about what was taught, their

conceptions of the nature of those laws, and theories.

This required focusing my attention not only on the implicit, subjective aspects of teachers' knowledge of physics they talked about, but on the well defined, well structured scientific utterances. I had, for example, to be alert not only to the utterances "F = ma" which anybody anywhere, who studied physics in English, would bring about in his answer when asked about Newton's Second Law of Motion, but to a multitude of other possible, less obvious, and sometimes unspoken aspects of the law, like: its relation with the First and Third Laws, the teacher's conception of the law whether it is a basic law of nature or a mere definition of a concept embedded in the formula. Pardoxically, while the implicit or hidden aspects were relatively easy to investigate, the obvious was problematic.

The reason for that is the methodology adopted for the study. According to Erickson (1982), interpretive methodology has been used in trying to study aspects of the "hidden curriculum" rather than the "manifest curriculum." In order to focus on the deliberate teaching of cognitive subject matter a shift that involves a redirection of attention from the exotic to the commmonplace becomes necessary Erickson (1982). This shift was extremely important in this study. While I had to enstrange the familiar in the setting in order to attend to its unseen aspects, I had, at the same time, to focus on the direct conventional scientific language and knowledge of the

teacher as deliberately taught or discussed. In addition to that I had to attend to the textbook scientific language and explanations and take all of that as given. Newton's Second Law of Motion, for example, includes several cognitive notions explained in the book and were spelled out by the teacher as part of his instructions. Those notions and meanings were originally constructed by people other than teachers. Teachers in turn are assumed to preserve the scientific authenticity of those meanings and notions. That is why it was assumed here that the researcher and the teachers could, or perhaps should, share these conceptions or meanings. However, those supposedly well structured and defined cognitive notions were not all that was present in physics classes. A variety of other things were in there as will be seen.

For some time it was not clear to me how to deal with the commonplace, physics or science knowledge in this case. Eventually, however, I decided to deal with it as it was structured and explained in conventional books including the textbooks used by the teachers. While different science books would, presumably, reflect shared scientific meanings for scientific concepts, their levels of treatment or explanation of those concepts should not be expected to be the same. Physics books usually agree on the basic definitions and meanings of physics concepts. However, each may deal with those meanings at a different level of sophistication according to the author's objectives and

goals in writing the book. Teachers are assumed to share with the textbooks the scientific meanings and definitions of the technical concepts discussed.

These shared sets of meanings and definitions do not imply full agreement among authors or scientists about the nature of scientific knowledge. Disagreements among scientists, in spite of their importance, are not usually included in science books written for instructional purposes. Physics books and physics teachers are expected to agree on the definitions of the basic concepts embedded in the law: $F = ma$. Within the domain of classroom instructions they would all refer to "F" as the force acting on the body under consideration, "m" as the mass of that body, and "a" as its acceleration. They would also agree on the form of standard units used in measuring those concepts and on the meaning of the equal sign used in the formula. These domains of agreement which were originally constructed and developed by a specialized scientific community are extremely fundamental. For one thing they form a reference framework for teachers as well as any individuals interested to learn or practice science. Each instance of application of that law may be potentially problematic. In order to "correctly" apply that law to a particular instance, and thus teach or learn sciencce, the basic definitions as had originally been intended should be kept in mind or preserved throughout the necessary manipulations. But teachers as well as scientists or authors may disagree

in their conceptions of various aspects of the law. They may, for example, disagree on whether or not the law is really a basic law of nature or simply a certain definition. Their conceptions of the various notions may also vary. The useability and limitations of the law may not be conceived identically across various interested individuals.

These ideas were kept in mind while proceding for the analysis of data gathered through various means. Data analysis was an on-going process. As suggested by Schutzman and Strauss (1973), I used to return to my notes almost each day after I had left the school in order to make some notes about questions to ask or ideas to be clarified. This resulted in a lot of comments, memos, and speculations which I wrote regarding various parts of my fieldnotes. This in turn led to new questions to be asked or discussed either formally in an interview or simply during daily conversations with the teacher. The whole process was always led by the general questions about the teachers' knowledge of the subject matter and the way they taught it. With time some patterns and working hypotheses were then sought through more focused observations or interviews.

Though the study did not start with specific apriori questions, some conceptual issues did lead the study throughout it various stages. The general research interest had always been the teachers' knowledge of the subject matter and the way or ways that knowledge was taught or discussed in classroom. At the beginning of data collection

I kept my scope of observation very wide. But never was it unmanageably wide. In other words, I did not collect my data in a completely random way. There was a measure of specificity in my observations even at the beginning of my research work.

The process of starting from broad conceptual questions and then zooming into more specific ones, and going back to the original questions with some modifications and new questions, did not only help in carrying out some preliminary analysis, but also achieved, I think, two important characteristics of this type of research. First, it gave me, as a researcher, easier mobility to move back and forth in my investigations between the wide perspective of my observation and the narrow or specific one. A dialogue was thus created between the two. While the general or wide perspective gave direction to the specific one, the specific in turn informed additively or subtractively the scope of observation. As time went on the general perspective tended to be more tuned toward certain research orientation while the specific became more enlarged and enmeshed in a larger and more coherent net of meanings. Second, by identifying broad conceptual questions before entering the field setting, it was possible to include a deductive mode of investigation with the inductive one. Through some deductive reasoning it was possible to formulate some questions about some specific issues related to the broad ones. On the other hand, inductive reasoning

in turn informed and modified the broad scope of the study. Thus induction and deduction were, as Erickson (1984) put it, in constant dialogue. The consequence of that was a continual modification and development of the fine structure of the research design throughout the study (Burgess, 1984; Bogdan and Biklen, 1982).

By the end of my observations, I had written a lot of fieldnotes, collected a lot of handouts, and transcribed a good part of my audiotape. Patterns and assertions emerged; confirming evidence as well as some refuting or discrepant cases were compiled. "What next?" was, then, the question I asked myself. Another round of dialogue with, or interrogation of, the data was felt needed. After I had done that I decided to transcribe the rest of my audiotapes for I discovered that both interviews and classroom recordings included very relevant and important information. So all interviews which comprised around ten hours of tape recording as well as approximately sixteen hours of classroom recording were finally transcribed.

The process of transcription was very painful, time consuming, but extremely helpful and educative. I had to spend many hours listening to these recordings which were not always audible enough. There were, and for more than one reason, some instances when the audibility of the recording was not perfect. And so I had to listen to the same portion sometimes several times. Even with several attempts to listen and discern, a few words phrases and

sentences were not understood and thus blanks or question marks were left in their contextual location in the narration of the transcripts. Some of the reasons for the imperfection of some portions of the recording could have been avoided. In a sense having some imperfections in the recordings was educative for I always paid a high price for any recording mistakes like forgetting to put a new set of batteries, or improperly adjusting the machine knobs, or simply positioning the machine carelessly. Many of these mistakes were practically avoided but a very few of them plagued small portions of my tapes and were a nuisance during transcription.

Apart from these problems which left only very minor effects on the content of transcriptions, the fact that I did a verbatim transcription for practically all the recordings gave me ample time to reflect upon virtually every single sentence in the contents of those recordings and to write some relevant notes and memos. That proved very helpful in various steps taken in data analysis. Many of the regularities, patterns or key topics that were embeded in the data appeared through the process of transcription. These topics, phrases, or sometimes single words were used later as coding categories.

The cassettes had been numbered sequentially and in a chronological order. After having their content transcribed all pages were also numbered sequentially and in a chronological order too. However each segment of the

transcripts was given some heading information which included a reference to the topics discussed, date of discussion or interview, the code name of the teacher who participated in the discussion, and a reference to the number of the cassette on which the information had been stored. A distinction was made between the interview material and that of the classroom. The fieldnotes were numbered in the same fashion but separately from the transcripts. Classroom documents were also filed in a sequential chronological order.

The next step followed was another reading-over of the whole corpus of data collected. The coding categories developed during the on-going analysis and the process of transcription were slightly modified. A number of new ones were added. In choosing a code, I followed the rules described below.

1. I kept looking for some key words, phrases, or sentences which a teacher said at one time or another and then used that word, phrase, or sentence as a code for a category or a pattern that repeated itself over time. Often that worked well. Occasionally, however, I needed more clarification from the teachers on their meanings of those utterances.
2. Some key words or topics discussed in the textbook or the teachers' handouts were also looked for as codes. These included scientific topics, concepts, laws, theories, etc. These categories were the ones referred

to at the beginning of this section as the commonplace in my observation whose meanings and authenticity had been presumably constructed by the scientific community.

3. While priority was always given to possible codes uttered and explained by the teachers, on numerous occasions I had to use a code that I somewhat derived or inferred from the data. Whenever possible I had to go back to the teacher and discuss both views, his and mine, of that code in order to arrive at a shared perception of the events and phenomena under consideration and thus avoid or minimize the imposition of my own perception and understanding on what was going on.

The coding categories were organized in a notebook as they appeared in my reading of all forms of data. Under each category I listed brief reference phrases or short sentences that were instances of that code category. The listed phrases and sentences were taken from various sources of data. After each phrase or sentence I added some information that would tell me, in a glance, the location of that phrase or sentence in the corpus of data, the teacher responsible for that, and the source of the data where the phrase appeared, e.g. interview, fieldnotes, documents. Some discrepant cases were also listed.

It wasn't a rare occurence that a certain instance or event was coded under more than one coding category. Each

coding category was then assigned a number. A photocopy of all fieldnotes and transcripts was made after various coded segments of the data were encircled on the original copy. Brief visible notes were added which included mainly a number that corresponded to the number of coding category under which that coded segment appeared. Number of the page of the source of data (fieldnotes, interviews, etc.) was also written within the encircled segment. This was necessary for the next step which included cutting up those segments and putting them in folders each for a specific coding category. Those pages which included segments of data that appeared under more than one category were copied more than once and as needed. The master copy was kept as a reference throughout the whole study.

At the beginning of the coding process the number of categories reached around fifty-five. With more scrutiny of those categories a lot of overlapping among some of them appeared. Others were discarded as irrelevant while a few new ones were added. Overall, however the number of categories was reduced to about fifteen.

The final step in this mechanical process of sorting the data was to cut up those encircled segments and put them in the appropriate folder. Each folder was labeled by one or more codes. All cut-ups related to the code or codes were then put into the folder ready for the final process of reporting the findings.

CHAPTER IV

FINDINGS AND INTERPRETATIONS: TEACHERS' KNOWLEDGE AND CONCEPTIONS OF PHYSICS/SCIENCE

In this chapter data from fieldnotes, interviews, textbooks, and handouts are presented in order to describe and interpret the two physics teachers' knowledge and conceptions of physics. I will start, however, with a brief description of the contents of the textbooks used and the teachers' views about them since these contents and views were the starting point not only for the exploration and delineation of the teachers' knowledge of the subject matter they taught, but also for the way the subject matter was treated in classroom, which was the second focal point of this research. In the next chapter this second major research issue will be discussed. A description of how the subject matter was treated or dealt with in classroom will be given, and the teachers' knowledge of physics teaching will be depicted. Some additional findings will be discussed in Chapter VI. These will include certain topics which had not been originally planned for studying but later found of significance to the focal issues of the study.

Textbooks

Two books were used in the classes observed for the study. The 1982 Prentice-hall Fourth Edition of Introductory Physical Science, by Haber-Schaim, U., et al.; and the 1981 edition of Holt, Rinehart and Winston Project

Physics, by Rutherford, F. J., et al..

Introductory Physical Science (IPS)

Description:

The curriculum was originally introduced by the Introductory Physical Science Committee originated in 1963 by Educational Services Incorporated. The program was piloted in 1963 to 1965 and used extensively by 1966.

The curriculum was designed for eighth and ninth grade students. It emphasizes the basic skills and attitudes of science through the study of matter in a laboratory-based approach to physical science. The materials and sources of the curriculum include some audiovisual materials in addition to the IPS textbook.

Contents:

The course, as the title implies, is intended to be an introductory one which provides students with a beginning knowledge of physical science. It does so through a variety of laboratory experiments which are to be carried out by the students themselves. These experiments comprise the body of the text.

Each experiment requires students to engage in an inquiry approach to learning science. Inquiry is initiated through some introductory paragraphs that would stimulate students' thinking and direct it toward certain fundamental questions to be answered. An experiment is then suggested

and fully described. Throughout the experiment some key questions are asked in order to help students develop their reasoning abilities. Some application questions are also included at the end of these experiments.

The course requires students have first hand experiences with materials and apparatus thus enabling students to learn some basic science skills. It encourages students' discussions and questions. Emphasis on problem-solving situations and learning by discovery is clear throughout the text. Inductive reasoning in which students are asked to look for patterns and regularities in the data they collected is also emphasized. New concepts and ideas are introduced and developed in the on-going process of investigation. Some industrial and everyday applications of physical science processes are discussed.

The inductive mode of reasoning is used not only at the level of some laboratory experiments but also at the level of the text as a whole. In the preface to the text the authors state that:

> "The theme of the course is the development of evidence for an atomic model of matter. Rather than broadly surveying the entire field of physical science, we have taken a well-defined path toward this major objective" (p. 6)

The text includes ten chapters, an epilogue, and an appendix on scientific notations.

The first chapter includes an experiment on the distillation of wood and is meant primarily to raise some

stimulating and challenging questions to be thought of during the course, some of which are beyond the scope of the text.

The concepts of volume and mass are developed in chapter two. Related measurement skills and equipments are dealt with. Through a series of experiments that involved various mass changes the law of conservation of mass is finally developed in this chapter.

Chapter three deals with the characteristic properties of substances. These properties include freezing and melting points, and density. These properties are used to distinguish between various substances that may appear to be the same. One of the useful applications of these ideas, namely the hydrometer, is discussed.

Some new scientific concepts and definitions are introduced in chapter four. They all have to do with solutions: solubility, concentration, solvent, solute, saturated solution, etc.. Solvents discussed are water and alcohols, while solutes included solids, liquids and gases.

Ways of separation of mixed substances are discussed in chapter five. The mixtures discussed included solids, liquids, and gases. Experiment on separation of these mixtures are suggested. They include: fractional distillation and its application in petroleum, industrial distillation of wood, separation by flotation, filtering, fractional crystallization, paper chromatography, and fractional distillation of gases. In all these methods

some characteristic properties of the mixed substances are used in order to separate various substances.

Chapter six is a sort of continuation of the discussion in chapter five. The emphasis here is on pure substances or compounds that cannot be separated or broken into new different substances through any of the previous methods. Decomposition and synthesis of some compounds, water and zinc chloride, are discussed in this chapter. At this point a distinction is made between mixtures and compounds and the law of constant proportions in compounds is introduced. The concept of chemical reaction is then explained.

Discussion of elements is what comes next in this line of investigation that is moving toward an atomic model of matter. This is what the book does in chapter seven. It develops the concept of element and then goes on to discuss some industrial methods used in the production of some metallic elements, namely iron and aluminum. Spectral analysis as a way of distinguishing elements is discussed. Finally, radioactive elements and decomposition, where elements decompose into other new elements, are discussed.

The atomic model of matter is introduced in chapter eight. Assumptions introduced into the model are used to account for the properties of elements, compounds and mixtures explained in previous chapters. Some aspects of the atomic model are illustrated through some activities. Formation of compounds, the law of multiple proportions, and radioactivity are also explained in terms of the introduced

model. Some predictions based on this model are made and then tested.

In chapter nine the model is extended to include the motion of molecules in order to make it possible for the model to predict the properties of gases. Various relationships between pressure, volume, and temperature of gases are predicted. Predictions made are found to agree with the corresponding empirical findings. The chapter ends with a discussion of molecular motion in liquids and solids in terms of the model.

Finally, chapter ten focuses on the sizes and masses of atoms and molecules. Various indirect methods used to estimate that are suggested. Some related experiments are described.

Harvard Project Physics (HPP)

Development of the course started in 1964 and was supported by the National Science Foundation. The course came in response to the decline in enrollment of high school students studying physics after the introduction of the Physical Science Study Committee (PSSC) physics course in 1960. While the PSSC course was aimed at above-average students, the HPP was developed to take care of a wider range of students. The course was thus designed with more flexibility in the way it could be used by teachers. It can be used in a conventional manner or in an individualized way. The material of the text is made available in one

single book or in individual booklets for specific chapters.

The Project Physics text develops topics through a story line that uses history, present-day events, and numerous examples. It attempts to show how scientific thought and ideas evolved through historical events, stories, explanations and formulas. In that sense the HPP text has a different orientation from the PSSC and other conventional physics texts. Its orientation may be summarized in a quotation by Rabi, I.I., a Nobel laureate in physics, which appears on the preface page:

> "I propose that science be taught at whatever level, from the lowest to the highest, in the humanistic way. It should be taught with a certain historical understanding, with a philosophical understanding, with a social understanding and a human understanding in the sense of the biography, the nature of people who made this construction, the triumphs, the trials, the tribulations" (p. iii)

Contents

The text covers a very wide range of classical as well as modern physics topics. It includes twenty-four chapters organized in six units.

The first unit focuses on the concepts of motion. It starts with the introduction of certain fundamental concepts: speed, velocity, average velocity, instantaneous speed, graphing and slope, and acceleration. Galileo's study of free fall is then introduced in detail. Equations of straight line motion are developed. The unit introduces next Newton's laws of motion. Finally, the unit discusses

other more complex forms of motion, namely, projectile motion and circular motion. The motion of earth satellites is discussed as an application on this form of motion.

The second unit talks about motion in the heavens. Greek astronomy is the starting point for the detailed discussion included in this unit. Works of Copernicus and Tycho are then introduced in a historical order. This is followed by Kepler's and Galileo's works. The historical development of the Copernican system is discussed in detail. Finally Newton's synthesis: the unity of earth and sky as described in his Principia is given.

Unit three explains how classical mechanics, or Newtonian mechanics, was extended to cover a wide range of physical phenomena. The conservation laws (conservation of mass and momentum), heat and wave motion, and behavior of gases are some of those phenomena investigated by means of Newton's theory. A mechanical view of the world is thus established.

Unit four discusses the development of another fundamental field of physics, namely, light and electromagnetism. Various developments in this area between the 17th and beginning of 20th century are discussed.

Unit five is the beginning of what is usually called modern physics. It starts with the historical developments that lead to the emergence of modern physics ideas. These include, among other things: cathod rays, Milikan's experiment, photoelectric effect, and x-rays. The

Rutherford-Bohr model of the atom is then introduced and finally some relativistic and quantum mechanical ideas are discussed.

Unit six is a sort of continuation of unit five. But while unit five is concerned with models of the atom, unit six goes deeper and more specific in its discussion. It discusses the nucleus. To do so the unit deals first with radioactivity, its discovery, characteristics of emitted rays, and various transformations. Isotopes are then discussed. This is followed by more probing of the structure of atomic nucleus by discussing some important related discoveries like artificial transmutation, the neutron, and the neutrino. Finally, nuclear energy, nuclear forces, and some nuclear models are explained.

Teachers' Views About The Textbooks

Data collection for the study extended over the entire first school semester. During this period three units, comprising twelve chapters, of the HPP were dealt with in some way or another by the teachers. The IPS content coverage was approximately the same in terms of number of chapters. Mr. Davis had already started chapter five in the IPS when the semester ended. In terms of book pages, around one-half of both sets of contents were covered during the first half of the school year.

In spite of some differences in the way the two textbooks were treated in classroom, there was an important

common feature about the role of the textbook in physics teaching-and-learning in that setting. At the beginning of each IPS hour Mr. Davis used to distribute copies of the textbook to the class, and then collect them at the end of the hour. Typically, students would use the textbook together with a related handout in their classroom work. In the HPP class however, students rarely used their textbooks. A typical lesson would include mainly handouts. On very few occasions a reference was made to the textbook, like recommending certain readings, or requesting that students would bring their texts with them during a certain hour. What I saw as a common feature in both classrooms, as far as the textbook is concerned, is the relative position the textbook occupied in the physics teaching-learning situation. While this position was central as far as the teacher and teaching were concerned, it was rendered peripheral for the student and his physics learning. The textbook was often the only source of physics or science knowledge discussed and developed in classrooms. Physics concepts, relations, formulas, laws, theories, and skills taught were taken mainly from these textbooks. Sequencing of lessons, chapters and units by the teacher was done mainly after the patterns adopted by the texbooks' authors. The teachers' strong reliance on textbooks stood in very sharp contrast with the students' very minimal use of them. Students in the IPS class used the text only during their lessons particularly when they had to read the procedures to

be followed when carrying out their experiments. Project Physics students, on the other hand were given textbooks, but they rarely used them inside the classroom. There were no specific instructions given to students as to how to use the textbook. Very few of them seemed to read it. Both teachers admitted that students could pass their courses without reading the textbook. At one occasion I asked Mr. Davis to ask his students if they felt it was necessary to read the HPP textbook. None said it was. When he asked to know how many of them did any readings at all, only three students said that they occasionally had done so.

The very marginal position of the textbook in the direct interaction of students with their learning environments was one of the early observations that appeared to be intriguing enough to require more probing about why the textbooks appeared as if they had been unimportant for students to read. At one point it looked as though those books had been prepared for teachers only.

A good part of the first interview was designed, first, to check on my perception of what was going on as far as the textbooks were concerned, and second, to elicit teachers' responses toward some other aspects of the textbooks. In what follows I will summarize their relevant responses and make some interpretive comments on them.

IPS Textbook

Various sources of information about Mr. Davis's views about the IPS seem to include partial agreement or convergence between these views and those of the authors of the textbook. In a handout about the course description two main goals were stated for the course: first, to understand the basic principles of the physical world, and second, to develop lab skills necessary for future science courses such as chemistry and physics.

In the interviews, however, the second goal only was emphasized. In his description of the course Mr. Davis stated:

> "IPS is, I think, science skill building, very much that.....The IPS is more of a learn by doing things" [more than the HPP] [1st Interview: 9/23/86]

In the second interview he went on to describe the IPS approach to teaching.

> "In the IPS it's all pretty much inquiry. The student does the experiment, may be asked a second question, go to another experiment and lead from the way through that....The IPS is more expensive than Project Physics because of the consumable materials all the time. And things get broken because kids are using them and when kids use them they learn to some extent. You know you got your hands on a thermometer, you can see how it works. I think that's beautiful. It brings a high degree of frustration to me, sometimes. But I have to see kids do it rather than just hear about it" [2nd Interview: 10/14/86]

While the textbook speaks of giving students "beginning knowledge of physical science and insight into the means by

which scientific knowledge is acquired," the teacher, on the other hand, seemed to emphasize the second dimension only. The absence of what the textbook calls "beginning knowledge of physical science," or what the teacher described in his course description as the "basic principles of the physical world" is strongly implied in the following excerpt from the first interview:

> "I am still getting a feel for the IPS book. I feel funny with it sometimes, because it's more of a lab manual. And you certainly can't fall back on it...you have to supplement it with other things all the time.....I would like to see somebody take the IPS materials and develop some supplemental things...or that readings that kids do at the library" [1st Interview: 9/23/86]

A list of supplementary topics that was prepared by the teacher in order that students would do some library research included over thirty physical laws and principles: for example, Newton's three laws of motion, Kepler's Laws, Big Bang theory, Hook's Law, Boyle's Law, conservation of mass and energy, etc..

The dichotomous nature of scientific knowledge implied in the two perspectives, the authors' of the IPS and the teachers', is clear. Both made a distinction between content, basic principles and laws, and process, procedures followed in developing knowledge. However, while the authors saw the textbook as including both aspects, the teacher felt that it was more of a lab "manual," or a set of procedures to be followed by students while carrying out experiments. This may explain why Mr. Davis used to talk

about the two textbooks the IPS and HPP as complimentary to each other implying that while the IPS emphasized experiments, seen as procedures, the HPP on the other hand emphasized laws and theories.

There is another fundamental point which Mr. Davis did not bring about in the discussion about the textbook. Neither in the course description, nor in the interview transcripts, was any reference to the theme of the book, namely, the development of the atomic model of matter. While it may be assumed that this theme was absent from Mr. Davis's perspective, the fact that he covered about half of the textbook might have still kept him far from the periphery of the model and thus saw no reason of talking about that model. It could have also been the case that the inductive line of reasoning adopted by the textbook was not discerned by the teacher. In other words, it is possible that the teacher did not discern how all those particulars about the constructs of volume, mass, characteristic properties, and solubility, would eventually be considered a strong evidence for a model of matter that implies discrete entities called atoms, which in turn, have certain characteristics. The textbook itself, on the other hand, does not seem to work purposefully on these issues in its first five chapters. It does not, for example, try to stimulate the students' thinking about alternative ways of looking at matter and its constituents, like discrete-versus-continuous models, and then weigh the evidence

presented against this dichotomy.

The absence of this important thematic issue from the teacher's perspective as well as from practically the first half of the textbook gives, I believe, some support to the following speculative conclusion. Students' perspective on the atomic model to come would lack the line of reasoning claimed by the authors of the text. The students would eventually see another fragmented piece of information which is arbitrarily imposed upon their knowledge and experience. What would have been explained in earlier chapters would hardly be seen as evidence to the atomic model or even related to it.

HPP Textbook

There were three dimensions in Mr. Davis's views about this textbook: orientational, critical, and comparative.

The orientational dimension summarized how the teacher viewed the textbook in its approach to introducing physics to both the teacher and the student, and what influence he thought that approach had upon both of them. This dimension seemed to emphasize the humanistic approach of the text, which seemed to have left positive attitudinal influence on both the teacher and the student as far as physics knowledge and physicists were concerned. The following excerpts from interviews reflect this dimension.

> "The Project Physics textbook made physics for me come alive with people with events happening, with...I guess each topic has a story line and

> that became a neat way of teaching physics...And a sort of present science as a way of changing, growth, how ideas come, and the disagreements that existed among people. It shows physicists as people; and I think this to me was, and is still, an important attraction for that text" [1st Interview: 9/23/86]

When asked about the educational importance of this historical approach, Mr. Davis responded:

> "I think educationally it helps me see physics not so much as something that I couldn't reach for and be part of myself. And I think students also feel that they are involved, or can reach and become involved in physics themselves. They can see these people had feelings and successes just like they have feelings and successes, and it's not just some unique people that are often in historical pages, somewhere that no one ever came here. These are people that are among us" [1st Interview: 9/23/86]

In his criticism of the textbook Mr. Davis emphasized one issue, namely, the sets of problems and derivations included in the text.

> "It certainly lacks a lot of luster when it comes to finding nice problems to solve or derivations of this, that, or the other equation one may come across.....Some of the problems in the Project Physics book are really bizarre. You know they don't build in terms of complexity. They don't start easy and get harder and harder. They just start somewhere...So it's very hard to rely on the textbook. You have to build your own as you are using the text." [1st Interview: 9/23/86]

Finally, Mr. Davis very often referred to the IPS when talking about the HPP text and vice versa. The implication was that each had something the other lacked. He occasionally referred to some issues he had discussed in one

class while teaching the other.

In general terms, Mr. Stewart's views about the textbook and the course may be described along the same three dimensions: orientational, critical, and comparative. However his views were more detailed and comprehensive. He, like Mr. Davis, emphasized the importance of the historical and cultural approach adopted by the textbook. However, the reasons he gave for the educational significance of this approach went beyond what is attitudinal or affective to include students' reasoning and cognition. The following excerpt illustrates that:

> "The course takes an idea, gravity say, and picks up on the idea of gravity from very early concepts, critical discussions or philosophy having to do with those concepts, critical experiments that shed new light on these things, famous people who had unique insights that opened up these understandings. So the course does that with ideas of how is it that we believe that we are on a planet that is encircling the sun, that is spinning, that is going off in space.....The student thus can come away with an idea that the spinning earth idea is not just a scientific idea that was equally explained by several other methods, but over a period of time they saw the experimental evidence that led us to believe that it must be this way; it can't be any other way. This is true for a number of things.....This course develops the idea why we believe those things exist...;and, maybe...I guess I am a story teller. I enjoy with the students developing this understanding through historical development of people and ideas, and building on these concepts from the ground up as civilization did. And I think there is a number of advantages to that. One is that they get a better handle of what these concepts are, what an electron is through experiments and thought and hypotheses, and so on.....Another advantage is that it shows that physics is not off in a field by itself clear away from the main stream of life; but physics interacts and interfaces with history and culture

> development, and religion and theology and all kinds of ideas. And physics is just one set of ideas that meshes with all these others." [1st Interview: 9/23/86]

Mr. Stewart's strong positive views about the course went beyond the historical cultural approach adopted by the textbook. He saw in the course the very right one that fitted a variety of factors and influences affecting his setting.

> "Project Physics was an impedence match, I guess, between course materials, philosophy coming in by textbook to us and our own prejudices, experiences, biases towards this, against that. And so it seemed to match not only...my philosophy but also seemed to match the kids at "Howard" High School. It seemed to be the right course for them" [1st Interview: 9/23/86]

When probing further into more specific characteristics of the textbook which he found favorable, Mr. Stewart mentioned two other points, readability of the textbook by student and flexibility in the organization of the contents:

> "The Project Physics course, the way it's organized is something like a string of pearls in a necklace. That each one is somewhat independent from the other." [2nd Interview: 10/14/86]

Nevertheless, Mr. Stewart was not without some criticism for the course which, however, was not limited to the problems included in the text as inappropriate but went further to include other specific content areas. Unit two about motion in the heavens, or, as he called it "structure of the universe", was seen to be unnecessarily long. The

same criticism was raised against parts of chapter ten that dealt with the discovery of the steam engine.

It is interesting to note here that the unit criticized for being too long, unit 2, was given around six weeks to deal with; while unit 3 which included the chapter on the kinetic theory of gases was given around four and a half weeks and at the end of the semester. Furthermore, a look on the contents of unit 2 reveals topics that often are included in physics books, separated into classical mechanics, and astronomy.

Unit 3, on the other hand, consists of topics which are classical physics topics. They are all central physics concepts. The steam engine and its development may be of more of interest to an engineering student than to a physics one.

Mr. Stewart criticized unit 2 for being overtreated. He appeared as though he concerted with this over-treatment by allocating more time for the unit. In fact some of the topics, particularly those dealing with astronomy, like the Ptolemic model, retrograde motion, the Copernican System, and Tycho's observations were discussed not only with a lot of elaborations but with very clear enthusiasm on the part of the teacher in spite of their inherent teaching and learning difficulties. Some extra activities were also discussed.

Mr. Stewart also criticized the section on steam engines and on the basis of over-treatment. Again he seemed

to respond accordingly in his classroom treatment of the topic. Actually his lecture on the topic was very thorough, full of minute historical and technical details about the topic with several related demonstrations.

The surface explanation of that would be to say that the teacher was trying to follow the textbook appropriation of time and contents for various topics. However, this explanation would not hold for the majority of the topics discussed and particularly for those included in unit 3. The superposition principle, interference patterns, standing waves, wave fronts, and diffraction are just examples of some of the very fundamental physics topics which were given cursory treatment in classroom but occupied a reasonably appropriate space in the textbook.

A more plausible explanation would be in terms of what Mr. Stewart often talked about: his personal biases. In various discussions and interviews with him, I learned that his father had been a tool engineer. He himself spent two years as an engineering student before he moved to physics. As a physics senior Mr. Stewart had a college teaching assignment where he taught some astronomy and had an easy access to the college observatory. This academic background seemed to have been carried over and sustained actively throughout the twenty-eight years of experience in physics teaching Mr. Stewart garnered.

The third comparative dimension of Mr. Stewart's views about the textbook was almost always clear whenever he

talked about the Project Physics course. The PSSC physics textbook was a sort of a reference point in his discussions of the HPP textbook. The implication was always that the PSSC was too difficult, elitist, monolithic in its structure, and restrictive in its method of teaching physics; while the HPP was almost just the opposite. The following excerpts from a transcript of an interview illustrate that. In this excerpt, and after he had explained to me how the HPP's humanist approach to physics made it reachable by a greater number of students, he started to respond to my question about other dimensions of the HPP course that made it attractive to him:

> "Well, one thing that sets this book apart from the PSSC was the book's inherent readability on the part of students. It didn't contain extraneous materials. It didn't proceed in a linear way, the way as I explained to you the PSSC was: a structure that you bought in a certain order, in a certain sequence, interlocking of ideas in a certain way. And you have to get them all apart or they didn't fit. Project Physics seems to be more like pearls that you can arrange in different ways. You can strand out linearly. Or you can arrange the pearls in a different manner. A good deal more flexible than the PSSC, not only from the text but the back-up materials the Project Physics did" [1st Interview: 9/23/86]

Being a veteran teacher, Mr. Stewart did have a long experience of using the PSSC course. I had observed him using the textbook for a second physics course called "Advanced Physics". And it may be argued here that just like Mr. Davis who was teaching the IPS in addition to the HPP and referring to both of them when discussing some

issues, Mr. Stewart might have been simply explaining things in terms of what he had experienced. While this is a legitimate conclusion, I believe there was another important reason that kept Mr. Stewart defending the HPP and criticizing the PSSC.

The PSSC has gained the reputation of being a serious physics course. It reflected the structure of the discipline, physics, and, thus, gained respect and approval of the physics community. Historically, it was very much influenced by physicists. The HPP, on the other hand, was in some ways a reaction to the PSSC. Physicists, or scientists in general, as well as humanists contributed to the contents and structure of the course. Association with the PSSC on the part of any physics teachers would, thus, have certain academic implication if the assumption that high school teachers consider themselves subject matter specialists, is granted. Actually this point became clearer as the study went on. And those comparisons, Mr. Stewart made between the two courses would appear, from a larger perspective, as a way of defending his approach to physics teaching and a sort of reply to any unspoken criticism of the way the subject matter of physics was dealt with in classroom. Mr. Stewart did not seem willing to dissociate himself completely from the PSSC in spite of all his criticism of this course. The implication of that will be discussed as the wider picture of dealing with the subject matter will become clearer.

Description of Teachers' Knowledge of Physics

Examination of data from various sources: classroom transcripts, worksheets, interviews, and fieldnotes, revealed various possible levels of description of teachers' knowledge of the subject matter. Each unit or chapter would be a possible level of description. A concept-level, or a topic-level would also be justified for some purposes.

Description at any level would imply certain trade-offs. Focusing on teachers' knowledge of physical concepts as such would, for example, provide us with detailed descriptions of teachers' understanding and treatment of these concepts, while, on the other hand, it would say little about higher order physics knowledge structures. Inversely a unit-level description would sacrifice specificity for the broad-scope perspective. A search for an optimal level of description would somewhat be helpful. However, there were certain important dimensions in teachers' knowledge which eluded any one level of description. For that reason I decided to choose two levels of description.

In the first level I will present a sort of overview of various dimensions of teachers' knowledge of the subject matter as they presented themselves in the data. This level was the wide-angle perspective on teachers' knowledge. It would also be fitting to describe it as a macro-level description or a sweepview. The macro-level description practically all the contents covered in the two courses

during the period of observation (e.g., Fall semester 1986).

In the second level more focusing was done. One central topic from the HPP course, was chosen. Various dimensions of teachers' pertinent knowledge as expressed in various sources of data will be presented. This will be called "topic-view" description. It examined teachers' various aspects of knowledge of the central topic: momentum and conservation of momentum. The topic includes central physical knowledge the presentation of which I fully observed in the due course of my observations. The way it was treated in class was somewhat typical of what the teachers did in other topics. Discussion of other specific situations outside the realm of those topics will be brought in whenever deemed explanatory.

A Macro-Level Description of the Teachers' Knowledge of Physics

Examination of the corpus of data revealed several knowledge clusters or major categories or dimensions of teachers' knowledge of physics and physical science. In what follows each knowledge cluster will be discussed through a variety of examples.

Knowledge of Vocabulary Terms of Physics

Both teachers employed a very large body of physics vocabulary terms. This stock of basal physics knowledge included a range of different physics words and concepts. This range may be described under three sub-categories:

factual and notational terms, experiential or concrete terms, and theoretical or abstract concepts.

Factual and notational terms included a host of bits of factual information as well as notations. Teachers knew very many physical constants and their values, e.g. speed of light, speed of sound, Planck's constant, constant of universal gravitation, periods of revolution of some planets, etc.. Their stock of physical knowledge included also many symbols and abbreviations. Apart from concepts like force, mass, and velocity which will be discussed later, teachers knew the symbols used to stand for these and many other similar concepts. They knew, for example, that "F" would always stand for force, "f" for frequency, " λ " for wavelength, " Δ " for a small increment and so on. Their usage of these symbols as well as many others, like those of elements and compounds, reflected their recognition of the conventional consistency required by physics books and the scientific community at large in using them. These symbols are an important part of the scientific communication. Those conversant in physics or scientific knowledge speak them fluently. They seem to know very well what a Greek letter would stand for in the context of a certain conversation.

Both teachers knew also a lot of abbreviations like rpm (revolutions per minute), AU (astronomical unit), Hz (Hertz, a unit of frequency equal to a cycle per second), and so on. Again these abbreviations were used in various aspects of

the teachers' classroom physics discourse.

A second sub-category of teachers' knowledge of physics terms was found to be related to what may be described as concrete or experiential concepts. These would include terms or concepts which have clear concrete denotations or referents. They would include terms used to refer to some physics artifacts like laboratory equipments, for example, flasks, beakers, timers, oscillators, hydrometers, oscilloscopes, thermometers, celestial spheres, etc.. Included under this sub-category would also be names of many scientists like Newton, Galileo, Kepler, etc.; names of substances like copper, oxygen, methanol, etc.; and names of other physics or science objects like names of planets, moons, and stars.

Many of these experiential concepts may have two levels of meanings. One level would be the direct denotational meaning given by the term. A term like Venus may mean that planet which you can see at a certain point in the sky. It could also mean that planet with part or all of its known physical characteristics. Only the first meaning was implied above. The second meaning which explicates the features of the object referred to may be more appropriately included under the third sub-category.

The third sub-category of physics terms and concepts teachers knew included words and expressions with abstract or theoretical denotational meanings. However it should be emphasized here that the degree of abstraction may vary from one concept to another. In other words, there would be a continuum of the degree of abstraction involved in these terms ranging from terms with some degree of experiential meaning like "force" and "work" to terms with very little direct experiential meaning and much of theoretical meaning like energy, rigid body, elastic collision, inelastic collision, time, mass, atom, molecule, electron, neutrino, etc..

The partially experiential meaning of some terms may reflect the historical genesis of those terms as originating from our commonsense language. There is an overlap of meaning between the commonsense usage of the word "work" and its usage in physics. While this overlap may be helpful in physics learning or teaching during its very elementary stages, it is irrelevant at more advanced stages of physics knowledge articulation. Indeed, it may be argued that eventually we have to totally discard the commonsense meaning whenever we talk physics. This point may have some serious implications not only on the often stated dichotomy of scientific and commonsense knowledge, but more relevantly here on physics or science teaching and learning. I will come back to this point in the next chapter. Suffice here to say that teachers did know and use a large body of these

concepts in their classroom physics discourse.

Knowledge of Higher-Order Physics Relations

Both teachers knew and used a variety of relations among various physical concepts. Relations also varied in the degree of abstraction and the number of concepts expressed or included in them. Some of them were only merely reciprocal definitions among two concepts like the reciprocal relation between the period of revolution "P" and the frequency "f", $P = \frac{1}{f}$. Others included more than two concepts and were stated as relations or laws.

While some of these relations and laws combined concepts with some clear connections with commonsense knowledge and experiences, others were of less experiential denotations. Definitions like average velocity, which included the concepts of distance and time, and density which included mass and volume, were examples on such relations with some experiential references. The relation between the wavelength of a disturbance, its velocity and frequency would have less experiential connections. Some of those relations were still of higher level of abstraction like equations of straight line motion with constant acceleration, and the relation between the total distance fallen (in a free fall situation) and of both the total time of fall and acceleration of the falling body, assuming that the body started from rest:

$$d_{final} = \tfrac{1}{2}at^2_{final}$$

Laws known and taught by teachers were of two different kinds: empirical laws, and derivational laws. Again in the case of empirical laws concepts encapsuled in them did have some observational or experiential meanings, though of different degrees from one another. The law of lever implied in the construction of unequal-arm balances included concepts like weight and distance with some clear connections with our daily experiences. Kepler's empirical laws: law of areas, law of elliptical orbits, and law of periods, are of less clear connections with commonsense experience.

Derivational laws included those relations derived through mathematical deductive reasoning from certain theories, postulates, or hypotheses. These laws are still more seemingly detached from everyday experiences. The first two laws of thermodynamics would be examples of such laws. The first law, which is another statement of the general law of conservation of energy, was derived from the postulates of the kinetic theory of heat. This law summarizes the relationship between the change in the total energy of a system " ΔE", the net work on the system " ΔW", and the net heat transfer to the system " ΔH"

$$\Delta E = \Delta W + \Delta H$$

All of the three concepts involve a high degree of detachment from everyday experiences. The second law is still of less observational connections. One way to express this law would be in the highly abstract form:

$\Delta S = 0$ for reversible processes
$\Delta S > 0$ for any other processes

where " ΔS" stands for the change in the entropy which is defined as the heat gained by the system "ΔH" divided by the temperature of the system "T".

Clearly at this stage such laws are highly theoretical. However I will refrain here from stating that they are totally mathematical or abstract in order to avoid any philosophical discussion about the nature of mathematical knowledge and whether or not it is totally or purely theoretical. I will, however, hold the belief that the mathematical formulations implied in these and many other similar laws and theories held by teachers raise the level of detachment from everyday experiences and observations to varying degrees. To stretch this statement beyond what is discussed in classroom, we may think of some mathematical formulations, like quantum mechanical ones, as completely detached from what we experience in everyday life. However to say that such a knowledge would become totally abstract and theoretical is, I think, beyond the knowledge given. After all if such a thing as complete abstraction exists, then it should be beyond the realm of physics which is concerned with nature and its phenomena. Mathematics as a pure entity is not a science.

Teachers' knowledge included some theoretical postulates and propositions some of them in the form of theories. Galileo's postulate of the uniform acceleration in free fall, Newton's universal gravitation, postulates of

the kinetic theory of heat, and kinetic molecular theory were all discussed in one way or another. Relativity as a theory was invoked occasionally but never in specific aspects. This category of knowledge represented the most sophisticated type of knowledge about the subject matter discussed in classroom. It ranks high in the hierarchical structure of our scientific knowledge.

Teachers' Mathematical Knowledge

In their explanation and application of various laws and relations teachers relied upon another dimension of their knowledge, namely, their mathematical knowledge. Practically all relations discussed were formulated in simple algebraic forms which required for their application simple manipulations mostly of the form of finding an unknown in first order equations. On some instances where more sophisticated knowledge was required teachers still showed their willingness to go into that sophistication. However, those instances were very few in number. Besides algebra, teachers knew and used a lot of geometry. However, all the geometry used was limited to plane geometry, dealing with plane figures only. Points, lines, triangles, spheres, ellipses were brought into discussions at various occasions. Vector manipulation, for example required for their representation a lot of knowledge about points, lines, triangles, parallelograms; while the unit on astronomy required knowledge on circles, ellipses, and sometimes

spheres. Teachers did know all the fundamental relations and characteristics governing all planes mentioned. Trigonometric functions, especially the tangent function, were also discussed. Although teachers, on some occasions, articulated some of their knowledge about spherical geometry, that domain of their knowledge did not seem to be of significant relevance to the classroom setting.

Teachers' Philosophical and Historical Knowledge of Science

I have deliberately included the philosophical and historical dimensions under one knowledge cluster in this section. This is because I believe that in the research setting there was a strong connection between the two. As explained earlier the HPP adopted an historical approach to introducing physics ideas. This inevitably had certain philosophical implications. Both teachers, therefore, were occasionally involved in historical as well as philosophical classroom discourse. However, while the teachers were fully aware of the historical component of their discourse and referred to it as such, rarely, however, they explicitly referred to some of their physics discourse as philosophical. They never left me with the impression that they were deliberately or consciously involved or even interested in a classroom discussion about some philosophical issues pertinent to physics knowledge. This became clearer when I tried, through interviewing them, to probe for some philosophical dimensions in their knowledge.

Different understandings appeared when some philosphical terms and expressions were first discussed. Examples of these would include subjectivity and objectivity in science, induction and deduction, and progress in science. After detecting some differences in our understandings of their meanings, I decided to discuss them first with the teachers in such a way that would bring a shared understanding of these expressions before documenting the teachers' pertinent views. That, however, did not eliminate all differences in our understandings of meanings of certain terms. When, for example, I asked whether science progresses in a linear fashion, implying a certain direcitonal progression toward a certain goal of better or more truthful knowledge, or by replacement, implying the supersession of old ideas by new ones, I discovered that the word linear was understood differently. I had, in a subsequent interview to ask the same question but differently.

What I had learned from that was both revealing and useful. Teachers had their own meanings and understandings of certain terms and expressions. These meanings seemed more connected with their daily work and experiences than with the researcher's or any other seemingly objective forms. It is interesting to note here that the initial response of Mr. Stewart to the word 'linear' reflected his usage of the word to describe the structure and progression of physics knowledge as it is portrayed in school physics textbooks without any reference to value judgement or

verismilitude issues pertaining that knowledge. I, thus, became more careful about using some terms in my discussions. Whenever in doubt about mutual agreement on certain meanings, I attempted to, first, discover the teacher's counterparts of my words or ideas, and second, conduct the discussion or interviews within the medium of his contextual meaings, not mine.

That is why from an 'objective' framework the teachers did not appear to philosophize during their classroom discussions. They did not claim to use philosophical arguments in their discussions. But their counterparts of what we term as such were in there. Their historical accounts of the development of physics knowledge did have certain bearings on whether physics progress was linear or not. Their accounts of accepted modes of reasoning in explanation and prediction of natural phenomena, their acceptance of certain scientific assumptions and principles, indicated this tacit dimension of their knowledge. It was these considerations on my part that made me pursue the search for more understanding of their philosophical knowledge.

Analyses of transcripts of interviews and classroom recordings and fieldnotes showed that teachers knew a lot about the history and philosophy of science. I have organized this body of knowledge under two major categories: knowledge of development and growth of scientific knowledge, and knowledge of the nature of scientific knowledge. I will

use the term science here but with the understanding that much of the discussion was primarily related to physics but then in some way generalized to science, which was meant to be physical science.

Teachers' Knowledge of the Development and Growth of Scientific Knowledge

Two subcategories of knowledge may be discussed within this context: teacher's knowledge of scientific historical acounts, and their knowledge of the logic and reasoning in organizing and sequencing physics knowledge.

Teachers' Knowledge of Sciencitic Historical Accounts

Both teachers knew a great deal of historical accounts that dealt with the development and progress of scientific ideas. Names and ideas characteristic of the Greek scientific culture were frequently discussed and referred to. Aristotle's ideas about motion, Eratosthenes' attempt to measure the size of the earth, Ptolemy's book "Almagest" and his famous system were very frequently discussed or referred to when discussing other scientists' corresponding ideas. The middle ages were left almost blank in the sequencing of scientific knowledge discussed. Only very few and causal references were made to the Moslem science that flourished between the seventh to the thirteenth century.

Teachers knew a great deal about the history of European science that started later, after the 16th century. Major physics discoveries and ideas were intensively discussed and compared with those of the Greeks. A lot of

biographical knowledge about great scientists like Galileo, Kepler, Brahe, Copernicus, Newton, and Libnetz were also brought into the classroom discourse by both teachers. Both important discoveries and some minute personal details about those scientists were often discussed. Mr. Stewart, for example gave a biographical introduction of over 900 words about Newton before starting a discussion about his laws of motion.

The history line adopted by the HPP textbook and utilized by the teachers was not limited to a narration of names, places, ideas, and major scientific discoveries. Other social issues acting on, and being influenced by, science were also raised. Among these issues teachers knew about the cultural and religious milieu that prevailed in Europe at various eras. They knew how science battled with some of those issues.

Teachers also kept the correct chronology of scientific events. That was clear in the chronological order that permeated the major topics they discussed. It was also evident in some of their explanations of the development of certain ideas or theories like the historical development of Newtonian mechanics and the theories of heat.

As far as this historical dimension of teachers' knowledge was concerned, I was not able to detect major significant differences between the two teachers' pertinent knowledge. The only difference that appeared to me was a matter of quantity rather than quality. Mr. Stewart seemed

to have a more elaborate and detailed historical account than what Mr. Davis had. However both appeared to know more or less the same key issues embeded in these historical accounts, which were a central part of the HPP course content.

Teachers' Knowledge of the Logic and Reasoning in Organizing and Sequencing Physics Knowledge

As science progresses it needs organization which in turn requires among other things some form of sequencing. The story line of the development and progress of scientific knowledge served several purposes. It, for example, examined the interfaces between science and several social issues. Both teachers, as was explained earlier, found that educationally helpful and useful.

In a sense teachers used this story line, as Mr. Stewart explained: "to hang physics concepts from". In other words it was utilized not only as a means of exposing or explaining what they knew about physics, but also as a way of sequencing and organizing their knowledge. This was done at several levels. First, across the various chapters and units they discussed, there was a directional trend of moving from old, simple, and classical issues in physics like ideas about motion, to later more sophisticated ideas like electromagnetism, to modern topics like radioactivity, and models of the atom and nucleous. Second, within each particular topic or chapter there was always the tendency of moving from the old treatment to the more recent pertinent

ideas.

Hung on this line through the chapters, and segments of lines through various topics of sequencing, were the teachers' knowledge of concepts, relations, and theories or models organized in large structures of knowledge which Mr. Stewart called "interlocks". These "interlocks" included whole areas of physics knowledge like, mechanics, optics, and electromagnetism. But these chunks of knowledge were not totally independent structures. As will be explained in the next section they were seen as "interlocking with each other" in a consistent, and still larger, structure of knowledge. Both teachers, but with varying degrees, knew not only how to preserve a consistency and coherence within the different structures they knew, concepts, relations, and theories, but also how to mesh, or "interlock", these structures in a larger picture which they called science or physics. They knew, for example, that Maxwell's equations brought together the classical fields of optics and electromagnetic radiation in a unified electromagnetic theory.

The teachers used mathematical and logical reasoning to preserve the internal consistencies in the relations and laws they knew. For example, each of Newton's Laws of motion and Kepler's laws of planetary motion would be a knowledge structure that was kept internally consistant through the mathematical reasoning involved in the formulation of that law. Galileo's logical reasoning about the constancy of acceleration involved in free fall which

the teachers knew was another example on this dimension of teachers' knowledge.

The teachers' knew and practiced deductive reasoning on a wider scale. They deduced Kepler's laws from Newton's Laws and universal gravitational postulate, and the relationship between work and heat from the assumptions of the kinetic theory of heat. Through such reasoning they not only explained how science progressed, but also how they organized their knowledge of science in larger structures with the help of more encompassing unifying principles. In an interview with Mr. Stewart he gave the following example while talking about Maxwell and his electromagnetic equations:

> "...that in his laws he explained interaction between electricity and magnetism. He predicts, surprisingly, that light is an electromagnetic wave. And that in his laws he tried to include the reference to the ether...the references to ether drop out. And so here his laws unify electricity and magnetism and lots of other things, bring them all together in the same way as Newton did with mechanics. Synthesis takes place in science from time to time" [3rd Interview: 11/26/86]

Induction as a mode of reasoning was used but somewhat loosely. In the HPP course a very few lab activities were done in which inductive reasoning was employed to organize the findings. In carrying out an experiment on acceleration, teachers did use some elements of inductive reasoning in trying to reach the conclusion that the object they used for that experiment was accelerating constantly.

However due to the fact that students were told in advance that the main idea was about constant acceleration, the whole experiment would reflect a mode of verification rather than an exercise in induction. In the HPP course there were several similar activities which were attempted by means of somewhat deficient form of induction. Among these were the Kepler's second and third laws. The situation was not fundamentally different in the IPS course where all activities were organized with the suggestion of using inductive reasoning. When Mr. Davis wanted to teach the idea of conservation of mass through an experiment where some ice in a cup was converted to water, he simply gave a list of values supposed to be " m's", or changes in the mass after some hypothetical measurements, and asked students to draw a histogram of these values in order to show them that " m's with negative values where almost like those of positive values and therefore they would cancel each other and the net change in mass would be zero. The technical statistical procedure and language pertinent to that was not used.

This does not mean that teachers did not know how to reason inductively. In fact they did. This became clear as I started to talk to them about other alternatives in teaching physics. In the next chapter it will be explained that in fact they had used in the past an inquiry approach that required inductive reasoning, but for a variety of reasons they eventually settled on doing what they did which

implied among other things using a deficient form of induction which I call psuedo-induction.

Finally the teachers knew that induction and deduction were ways of reasoning embedded in what they did. However, they did not express that knowledge explicitly in their discourse. In the context of talking about them in an interview, Mr. Stewart stated:

> "I am not sure that we say, today we're going to study logic. But I think there is a component of that in the course; and one of the places where I think it probably pops into the course without planning for it, is when we look at the classical experiments in physics". [3rd Interview: 11/26/86]

Teachers' Knowledge of the Nature of Scientific Knowledge

The teachers'science discourse reflected some of their scientific philosophical knowledge. They occasionally expressed what they knew or believed in as far as the nature of scientific knowledge was concerned. In the classroom they did talk, for example, about the nature of scientific laws and knowledge in general, about the significance of some scientific accomplishments, and about hypothesizing. But some other issues like subjectivity and objectivity in scientific knowledge, whether science progress by accretion or displacement of old structures of knowledge by new ones, and the relationship between scientific knowledge and "truth" were generally beyond their discussion. To elicit their responses on such issues I interviewed them directly on these matters. Analyses of their discourses and

responses revealed a lot about the teachers' perspectives. When asked about how he viewed physics knowledge, Mr. Stewart responded:

> "From the outside down I view physics and science and the exact sciences generally as a mosaic of interlocking ideas. And all of the interlocks, and all of the cross connections are in, actually, three dimensional matrix of ideas; and concepts and constructs are all internally consistent and externally consistent. That there is this structure, this logic that is absolute and inviolable within the framework of these ideas and laws and rules. And of course you get down on the smaller scale of atomic physics how things work out and down to the structure of the nucleus. You can get down to those points. But I think the first thing you should come across as somebody beginning to study physics is that the ideas are both correct within the phenomenon, optics ideas are correct within the realm of light, but they are also correct when these phenomena are extended to other areas such as electromagentic wave behavior. Generally that everything locks together in a structure an interlocked structure. I think this is number one picture that I would like students to get out what physics is." [1st Interview: 9/23/86]

There are a number of elements in this picture, the "jigsaw puzzle" analogy as he referred to it on another occasion, which needs to be emphasized. Apart from the patterns of organization, sequencing, and consistencies of physics knowledge involved in this picture, Mr. Stewart seemed to have stated or implied the following:

- Physics is one of the exact sciences.
- The logic involved in physics knowledge is "absolute and inviolable."
- This picture is important for a learner of physics.

We shall see in the next chapter how this view of science was translated by the teachers into a rationale to cover a very wide domain of physics contents.

In the same interview and after Mr. Stewart explained to me his conception of physics, I asked him about the relevance of old physics, Aristotelian physics for example, to what scientists or physics teachers do, since these ideas had been superseded by difference systems of thought. His response came to indicate his belief in the relevance and utility of past ideas.

> "I think we operate at all levels at once. That we are all Aristotelian to this day. We talk about the sun rising and the stars turning and the way the planets set and rise, and so on. We are really describing our world in Aristotelian terms. It is appropriate for us to speak in those terms; and likewise there are times when Newtonian physics is perfectly adequate for what we're doing and how we explain things. There's other times when we need to go the added sophistication of relativistic corrections for Newton's equations. So it depends where we are working...but we work on these levels at once...and so it wouldn't make any sense, I would think, to start kids with general relativity and work back with special relativity and then back to Newton where this is a special case of special relativity. That would be a logically absurd direction to go. So it seems more reasonable to go from the simple ideas, simple constructs as man before sophistication and technology was, and as man developed these ideas, and bring them up to where you have a foundation for special theory of relativity. So I think the relevancy is that: number one, that it's a story line to hang physics concepts from, and it's in keeping with all our everyday experiences to think of our physical concepts on many different levels. So what Project Physics has that most of physics courses don't have: It has a continuity." [1st Interview: 9/23/86]

When asked what he would perceive down the road along this line of progress he had described, Mr. Stewart responded:

> "I don't think we will ever get at the point where we will have more answers than questions. And so happily the field of science and the investigation of science will always have things to work on, to ponder about. And I don't think we will ever get at the end. We're looking now at the tougher questions, the questions that involve larger scale of operations to a smaller scale of operations than we've ever been able technically to deal with before..." [1st Interview: 9/23/86]

So Mr. Stewart thought of science as an endless process. When asked if he perceived any change in quality in the nature of our scientific knowledge, or whether our present status of knowledge is a real progress and advancement in scientific knowledge, Mr. Stewart's response was:

> "I think where we are in science right now, whether it's physics or chemistry is in lots of ways like what we've been. The conversations that are going on now about creatitionism versus evolution, for example, are very similar to discussions that took place in Galilean days: of whether the earth moves or not, the Copernican view, in that scientific evidence seems to force philosophical changes in some of the basic structures of other areas of thinking: in theology, and so on. I think some of that sort of thing is still going on. But the dimensions of science, the areas in which science is being investigated, is much wider now than it ever had been before." [1st Interview: 9/23/86]

As for the issue of subjectivity-objectivity of scientific knowledge, Mr. Stewart had the following to say:

> "Science by itself in its purity is, maybe, the most objective theories of human endeavor, maybe next to mathematics. But the application of science through technology, through economics, that is put on that through politics, then science as it's applied become subjective. Physics, for the greatest part, is very objective" [2nd Interview: 10/14/86]

The teachers' answers for the question about induction and deduction and their role in physics knowledge and physics teaching were unusually brief. Mr. Davis responded by simply saying: "I really don't know!" Mr. Stewart, however, explained that the place where induction and deduction would come was the context of what he called "classical experiments." As an example on that, he cited the e/m experiment - charge of the electron over its mass. He thought that the framework of the experiment as well as the "logic that evolved out of the results of that experiment" that went beyond the experiment itself, represented a case where induction and deduction were used both in our physics knowledge and its teaching. However, induction and deduction as such were not among the teachers' classroom vocabulary words. The unease, I suspected, that characterized their answers discouraged me to prove for more specific details on that.

To summarize, Mr. Stewart saw science as a very objective endeavor, and that physics is exact. Physics is a mosaic of internally and externally consistent "interlocks" of ideas. The logic that preserves that consistency is absolute and inviolable. Various systems of ideas, old as well as new, are still important and usable. Each system may be described as contextually appropriate. "It is appropriate for us to speak in these terms (Aristotelian terms); and likewise there are times when Newton physics is perfectly adequate for what we're doing." So each set of ideas may be evoked, and appropriately, at the right time. Science, according to Mr. Stewart, progresses in a continuous way where recent ideas become simply of a larger scale of operations. Today's problems are also wider and more questions are waiting answers than ever before. Mr. Stewart saw no end down the road for this progress. He also described some modern disputes over some scientific issues as similar to old disputes over other issues.

As I was interviewing Mr. Stewart over some of these issues I realized that he was not at his ordinary ease answering them. Particularly the questions about the issues of subjectivity-objectivity, induction-deduction, and progress of science. That is why I did not probe further for more explanation about these and other philosophical matters. At one point I suspected that he was thinking of my philosophical questions as irrelevant to his daily business of dealing with mundane problems and realities.

Indeed, I asked him if he found some of my questions difficult to answer or irrelevant. With an affirmative gesture by his hand he said "the subjective-objective question."

For Mr. Davis, the key ideas about the nature of science pertain to modeling and models. Through the process of modeling scientists can explain and predict natural phenomena.

> "I think science is..., it certainly has facts, and it certainly is a process. But I firmly believe science is a way of looking at the phenomena of the world, and I guess being able to predict what would happen with it. It's a case of modeling. I think of science as modeling, whether it's modeling physical things, or whether it's biological things. It's just...it's looking at the world and making observation, collecting some data and making a model that would describe the particular thing that we look at. As we watch it we see it happen, and we can predict when it's going to happen again" [2nd Interview: 10/14/86]

In classroom Mr. Davis often talked about mathematical models and what he called "breaking of a pattern". The following is an example where he was making an introduction to Kepler's empirical laws:

> "One of the most important points to realize in this chapter is that Kepler does the work without any previous theory to base it on. He just takes the numbers and looks at patterns. That really comes down to a bottom line, I think, of what I see in science as the breaking of the pattern, the understanding of the pattern." [Fieldnotes: 11/17/86]

So for Mr. Davis the pattern is out there in nature and scientists work to "break," or "break" into, those patterns.

The ideas of assuming objective forms of truth out there in nature and the discovery of these forms of truth was clear at least on another occasion where Mr. Davis was talking about momentum and the conservation of momentum.

> "Sometimes you worry how human beings ever stumbled on such ideas of mass times velocity to be momentum; and that momentum is conserved before and after collision. Momentum is conserved in all cases. I don't know!" [Fieldnotes: 11/24/86]

"Breaking" the pattern, or simply "stumbling" on the truth was described by Mr. Davis as "a spontaneous" process that may happen to a person at a certain moment in time. It was not something that would come gradually through more and more intensive work and argumentation, but rather as a swift revelation on the part of the scientists working with the data:

> "I think it's more spontaneous; that there is a sort of collection of data and a period of time where it's trying to be explained; and a person happens to be born, and then happens to be working with the data; and may be there is a lot of chance, or a sort of spontaneous creation at this point. At least that's in my mind how I see where many theories have come." [1st Interview: 9/23/86]

What I found interesting in the last quotation is the phrase "spontaneous creation". If introducing a theory or a pattern is an act of creation on the part of the scientist, how would that square with the idea of patterns out there in nature? This conflict of views became clearer when Mr. Davis was asked specifically about subjectivity-objectivity

issue in scientific knowledge. Mr. Davis gave the following surprising response:

> "...and I watch my students collect data. I watch them change data. I think, to some extent, like all students, scientists are the same. Either some data is interpreted or rearranged what you like it to be, or interpret it as you like it to be, to some extent. So science is not as objective as it may be described. Scientists are doing similar types of things. And hopefully they will communicate enough between them...so that these subjective anomalies can be identified and washed out. I am sure that scientists are no different than me. You get to a certain point where you want something and you see it in there. So there is a lot of subjective nature to it. You hope it would be objective." [2nd Interview: 10/14/86]

As far as the significance of old physics ideas is concerned, Mr. Davis thought that the "idea of change" was what he considered important. In other words the contents of old systems of thought were not essential but rather the process of change itself was. He also believed that as models change over time, the new "models" become "better" than the old ones.

> "One of the side goals, I think, that I see was important is this idea of change; and how people can have a new model, a new description of nature; and the resistance to change certainly exists; and then there is an acceptance if the model does continue,.....sort of model building; and how models are introduced, accepted for a while and new models come in. If the new model is better than the old model, and explains more, then the old model is somehow... What is good is accepted and what is not fitting them reject that and continue on." [1st Interview: 9/23/86]

When asked about induction and deduction and how they are used in scientific reasoning, Mr. Davis noted that though they were important in scientific inferences and he would use them in both courses he taught, still:

> "...the two words are not used often enough to become part of the language that we are conveying to the kids. We have not used them in that formal sense". [2nd Interview: 10/14/86]

Mr. Davis, therefore, saw science as a case of mathematical modeling. Scientists may, through a process of "spontaneous creation", "break" the "models" that are out there in nature describing certain phenomena. Scientists are somewhat subjective in their attempts to explain and understand what they see. When a model is discarded it is because there is a "better" one that can explain more contents than the first one. The idea of change in models explaining nature is educationally useful. In his response to the subjectivity-objectivity issue, Mr. Davis raised what may be described as a social dimension in physics knowledge. As quoted before he expected that communication among scientists may "wash out" "subjective anomalies" in scientific knowledge. Like Mr. Stewart, Mr. Davis found some terms and questions a bit beyond the context he was working in.

A Micro-Level Description of Teachers' Knowledge of Physics: Conservation of Momentum

In this section, I will closely look at the two teachers' knowledge related to the concept of momentum and the law of conservation of momentum. This, however, will be preceded by a review of the related ideas discussed in the textbook. In the next chapter the way those topics were treated or discussed in the teachers' lesson plans and classroom discussions will be examined as a specific example on how teachers dealt with the subject matter.

The ideas about momentum and conservation of momentum came in chapter nine of the textbook, the first chapter in unit 3, titled: "The Triumph of Mechanics." Prior to this chapter various physics developments related to motion phenomena were discussed including Newton's laws and their applications to the motion in the heavens. The intent of the third unit is to give some important examples on how the principles of Newtonian mechanics, hitherto applied with the motion of simple isolated bodies like planets and projectiles, were extended to cover more complex phenomena. This process required, among other things, the introduction of new physics concepts, and the emergence of new principles and laws. This eventually led to a new way of looking at mechanics. Of these concepts and principles, momentum and conservation of momentum were presented as a powerful way of solving some scientific problems. The idea of contemplating a mechanical view of the world was consequently inevitable throughout the discussion of the unit in the textbook.

Chapter nine on the conservation of mass and momentum included seven sections: conservation of mass, collisions, conservation of momentum, momentum and Newton's laws of motion, isolated systems, elastic collisions, and Leibniz and the conservation laws.

The first section discussed the historical developments of the idea of conservation of mass. It started, as usual, with some of the related Greek ideas, and then leaped two millenia to talk about Francis Bacon's corresponding ideas in his Novum Organum. Gradually, the section moved to a discussion of the works of the French chemist Antoine Lavoisier (1789) in which he produced some scientifically sound experimental evidence for the assumption that the mass of any closed system remained constant. The precision involved in that evidence was investigated and the earth as an approximately closed system was discussed.

In the second section, the concept of collision was discussed in order to show how scientists and philosphers starting with Descartes, in 1620, perceived a certain physical property or quantity that had to do with motion would be conserved in collisions of bodies. Descartes himself defined that quantity to be the mass of the object multiplied by its speed, and called it "quantity of motion". The section also attempted to explain the insufficiency in Descartes' assumption.

Section three built on the previous one particularly Descartes' definition of the "quantity of motion" and his

conception of its conservation. The concept of "momentum" was introduced as a new concept that superseded the concept of the "quantity of motion". The definition of "momentum" became different: mass of the body times its velocity; and the new conception of conservation of momentum also became different. In the case of two carts colliding with each other, the following equation was given as a representation of the law.

$$M_A \vec{V}_A + M_B \vec{V}_B = M_A \vec{V}_A + M_B \vec{V}_B$$

Where M_A stood for the mass of cart "A",

$\vec{V}_A$ stood for the velocity of cart "A" before collision,

M_B stood for the mass of cart "B",

$\vec{V}_B$ stood for the velocity of cart "B" before collision,

$\vec{V}_A'$ stood for the velocity of cart "A: after collision,

$\vec{V}_A'$ stood for the velocity of cart "B" after collision.

Both the importance and the universality of the law was emphasized. The general form of the law for a number "n" of colliding objects was also given:

$$\sum_{j=1}^{n} (M_j \vec{V}_j) \text{ before} = \sum_{j=1}^{n} (M_j \vec{V}_j) \text{ after}$$

In the following close-up section analysis of collision in two dimensions was given. A reference to the applicability of the law in three dimensional cases was also made but no examples or analysis of this case were attempted.

The fourth section attempted to reason out the law of conservation of momentum from Newton's laws. It showed mathematically how Newton's second law may be formulated in a way that would, with the application of Newton's third law, deduce the empirical law of the conservation of momentum. A wording for the law was given "The momentum of any system is conserved if one condition is met; that no net force is acting on the system". The section also emphasized that Newton's laws may be derived from this new physical principle which was indeed more fundamental than Newton's laws. Newton's laws and the law of conservation of momentum were not consequently separate or independent laws of nature. A detailed derivation of conservation of momentum from Newton's laws was then given.

Systems, isolated systems, and friction as an interfering factor in situations dealing with momentum were explained in section five.

Elastic collision and the historical experiment on hardwood balls were introduced in section six. Huygens' solution (1668) or explanation of the phenomenon was given in a mathematical formulation. For the two balls, suspended as two pendula, as one of them was released from rest at a certain height and swung down and struck the other, which had been hanging at rest, Huygen's equation was given as the following:

$$M_A V_A^2 + M_B V_B^2 = M_A V_A^2 + M_B V_B^2 \quad ,$$

where the representation of the symbols were taken as before.

In the final section some related scientific contributions were briefly discussed. Leibniz (1680) also realized that a certain physical quantity related to motion was conserved. However he did not agree with Descartes' "quantity of motion". Instead he suggested a different quantity calls "vis viva", and defined it as mass of the object times the square of its velocity. In his attempts to explain how this quantity was conserved in certain situations, Leibniz indirectly anticipated some fundamental connections between energy and the motion of molecules.

Teachers' Knowledge of the Law of Conservation of Momentum

A detailed analysis of various related transcripts, fieldnotes, and worksheets and handouts revealed a good agreement between the micro-level and macro-level analyses on the major categories or dimensions of the teachers' knowledge. In what follows I will describe the teachers' knowledge of the law of conservation of momentum along the categories infered in the general picture described before. I will, whenever possible, refer to any interesting variations between the two conceptualizations.

Teachers' Knowledge of the Vocabulary Terms Pertinent to the Topic

Teachers' knowledge included a host of concepts and symbols related to the topic. Physics concepts included:

mass, speed, velocity, vector, scalar, elastic collision, inelastic collision, kinetic energy, open system, isolated system, and momentum. Both teachers used the same conventional symbolism adopted by the textbook. Table (1) below summarizes the system of symbols they both used:

Table (1) Symbols and Their Referents Used in Teaching Conservation of Momentum

Symbol	Referent
V	speed
$\vec{V}$	velocity
M	mass
$\vec{P}$	momentum
V_A (V sub A)	speed of object "A"
$\vec{V}_A$ (V sub A)	velocity of object "A"
M_A (M sub A)	mass of object "A"
$\vec{P}_A$ (P sub A)	momentum of object "A"
V' (V prime)	speed after collision
$\vec{V}'$ (V prime)	velocity after collision
$\vec{P}'$ (P prime)	momentum after collision

Both teachers used the same set of terms and notations in the classroom. In fact the terms mentioned above were listed in a handout that outlined the chapter.

Knowledge of Higher-Order Physics Relations

There were two central relations which the teachers knew and used. The first was the definition of momentum "P"

of an object as the product of its mass "M" and velocity "$\vec{V}$"; or $\vec{P} = M\vec{V}$.

The second one was the formulation of the law of conservation of momentum. This relation was put in two forms: one form for two bodies colliding with each other, and the second for any number of colliding objects. For the two-body situation the form was:

$$M_A \vec{V}_A + M_B \vec{V}_B = M_A \vec{V}_A' + M_B \vec{V}_B'$$

While the general form was simply written as: $\vec{P} = \vec{P}'$, where "P" stood for the vector sum of all momenta of objects before collision, and P' for the vector sum of all momenta of objects after collision.

In addition to these central relations, the teachers expressed their knowledge of other related laws but in descriptive terms only. Newton's laws, previously dealt with, and conservation laws in general and conservation of mass in particular, were all explained in one form or another. Conservation of mass was the starting point for the discussion of conservation of momentum.

Both teachers indicated that they had attempted in the past to apply the law of conservation of momentum to two dimensional situations. They also used to discuss the relationship between this law and Newton's law of motion. For some reasons, however, they did not do that anymore.

Teachers' Mathematical Knowledge

Teachers knew the simple algebraic manipulations required for the applications of those formulas to some related physics problems in one dimension. Their mathematical knowledge went steps beyond that to include vector addition in two and three dimensional situations. However, as will be explained in the next chapter the teachers did not go beyond the one-dimensional case and thus only the very simple forms of mathematical manipulations like finding the product of two numbers, or finding an unknown in a simple first order equation, were discussed in the classroom in spite of their knowledge of the more sophisticated applications.

Teachers' Philosophical and Historical Knowledge

Some of Lavoisier's contributions to chemistry, particularly his experimental evidence for the law of conservation of mass in chemical reactions were known by teachers. They discussed that as part of the context of the law of conservation of momentum. Huygens' assumption about the conservation of kinetic energy in elastic collision, and both Leibniz' and Descartes' treatments of the "vis viva" and "quantity of motion", respectively, were not discussed in classroom.

Another dimension in the teachers' philosophical and historical knowledge of physics was that of the logic and reasoning in organizing and sequencing that knowledge.

Since our reference now in the micro-level analyses has been one topic rather than a wide range of topics as in the macro-level analyses, I found it more meaningful to call this dimension topic-context knowledge.

Ideally we can envisage several dimensions for this type of knowledge: scientific, historical, and cultural or social. For the topic under consideration, conservation of momentum, both teachers seemed to concern themselves mainly with the scientific dimension. The other two dimensions appeared to have only been implied in teachers' scientific discourse. In my attempt to elucidate this form of knowledge from the data, I will present various vignettes from both teachers' practices in which they attempted to present the concepts under consideration within a contextual net of other concepts and understandings.

For Mr. Stewart the topic was nested within four different overlapping levels of scientific knowledge ranging from the particular, the topic itself, to the general, physics or the study of nature. Some of these domains of contextual knowledge were spelled out during the first ten minutes of the first lesson on the topic, and were occasionally emphasized in the due course of the seven periods used for the entire chapter. The following is a transcript of part of the recording made during these introductory minutes.

> "Let me turn your attention to the sky, the motion of the stars, sun, and the planets, and so on. And after a lot of questions and difficulties of

> the results, Newton was the one who comes along and says: gravity is what holds the universe together. The planets are held into gravity about the sun. Otherwise, inertia would carry the planets in a straight line; but they're in a curve because they are pulled by gravity into a curved path. And so Newton again comes to the scene with a set of physical laws that hold on the surface of the earth, or anywhere else. Physics is a universal set of behaviors. And we can discover it by doing experiments here on the earth and extend this anywhere.
>
> Well, what we want to do in the next chapter is to extend this understanding of the way things move to see what sort of other understandings we can glean from that. We want to begin chapter nine today which is momentum; and we want to continue. You noticed the schedule says that we're gonna get a well deserved long weekend; and we all need that; and we'll continue our study of chapter nine next week. Let me point out to you what we're really looking for is a law that's so powerful, or a set of laws, or a different kind of law that's so powerful, that if it works, we can understand the entire economic system. The entire industry is all based on this type of rule in science. What I am talking about is conservation laws." [Fieldnotes: 11/24/86]

After some lengthy discussion of conservation laws and their importance in chemistry, especially the law of conservation of mass, Mr. Stewart made the following connection with the topic to be discussed:

> "A quantity that is conserved in addition to mass is called momentum. What is momentum? It's a vector; it's a vector product of mass and velocity. That's what momentum is. We can write this in symbols, momentum obviously can't be "M". So we have to choose a different letter. Instead it's chosen the letter "P" to represent momentum. So "P" is equal to mass times velocity (the teacher wrote that on the board P = M x V)." [Fieldnotes: 11/24/86]

On several occasions he emphasized the importance of this law. The following is an example.

> "What makes momentum worth looking at, worth studying, is the fact that it's a conserved quantity. In every kind of interaction you can imagine, in collisions where objects bump into each other, in collisions where they stick together, in collisions where they glance off each other, in explosions, in every kind of interaction you can imagine, momentum is always conserved. Since it's that's the case, it's enormously powerful, enormously useful and sometimes gets you in trouble!" [Fieldnotes: 11/26/86]

To show how the law might "get one in trouble", Mr. Stewart went on to explain how the police can use the principle in a two-car collision at a road intersection to decide which driver did not comply with the traffic speed rules.

Mr. Stewart, therefore, started with Newton's theory about the universe, a topic he had just finished, went up in the level of generalization to talk about the universal nature of physics laws. Because of this universality character of this knowledge, it should be possible to apply Newton's laws to phenomena on the earth itself. Understanding momentum according to Mr. Stewart's introduction, is an extension of the application of Newton's Laws to motion phenomena on earth.

But then understanding momentum and conservation of momentum would be part of understanding a family of natural laws labeled as conservation laws. One of these laws which was of interest to chemists and physicists was the law of conservation of mass.

Finally, the law of conservation of momentum was contextualized in two important sub-levels. The first was

the conventionally scientific level which would deal with object interactions: both microscopic, like interactions among sub-atomic particles, and macroscopic like solar systems and galaxies. The second sub-level had to do with every day experience: two cars colliding at the intersection and the police report.

Mr. Stewart, therefore, started at some level of generality, Newton's theory about gravity, went up to a higher level of generality, physics laws and their universality, then came back to a more specific and related concept, conservation laws, and finally zoomed into the specific topic he wanted to discuss, momentum and conservation of momentum; and made what he saw as appropriate connections with the students' life as well as with scientific interests and knowledge. Mr. Stewart's knowledge structures, thus, included some forms of contextual knowledge that enabled him to make several reasoned connections between the specific topic on the one hand, and various domains of scientific knowledge, on the other hand.

Mr. Davis also presented that sort of contextual knowledge as he dealt with the topic. However, unlike Mr. Stewart, he didn't go into elaborate description or occasional emphasis of various forms of that knowledge. Some structures of that knowledge, like the connections between Newton's laws and the law of conservation of momentum was not even mentioned in his lessons. However,

when I talked to him about that I found out that he was aware of these connections but simply chose not to discuss them. Instead he started with conservation laws in general, and then, just like Mr. Stewart, went into lengthy discussion of the law of conservation of mass.

> "My experience with conservation laws: You might put it down this way, that a conservation law is a natural law...It comes from nature. It means that the full amount that you have doesn't change. Now you can put that in a lot of fancy ways. One fancy way is that the whole is equal to the sum of its parts. You can say it this way: that the amount that you have before doing an action is equal to the amount that you have after the action. That the amount before and after is the same....Well, that's the statement I like: "the amount that you have doesn't change". [Quotation marks were added by the teacher while writing that on the board]. There are many conservational laws" [Fieldnotes: 11/24/86]

Mr. Davis then went on discussing the law of conservation of mass in physical and chemical changes. Afterward he went directly into the definition of momentum:

> "The next conservation law is that of momentum. What is momentum? It's the product of mass and velocity. We use "P", for momentum, "M", for mass, and "V" for velocity". [Fieldnotes: 11/24/86]

After this brief description of the definition of momentum Mr. Davis wrote down the mathematical formula together with the units to be used in that formula and started solving some mathematical problems on the application of that law.

As for the relevance and significance of the law of

conservation of momentum Mr. Davis had the following to say to his students.

> "Momentum and conservation of momentum is a topic that has a lot of interesting applications in science. It is very hard to think of an area where you don't get involved with mathematics. Mathematical models try to describe nature. And conservation of momentum is very very powerful. It...(inaudible)...itself all the way down to the very large things of galaxies in space, all the way to the size of subatomic particles. In fact conservation of momentum as a topic...There has never been found a violation to this law." [Fieldnotes: 12/2/86]

One final aspect of the teachers' philosophical and historical knowledge had to do with the nature of knowledge under discussion, momentum and conservation of momentum. As explained before teachers didn't philosophize much in classroom, and their discussion of the law of conservation of momentum was no exception. However, even the few philosophical sentences they uttered about the nature of the topic were, I believe, interesting.

For Mr. Stewart, conservation laws, were not discovered by persons, but rather developed as understanding or reasoning of certain experiences. In his own words:

> "It's not the kind of thing that was discovered by anybody. It's a sort of understanding that just evolves. What I am talking about is conservation laws". [Fieldnotes: 11/24/86

The key idea which I found interesting in this quote was his assertion that those laws were not discovered by scientists as such. Instead, there were certain

understandings which evolved over time.

Though I didn't probe further into what Mr. Stewart meant by that, my own interpretation is that, for Mr. Stewart, conservation laws were somewhat clear and axiomatic in human thinking. To say that matter was conserved in chemical interactions was to express some form of rationality that the human mind could accept without much dispute. If this interpretation is tenable then the idea of scientific evidence and its significance in our reasoning was not emphasized in Mr. Stewart's view. Actually, scientists like Lavoisier were very anxious to get some scientific evidence that would confirm the assumption that mass was conserved and thus talk about a natural law.

Mr. Davis saw a process of discovery in the knowledge of the law of conservation of momentum. He even expressed a sort of surprise over such a discovery.

> "Sometimes you worry how human beings ever stumbled on such ideas of mass times velocity to be momentum. And that momentum is conserved before and after collision". [Fieldnotes: 12/2/86]

So, for Mr. Davis the ideas were out there and humans simply discovered them or even "stumbled" on them.

Discussion: Teachers' Knowledge of the Subject Matter

In this chapter I have attempted to explore various dimensions of the teachers' knowledge and conceptions of physics or science. This was done through the examination

of a variety of data sources: worksheets, fieldnotes, and interview transcripts. As a prologue for all that I described the contents of the textbooks used and the teachers' views about these textbooks.

Examination of various documents revealed that each teachers' knowledge of physics included four major clusters of knowledge structures: knowledge of vocabulary terms of physics, knowledge of higher-order physics relations, mathematical knowledge, and philosphical and historical knowledge. Each of these clusters or major categories could include more than one sub-category and many knowledge entities or structures. This conceptualization was inferred from the macro-level analyses. Examination of teachers' knowledge of one topic, momentum and conservation of momentum, revealed the applicability of that conceptualization to the more specific level of investigation of teacher knowledge of th subject matter.

While some of the teachers' knowledge entities and structures embedded in the sub-categories and clusters were simple, others were complex. Relations, laws and theories were examples of such complex structures of knowledge. I have attempted to show how the teachers perceived the interdependency of those structures. Indeed interdependency permeated not only various structures within a major knowledge category or cluster but the whole body of teacher knowledge represented here as knowledge clusters. It was only artifical and for organizational purposes that I talked

about Newton's laws in isolation from their historical and scientific contextual development. The genesis of these laws and, to some extent, the teachers' articulation of them included a multitude of knowledge dimensions that were artificially described under different sub-categories in this study.

The existence of complex structures of knowledge in what the teachers knew about the subject matter gives support to another common finding in several educational studies done within the framework of cognitive psychology. In their attempts to find differences between the ways that experts and novices organize their knowledge, some researchers (Chase and Simon, 1977; Chi et. al, 1982; and Simon and Simon, 1980) found that experts tend to organize their knowledge into bigger chunks than novices. Other researchers dealing with knowledge of the subject matter (Leinhardt and Smith, 1985; Hashweh, 1985) also spoke of organizing knowledge in large chunks or structures called schemata. In this study both teachers did use these large structures to organize their knowledge of physics or science. They were often concerned to find out some unifying factors that would bring these chunks, or schemata into a larger structure of knowledge.

But the teachers in the study knew two other important and somewhat related issues: the historical development of these structures, and the logic and reasoning involved in the building of those structures. These two dimensions

intertwined together described teachers' knowledge of the way scientific knowledge developed or progressed through history. This part of teachers' knowledge was not purely logic-related. As was explained, both teachers recognized the relevance and significance of the social or cultural dimension in the way science progressed throughout history. Some cultural issues like religion and politics had their impact upon the way science progressed.

At this point it seems relevant to evoke Schwab's (1962) well known description of the structure of disciplines. While teachers' knowledge of concepts, laws and principles may conveniently stand for Schwab's substantive structures, their knowledge of the way science progressed and the way scientific knowledge was accepted went, I believe, beyond what Schwab called the "syntax" of the discipline. While Schwab talked about the "syntax" in terms of logic and mathematics, the two teachers raised some social issues. This matter requires, I believe, examining the teachers' pertinent ideas against a balanced philosophical background that would include both traditional and recent outlooks on the nature of scientific knowledge.

Currently there are two main views that compete to describe various aspects of what we call science. Until relatively recently the traditional view was the only description offered by many philosophers and philosophers of science such as Comte, Carnap, Hempel, Nagel, Popper,

Lakatos, and Newton-Smith. During the last thirty years, however, another view, I will call it the recent view, started to push forward for a fundamentally different perspective on what science it.

The traditional view, also called rationalism or positivism, approached science with a lot of emphasis on logic, principles of empricism, and formal or mathematical analyses. Science, according to this view, is controlled by logic and empirical facts and whose purpose is to formulate truths about the laws of nature. Proponents of this view advocate the existance of an external reality which is independent of the human observer. Words, concepts, and laws, are labels or signs that refer to certain things out there in nature. In a sense, therefore, there is a correspondence between our scientific ideas and reality in nature. Scientific progress represents a gradual move toward a better correspondence. According to this view history, culture, personal ideas and explanations in no way influence our scientific knowledge.

The recent view, on the other hand, has emphasized science as a social or human activity. Proponents of this new school of philosophy of science include thinkers like Norwood Russel Hanson, Michael Polanyi, Thomas Kuhn, Paul Feyerabend, and Stephen Toulmin. Kuhn is perhaps the best known and most influential author among them. So I will limit my discussions here mainly to his ideas.

The practice of science, according to Kuhn (1970, 1977)

is not, as the traditionalists asserted, guided by unchangeable or unchanging canons of scientific method. Instead it's heavily influenced by what he terms "paradigms": essentially shared sets of theoretical beliefs, accepted standards, procedures and exemplars. Paradigms are not absolute; they change or "shift" as the historical context and available data changes. Therefore, it is the community of scientists or researchers that determine within a certain historical context what is and what is not to be considered scientific, and what is and what is not to be warranted as knowledge. To learn science, therefore, an individual should be socialized into the shared paradigms.

Different paradigms according to Kuhn are incommensurable. This means, among other things, that the same terms may mean different things in different paradigms. Newtonian concepts of mass, time, and distance are fundamentally different from the Einsteinian counterparts. It also means that scientists do not make a transition from one paradigm to another on the basis of logic and neutral experience:

> "The transfer of allegiance from paradigm to paradigm is a conversion experience that can't be forced" (Kuhn, 1970, p. 151).

Sequences of paradigms, through what he calls "paradigm shift", or scientific revolutions, entail the emergence of new theories with increasing capacity for puzzle-solving under what later becomes as "normal science". Kuhn denies

any progression toward an objective truth. In his own words:

> "We may, to be more precise, have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the truth" (Kuhn, 1970, p. 170).

Kuhn, finally, does not deny the existance of an external world. What he is saying is that any interpretation a scientist gives to a certain reality should be taken as such, a mere human construction within a historical and social context.

How, if possible, can we relate the two teachers' philosophical knowledge about science to these views? I believe it is possible. Furthermore, I think that each teacher's knowledge comprised a mixture of elements from both philosophical approaches.

Mr. Stewart believed that science, in its purity was objective. He also saw physics as an exact science, and scientific laws ruled by structures of logic which were absolute and inviolable. These ideas are congruent with the traditional view of science.

When talking about Artistotelian physics, Mr. Stewart talked about "continuity" in science. He asserted the relevance and importance of both Aristotelian and Newtonian physics. As explained before he mentioned that, "we operate at all levels". This is, I think, a rather unusual assertion. It could be equally at odds or in agreement with

both views of scientific knowledge. For, on the one hand, what Mr. Stewart was saying was that different theories were both good and usable, very close to a Kuhnian conception, and at odds with the traditional view. But on the other hand, operating "at all levels" would imply our ability to move easily forward and backward from one paradigm to another, which is at odds with the notion of incomaptible or "incommensurable" paradigms; but when Mr. Stewart's notion of "continuity" is added to that, the interpretation may become in partial agreement with the traditional view that holds that science progresses by accretion. How can we interpret Mr. Stewart's assertion? I will come back to this question after I examine the rest of the teachers' ideas.

Finally Mr. Stewart thought that we are not better off as far as our scientific ideas are concerned. All that happened was the emergence of new theories with wider dimensions. According to him, we will always have more questions than answers. These ideas are very similar to Kuhn's ideas about new paradigms with broad scope of explanations and predictions.

Mr. Davis's ideas too exhibited this duality feature. On the one hand he often sounded traditional when he talked about laws that came from nature, or "how human beings ever stumbled upon the laws;" or still scientists "breaking" patterns of nature. However, in his description of how new discoveries, or models or theories were made, Mr. Davis came closer to the other camp. A previous quote illustrates

that. In his description of "breaking" a new model Mr. Davis stated:

> "I think it is more spontaneous; that there is a sort of collection of data and a period of time where it's trying to be explained, and a person happens to be born, and then happens to be working with the data; and maybe there is a lot of chance, or a sort of spontaneous creation at this point. At least that's in my mind how I see where many theories have come." [1st Interview: 9/23/86]

In this quote Mr. Davis reminded me of Kuhn's description of anomalies and how they accumulate over time to finally cause a "crisis" in normal science. Furthermore Mr. Davis's description of how new theories come: by a process of "spontaneous creation", is closer to Kuhn's description of the context of discovery in which the scientist's subjective dimensions, or simply the socio-psychological factors are to be considered, than to the traditionalists who advocate the step-by-step logical procedures embodied in the "scientific method".

Finally, Mr. Davis, just like Mr. Stewart, was a bit unclassifiable, I think, on another occasion. In his previous quote about the issue of subjectivity-objectivity in science Mr. Davis brought together two points: each from a different philosophical perspective. On the one hand he said, and repeatedly, that science was not objective, and scientists were really subjective just like anyone of us: "You get to a certain point where you want something and you see it in there". On the other hand, however, he swang back toward, but not totally, to the traditionalist view by

"hoping" that "anomalies" or discrepancies will be washed out. But how would these "anomalies" be washed out? Mr. Davis's answer was: by scientists "communicating with each other". So "anomalies" are "washed out" and thus "better" knowledge or more "truthful" knowledge would arise, a traditional view; but through communication among the community of scientists, a Kuhnian connotation.

Before I try to account for the teachers' philosophical knowledge let us try to see if the textbook advocated any philosophical position on this matter. Examination of the text revealed that it looked as if it leaned more towards the Kuhnian perspective. However, the traditional element is not absent. Kuhn's assertion that scientific change which involves the acceptance of a new theory and the abandonment of an old one, entails some socio-psychological factors, was implied at least in two places in the text. Talking about the Ptolemic and Copernican systems the textbook explained that:

> "Galileo recognized, as Ptolemy and Copernicus had, that the observed motions of planets don't prove either the heliocentric or the geocentric hypothesis right and the other one wrong. With proper adjustments of the systems said Galileo, "the same phenomena would result from either hypothesis". He accepted the earth's motion as real because the heliocentric system seemed simpler and more pleasing.
>
> Scientists quite often accept or reject an idea because of some strong belief or feeling that, at the time, can't be proved decisively by experiment". (p. 196)

On another occasion the book asserted that:

> "The popular image of the scientist is of a person who uses only deliberate, logical, objective thoughts, and immediately test them by definitive experiments. But, in fact, the working scientist feels quite free to entertain any guess, imaginative speculation, or hunch, probable or not, that might be helpful. Without them there would be little progress." (p. 223)

Another place where the textbook came very close to an important Kuhnian issue, incommensurability of paradigms, was in the context of talking about problems with Newtonian mechanics.

> "Many studies have shown that there is no way to modify the details of Newtonian mechanics to explain certain observations (ex. the angular motion of the axis of Mercury's orbit). Instead these observations can be accounted for only by constructing new theories based on some very different assumptions" (underline added). (p. 237)

On some other occasions the book's position became much less clear, or even ambiguous. Let us look at the following two quotations. The first one was given in the context of reviewing scientific growth and progress.

> "Science is a cumulative intellectual activity not restricted by national boundaries or by time. It grows as a forest grows. New growth replaces and draws nourishment from the old, sometimes with unexpected changes in the different parts." (p. 241)

If new growth replaces the old one, and if unexpected changes occur in the different parts of science, or if the new theories require very different assumptions, then the

statement that "science is a cumulative intellectual activity", becomes, I believe, problematic. I have made this comment because the word "cumulative" is a key descriptive word used by the traditional view to describe the way science progresses.

Let us focus on the second quote where the book left an important philosophical issue blurred. In the context of talking about conservation of momentum, the book stated:

> "Conservation of momentum is an empirical law discovered (perhaps invented or induced) as a generalization from experiment". (p. 260)

Now, was the law discovered, or invented, or induced? To say that it was discovered, is to leave the reader with connotation that something was out there in nature and somebody or some people discovered it. To say it was invented would imply somebody created that out of need or necessity. But can we talk about inventing an empirical law, anyway. To say it was induced, is probably more appropriate for an empirical law.

All previous quotes from the book would have, I believe, favored words like 'invented', 'constructed', or 'created' instead of any other words like discovered or induced. Nevertheless the book started its alternative words with the word "discovered". The grammatical structure of the sentence gave stronger position to this word than others.

The important point to emphasize here is that, in spite

of the fact that the book emphasized on several occasions non-rational aspects involved in scientific change, it still seemed reluctant to relinquish the notion of objective reality seen as implied in our scientific knowledge. A final quote may prove helpful in this respect. The following sentences appeared separately on three different pages of the textbook. They talk about three different eras and respectively: pre-Newtonian, Newtonian and post-Newtonian, and modern times.

> "Even at this time people were confused whether these theories represented real world or only models for easy calculation....
> But after Newton people started to believe that scientists were describing the real world...
> Today scientists and philosophers are much less certain that the common-sense notion of reality is very useful in science". (pp. 175-177)

Notice here that the book evoked the concept of commonsense "reality" in the context of talking about modern times. Newton himself did believe that his laws had real physical meaning and were not mere references to non-commonsense laws or realities. Did the textbook want to tell readers that there might be some unconventional or non-commonsensical "realities" that lie behind our modern scientific knowledge of quantum mechanics and relativity? Once again the book did not appear ready to give up the notion of objective reality as advocated by the traditionalists.

Neither did the teachers, as was explained before. Mr. Davis spoke of the subjectivity of scientists and our

scientific knowledge, but then he also talked of "breaking the patterns" or "stumbling" over laws out there in nature. Mr. Stewart did not think that there will be a stage when we reach some certainty in our knowledge, but then he still talked about physics as the most objective science next to mathematics. Were the teachers influenced by the book? I believe the answer is yes. But did they develop the same orientation of the textbook? I think an affirmative answer is less tenable in this case.

I believe the textbook influenced the teachers' scientific knowledge in two ways. The first was the direct presentation of the textbook views about science, scientists, and our scientific knowledge. Various parts of the text, just like the pieces quoted above, certainly had some influence on teachers' views.

But more importantly, I believe, is the indirect influence that may be attributed to the way the textbook organized and sequenced the subject matter, and hence advocated a certain approach to physics teaching. Teachers, year after year, were socialized into old as well as modern physics theories. They had to teach Aristotle's ideas, Galileo's, Newton's, and some modern ones. No wonder then, that Mr. Stewart saw in physics knowledge a continuous procession that diverges as we move forward in time but with no visible end or even goals. Mr. Stewart operated at all levels: Aristotelian, Newtonian, and modern. Kuhn (1970), in a footnote, asserted that physics graduates

socialized in modern physics paradigms found it very hard to reason in Aristotalian terms. Mr. Stewart did not find that hard; he attempted to teach that for about two decades. He became, perhaps, over-socialized in different, or incommensurable, paradigms of physics knowledge. All of that, I believe contributed to what both teachers knew and practiced.

But both teachers had originally studied science in college where no one had had the time, or the inclination, or even the courage, to raise the issue of objectivity in physics or science. Scientific knowledge and its correspondence to some realities are hardly questioned by physics professors or physics students. It is usually taught as an objective or reified body of knowledge. This, I believe, constituted the "center of gravity", so to speak, of both teachers' other relevant learnings. Even when their learnings seemed incompatible with that assumption, both teachers seemed unwilling, consciously or otherwise, to relinquish their beliefs in the objectivity of physics knowledge. This, in my mind, reflects, the way science is taught in our colleges. Two decades of experience did not seem to seriously change the implication in the subject matter taught during college years that physics knowledge is an objective form of knowledge that corresponds to real entities in the outside world.

CHAPTER V

FINDINGS AND INTERPRETATIONS: HOW THE SUBJECT MATTER WAS TREATED IN CLASSROOM

In this chapter data from various sources will be presented in order to answer the second major research question: How was the subject matter treated in the classroom? My answer will include a detailed description of the teachers' planning to teach the subject matter with a focusing on conservation of mass and momentum. Teachers' actual instruction together with the various lesson types they used will be discussed. The teachers' instructional objectives as well as their decisions about the treatment of the subject matter will be inferred and discussed in detail. As I present these findings I will attempt to sequence them very much as they appeared to me in the analysis of data.

But before describing how the teachers treated the subject matter, a discussion of a few points is due. First, the focal point, or the reference point, of this work is the subject matter. In my attempts to research that, I, whenever possible, examined the teachers' all forms of acts, and related that to that point of reference, the subject matter. In many cases that was a direct process, for the two high school physics teachers did spend most of their classroom time dealing with the subject matter. Physics and physics teaching were very central issues in their school life. On other occasions, however, the subject matter was not directly visible in the picture of some of their

seemingly important acts. On such occasions I tried through different means: discussions and interviews with the teachers, to arrange the various elements of the picture in such a way so as to bring the subject matter to the foreground. To put it differently, I tried to understand the implications of those acts with a reference to the subject matter.

Clearly with the subject matter at the "center of gravity", so to speak, not all of the teachers' actions were equally relevant. While some were very proximal to this point, others were relatively far away from it, but still connected with it. A teacher's life, as I imagine it is just like anybody else's, consists of an endless three dimensional web of relations and connections with various elements of his concentric spheres of environments in which he or she is immersed. I also imagine that web of relations to be non-static, not only because of external environmental influences, but equally well because of the active role we, as humans, play in constructing new strings or connections in that web, or destroying old ones.

What does that mean to this research? First, it means that what will be said is only a segment of that web portrayed from the reference point of the subject matter. Ideally, and if we can exclude the influence of the researcher, that portrayal would be a partial view of that web during a certain interval of time. Second, clearly then what will be said is only an approximation of events, as

seen from that reference point. Furthermore, in examining a certain issue in that web, I had, just like any researcher, to somewhat isolate that issue, or cut its connections with other proximal issues in the web. Where to make the cuts, is left to the judgement and rationality of the researcher. Under any circumstances, this procedure enhances the artificial element embedded, I believe, in the process of describing an event or an issue, and therefore enhances the approximate nature of whatever we say about our setting. Third, if the assumption that that web of meanings and relations was in continuous change is conceded, any research would become historical. Ideally, this would mean that the findings I will talk about, may, at best, have past validity. We usually tend to think that no major changes or influences fundamentally disturbed our research settings after we had left them. While this is a very plausible assumption, there is no reason to believe that that may be always true. Once again, this adds to the approximate nature of our depiction of the setting.

Planning for the Subject Matter

About middle of August 1986, two weeks before the beginning of the school year, I phoned the two teachers to tell them that I was planning, as agreed 10 weeks earlier. to come back to their school in order to do some observations for my dissertation research. When I asked Mr. Stewart about what they would be doing in the Project

Physics course, he went on giving me a brief overview of the contents included in the first eleven chapters they were planning to cover during the first semester. He, then, added that they might also cover chapter twelve on waves and wave phenomena. I did not take detailed notes of that conversation but I am certain of the content of his remarks which indicated that he was not sure whether they would be able to cover chapter twelve, but they would try that.

Four months later, that was, shall I say precisely, what happened! The teachers on December 15, 1986 gave a quiz on chapter eleven and distributed a very brief outline for chapter twelve in which only four work days appeared. There were a lot of interruptions and irregularities in the remaining days til the final exams on January 12, 1987. Even the four work days that appeared on the handouts were not really as productive as ordinary school days. Nevertheless the teachers did try to cover the chapter, and indeed some questions about the contents of that chapter appeared on the final examination.

How could the teachers predict so precisely the content coverage of the course? Or was it really a predicition, or an intention to cover such a wide range of topics? How did they manage to do that? To answer these and many other questions, I will start with a description of how the teachers planned to teach physics.

The Project Physics

At the beginning of each chapter a one-page outline for all the required work on that chapter was prepared and passed to the class during the first minutes of the first lesson on the chapter. The form of that one-page planning was invariable across various chapters. This form appears in figure (1). In what follows I will describe the contents of each category included in that form. Appendix (A) includes all lesson plans for chapter 9 on conservation of momentum together with another sample from the IPS handouts.

The heading of the format indicated the chapter number, name of student, the lesson hour, the date on which the worksheets would be returned for the teachers, and finally the two initials of the teachers since the sheets were used by both of them.

The boxes that appear in the "schedule" section were designated to summarize what the class was supposed to do on each separate day to come. In each box, brief information would be included that would indicate the day, the date, and a short phrase describing what to be done on that particular day. Phrases would include things like circular motion, problem set, Newton's laws, demo's etc.. The last box was always left for a quiz, and a reminder of the due date for all worksheets done in the due course of the "schedule" interval. A "bonus activity", or a "T.B.A." (to be announced) were also some phrases that appeared occasionally in some chapters.

CHAPTER _____ OUTLINE NAME

HOUR _____ DATE _____ S.D.

SCHEDULE

OBJECTIVES	IF GIVEN	BE ABLE TO
	_____	1.
	_____	2.
	_____	3.
	_____	4.
	_____	5.
	_____	6.
	_____	7.
	_____	8.
	_____	9.

ASSIGNMENTS

1.
2.
3.
4.
5.

THINKER

CAN YOU DO IT

Fig. (2) The Chapter Outline Form Used in the HPP Course

So what the teachers did was to segment each chapter, or in some cases two chapters together, into a number of topics or sets of activities and allocate one day for the discussion of that topic or activity. Chapters seven and eight were included in one sheet outline, so were chapters ten and eleven. Each of the other chapters received separate treatment and was planned for on a separate page.

The "objectives" part of the outline included two columns: "if-known", and "be-able-to". Under the "if-known" column, appeared, concepts, definitions, relations, and laws which teachers planned to discuss. All these entities were written in brief terms and directly connected to one or more lines in the neighboring "be-able-to" section which included description of what students were supposed to be able to do once they were given a specific piece of information. Number of entities under the "if-given" column was around six, while that under the "be-able-to" column was generally more than six. Here is a short list of examples taken from different outlines.

If Given	Be Able To
statements about projectile motion.....	Identify true statements
$Fc = \frac{MV^2}{r}$	Use equation to solve problems
Data for graph....	plot, and label, and calculate slope

In the "assignments" section teachers listed a variety of readings and activities to be done. Either part or the

whole chapter was very often assigned together with the study questions of that chapter. The rest of the assignments were usually related to the topics selected to be discussed through the worksheets that would be distributed the following days.

The "thinker" section included a puzzle, or simply a physics problem that would be somewhat related to the chapter under discussion.

Each chapter outline was then followed by several worksheets, approximately ten for each chapter, that would lay out all the instructional as well as the students' classroom activities. Prior to the commencement of each lesson the teacher would pass these handouts to students. With the exception of one single sheet which included a set of problems, all handouts and outlines were prepared in handwritten forms by Mr. Stewart. During his free hour, Mr. Stewart would pick up a previous copy of the handout he needed, prepare a ditto, and then run the needed number of copies for the coming day. The process used to take several minutes.

Each worksheet would deal with a segment of the subject matter that appeared in the chapter outline. To talk about the contents of these worksheets is to talk about the contents of the whole course. Worksheets included all concepts, definitions, ideas, laws and relations discussed in the classroom. They also included all sets of problems solved, graphs plotted, descriptions and drawings for

demonstrations and lab experiments. Worksheets were lesson plans and instructional guides for the teachers, guidelines for students' academic work, and note books on which they solved problems, drew graphs, filled in blanks, and studied or reviewed for the quizes or the final examination. Much less, however, was there any description of how to teach the contents included in them. Though that may sound as an element of flexibility in the format of these worksheets, later observations of the execution of various lessons showed that both teachers tended to use the same classroom instructional strategy for each lesson. It was as if there had been a prior or tacit agreement on the dynamics of translating each handout into classroom instructions. The physics course was virtually transformed into about 115 pages of chapter outlines and worksheets. Consequently, teachers "threw away the textbook", as Mr. Stewart told me in an interview. Shortly, I will present a detailed account of the contents of the worksheets on chapter nine: Conservation of Momentum. In following sections I will focus on classroom instructions through these worksheets. But now let me turn to the IPS course to give a description of how Mr. Davis planned for the course.

The IPS Course

The policy of generating daily worksheets for the class was also adopted in the IPS course. Here again the teacher transformed the contents of the course into a set of

worksheets, around 85 pages, which were used by both the teacher and students as frameworks for daily activities. Mr. Davis kept past copies of these handouts in a file, and all he had to do was to prepare the necessary number of copies for each lesson. Very rarely, perhaps only two times during the course, did I see Mr. Davis prepare them in class. A teaching load of five hours per day seemed to have kept him busy during the school hours. He told me on a couple of occasions that he prepared his handouts on his personal computer.

The contents of these worksheets were taken mainly from the textbook. However, a significant number of these handouts, around 10, had their contents taken from other textbooks or manuals. These included some material mostly relevant to that in the textbook, but for one reason or another the teacher felt that it did not receive sufficient treatment or exposition in the course textbook. These included worksheets on some basic skills: measuring various quantities like temperatures, distances, angle, etc., practicing some lab techniques, like using the Bunsen burner and manipulating glass tubing, more explanation and examples on significant digits, and more exercises on a variety of solubility curves. There were also a few handouts on science fiction, listening as a science skill, and a short narration on Galileo's discoveries and his use of the telescope.

Mr. Davis didn't follow a particular form in preparing

handouts. However, since the textbook suggested an experimental approach, the majority of these handouts dealt with specific experiments explained in the textbook. That is why those handouts dealing with specific experiments came with a sort of common form but not necessarily exact in its uniformity. Almost all of those handouts asked students to name the experiment, to cite its purpose, to sketch the apparatus used, to explain the procedure to be followed, and to explain the data and say something about the conclusions. After each question a sufficient space for answering was left. Other handouts dealt with other related questions or problems. Questions about solubility, definitions of terms and expressions, numerical problems about density, and concentration of solutions are some examples. The overwhelming majority of all questions appeared in worksheets were simply pertinent questions raised by the textbook. The few handouts suggested by the teacher without a reference to the textbook had their questions formulated by the teacher himself.

With the exception of a very few occasions where handwriting was used, worksheets were copies of typed materials or printed portions of some textbooks or manuals. A sample of these worksheets appears in Appendix (A).

An important component of planning that accompanied the worksheets had to do with lab activities and demonstrations. In both classes a variety of equipment was used. Both teachers had to prepare their classrooms beforehand for such

activities. That required moving around various pieces of equipment, checking some of them to see whether they were operable or not, repairing some whenever possible, or looking for replacements for those pieces that did not function. In the HPP class it was Mr. Stewart who generally took charge of that during his free hour. He would do that one day prior to the beginning of the activity. In the IPS class, however, Mr. Davis had to do that almost on a daily basis since the course required a lot of lab activities. Lab equipment would be distributed at the beginning of each hour and collected back at the end of it.

Planning to Teach Conservation of Mass and Momentum

As in other chapters, the teachers transformed the contents and organization of the chapter on conservation of mass and momentum into a set of worksheets preceded by a chapter outline. In a previous chapter I described the contents and organization of this chapter as they were dealt with in the textbook. In this section I will first describe both the organization and the contents of the chapter in the teachers' plans. Consequently, the knowledge contents included in the plans, and those excluded or deleted will be discussed. Lab activities and demonstrations planned for will be pointed out as part of the knowledge contents in these plans.

Knowledge Organization and Contents in Teachers' Plans

The one-page chapter outline together with nine other worksheets, Appendix (A), summarized the knowledge organization and contents of the chapter as they came in the teachers' plans. I will first describe the chapter outline and then give a separate brief description for each day's plan.

In the chapter outline, the teachers segmented the chapter into seven blocks with each comprising a day's work. So seven work days interceded by the Thanksgiving break were devoted to teach the contents of the chapter. Though there was no mentioning for the dates on the plan, which was unusual in planning forms, these days came between Nov. 24 and Dec. 4 of 1986. Table (2) summarizes the allocated contents for each work day during that period of time.

Table (2). A Summary Table of Chapter 9 Content Allocation as Suggested in the Teachers' Lesson Plans

Day #	Date	Contents Discussed
1	Nov. 24, 1986	Conservation lawas and problem set #1
2	Nov. 25, 1986	Study questions from the book
3	Nov. 26, 1986	Momentum lab block
4	Dec. 1, 1986	Collisions and cons. of mom. problem set #2
5	Dec. 2, 1986	Maxi demo's including the famous "shooting the kitty"
6	Dec. 3, 1986	Odds and ends and bonus
7	Dec. 4, 1986	Chapter 9 quiz

In the "objectives" subsection in the chapter outline the teachers included the following "terms to know": velocity, speed, momentum, conserved quantity, closed system, open system, elastic collision, inelastic collision,

mathematical notations, terms and definitions, and subscripts and the prime (′) signs. They also included as particular objectives the application of the relation P = MV, in two-body elastic and inelastic collisions. Students, as the plan stated, should "be able to":

"1. Identify quantities that are answered.
Solve:
2. Problems involving momentum.
3. Calculate the missing mass.
4. Predict the outcome of the collision with a precise word description.
5. Write a proper equation for the conservation of momentum.
6. Solve the equation for the unknown quantity, substitute and solve.
7. Math 'em up."
(Chapter outline, Appendix (A))

As for assignments, the plan suggested: reading the chapter, solving the study questions, the problem sets 1 and 2, doing the momentum lab block, studying conservation of momentum, and participating in the maxi demonstration.

Finally, in the "thinker" subsection of the outline students were challenged to prove that both momentum and kinetic energy were conserved in an elastic head-on collision of two spheres of unequal masses.

To see how this segmentation and outline of the chapter were elaborated upon and planned for on daily basis, I will now describe briefly the knowledge contents of each day's worksheets during the times allocated for teaching the chapter. Further, I will give serial numbers to these days, day no. 1, day no. 2, etc., to refer to Nov. 24th, Nov. 25th, etc., respectively.

Day No. 1

In addition to the chapter plan, two worksheets were distributed to the class. In the first worksheet, three main components were planned for discussion: a definition of a conservation law in general, explanatory examples on things that change and things that do not in solutions and a chemical reaction, and the specific definition of conservation of mass with a very brief reference to the related work of the French chemist Lavoisier 1743-1794.

The second worksheet planned to introduce the concept of momentum: a word definition, followed by the mathematical definition P = MV, and finally a set of seven mathematical problems in which students would find out an unknown in that relation if the other two values were given. An appropriate blank was always left to be filled in after each idea or problem.

Day No. 2

This day was to be devoted for study questions from the book as had been planned for in the chapter outline. It was the first and only time that I saw the study questions included in the textbook being appropriated for a day's work. However, very often these questions appeared in the "assignments" sub-section in the chapter outlines. There were no lesson plans or worksheets distributed on this day. As it turned out both teachers fell sick, and, thus, did not come to school on that day. The classes were left to a

substitute teacher who simply asked them to open their books and do whatever they were supposed to do.

Day No. 3

This was the day for what the teachers described in their chapter outline as "momentum lab block." One worksheet titled "Conservation of momentum lab block" was prepared. It included eight separate lab activities as mainly descriptive examples that would supposedly elucidate the idea of conservation of momentum. Four of these activities included collisions and "explosion" or separation of two lab carts in different situations. The plan required students who were to rotate over all activities, to describe what would happen before and after collisions. Two other activities included a marble rolling into a group of other similar marbles, and a rubber bullet that would bounce off the floor. A film loop showing an explosion, and a short computer program that simulated a collision between two carts were also included in the set of activities.

The worksheet organized those activities by giving a number and a short title for each of them. It then asked for students' comments or descriptions of what happened. Short blanks to be filled by students were left after each question.

Planning for these activities required moving around several pieces of equipment. That was done in the early morning prior to the beginning of the morning classes.

Day No. 4

Two numerical problem sets were planned for the day's lesson. The two sets included ten problems. Three of these problems were direct application of the algebraic relation P = MV. The rest were mostly collision problems. Lab carts, or "air cars", colliding either elastically or inelastically, were described quantitatively. Students were then asked to use the principle of conservation of momentum to calculate an unknown quantity, like the speed of a particular cart after collision, or the speed of the two sticking-together carts in inelastic collisions. A popular problem about two astronauts floating in space and pushing each other apart was also included. A final problem that dealt with two tiny objects, an oxygen molecule and a neon atom, colliding with each other was also described in the problem sets.

Day No. 5

According to the chapter outline this was the day for the "Maxi demo's including the famous shoot the kitty." The worksheet described two demonstrations to be done by the teacher for the class as a whole. The first demonstration was intended to be an application of the principle of conservation of momentum to a case of an inelastic collision or what the teachers termed "hit and stick" collision. The title given to the demonstration was "The bullet and the kitty". The main idea was to fire a rubber bullet into a

slowly moving object. The bullet would stick into the object and the two would now move at a speed a bit faster than that of the object and slower than the original speed of the bullet. Knowing the masses of both the object and the bullet, and the original speed of the object as well as the final speed of the object and bullet stuck together, would enable the class to find the speed of the bullet.

The second case was another example, though different in nature from the first case, on how to use the principle of conservation of momentum to calculate a speed of an object, a cannon ball, which, otherwise, would be difficult to calculate. In this example a volatile liquid that forms an explosive mixture with air was to be applied to the inside of the barrel of a small cannon mounted on a cart. A rubber ball would be put inside the barrel and then fired out. The objective was to use the conservation of momentum principle to calculate the speed of the fired ball.

It should be noted here that the worksheet did not include the details of what the teacher would be doing in class. Instead, the title and a simple sketch of the demonstration were first laid out. A suggestion as to how to solve the problem together with the appropriate symbols and formulas to use, were provided. Spaces to write down numbers and answers were also reserved on the sheet.

Day No. 6

Two worksheets that included six numerical problems on the conservation of momentum were prepared for the day. This was a bonus activity worth two points in the final grade. Usually on such a day the teacher would review any pertinent difficult concepts or ideas which the students would raise at the beginning of the hour (this is not mentioned in the written worksheets), and then would leave students work the problems out by themselves. Usually this would be done, as was the case here, one day prior to the quiz on that chapter. Students who may wish not to do the bonus activity may do any other academic work during that hour.

The bonus problems did not include any new ideas or cases on conservation of momentum. They were simply repetitions of previous problems but with different numbers to plug into the formulas to be used.

Day No. 7

This was a day for evaluation. A quiz was planned. There were three main parts in that quiz: a matching question, a true-or-false one, and a simple straightforward numerical problem on the conservation of momentum.

The matching question part of the quiz included six key concepts like momentum, elastic, inelastic, etc., and two scientists' names: Newton, and Lavosier. The true-or-false part was based on the cannon demonstration carried out in

class. It included seven statements which revolved around the concept of momentum and the law of conservation of momentum. Overall, then, the whole quiz was planned to focus in some ways upon the concept of momentum and the idea of its conservation in collisions.

Knowledge Left Out of Teachers' Plans

Clearly the teachers did not plan to teach everything included in the textbook. They left out several concepts and ideas. The main objectives of the teachers as reflected in their plans were: first, to emphasize the definition, mathematical and otherwise, of both momentum and conservation of momentum, and second, to give students the chance to practice the algorithm or algebraic manipulations needed for solving simple pertinent problems.

But, as was mentioned before, these handouts were not intended to be a literal text of what the teachers had to say, and how to say it. Nevertheless, not only the contents of what the teachers said were very similar, the lesson types or classroom instructional strategies adopted for each handout, or set of handouts for each lesson, were also of the same orientation. This chapter on conservation of mass and momentum was no exception. Though both teachers, in their attempts to flesh out their skeletal worksheets through actual classroom instructions, made very slight changes, they still preserved their domains of inclusion and exclusion. Furthermore, they used the same type lessons on

each day. Let us now see what was excluded from the teachers' lesson plans.

First, the historical scientific context in which the concept of momentum developed or emerged was totally absent from the teachers' worksheets. Newtonian mechanics, after proving very successful in explaining motion in heavens, held potential promise for explaining more complex phenomena related to other forms of motion on earth. This required among other things, the introduction of new concepts like momentum. Furthermore, Newtonian conception of the universe as an everlasting on-going machine stimulated philosophers and scientists to look for a rational explanation of this universe based on the conservation of certain physical quantities related to matter and motion. These ideas were articulated clearly in the textbook (one example of that is on p. 338.).

The specific developmental process and context of the very concept of momentum was also deleted. No mentioning whatsoever for scientists' and philosophers' perception of the conservation of a certain physical quantity that had to do with motion was there in the plans. Descartes' definition of the "quantity of motion" and his conception of its conservation, the scientific inadequacy of that definition and the emergence of the new concept momentum were all absent from teachers' plans. If these historical, developmental, and contextual dimensions of the concept were to be omitted from classroom discussion too, as they

actually were in this case, the notions of momentum and its conservation would be thrown or imposed arbitrarily upon students, who, in turn, were required to make sense of them. Stripped of their context of scientific rationality, these concepts would appear, at best, of little relevance to students' knowledge, and at worst strange, nonsensical and meaningless.

Second, the wording of the law of conservation of momentum was given and actually treated in the plans in an incomplete manner. All the worksheets emphasized the mathematical definition of momentum and conservation of momentum: $P = MV$; and $P = P'$, where P was meant to stand for the momentum of the system before collision, and P' for momentum of the system after collision. This would mount to saying that the "momentum of any system is conserved".

The book, however, gave a more precise definition: "The momentum of any system is conserved if one condition is met: that no net force is acting on the system", (p. 255). One related consequence of this deliberate omission is the complete deletion of the treatment of the section on momentum and Newton's laws of motion. In this section the book explained step by step how the law of conservation of momentum could be deduced from an established theory. It also argued that vice versa, Newton's laws could be derived from the fundamental law of conservation of momentum. All the deductive reasoning and manipulations included in that section were not mentioned in the plan.

There was still another important aspect of the definition of momentum missing or only very lightly mentioned in the plans, but was much more emphasized in the textbook. Momentum was defined as simply the product of mass and velocity. All problems and examples given in the worksheets required knowledge of speed only instead of velocity. The vectorial nature of the concepts as emphasized in the textbook was thus deleted from the teachers' plans. As will be shown later the teachers were aware of the scientific importance, especially for mathematical manipulations, of this aspect of the definition. However, they only mentioned that casually and without any serious consideration.

Third, analysis of collision in two dimensions explained in a close-up section in the textbook, was also omitted from the teachers' plans. In this section momentum as a vector was shown to be conserved. Teachers deliberately, as Mr. Stewart told me, omitted that together with any consideration of three dimensional cases. The general mathematical form of the law for a number "n" of colliding objects was never to appear in the teachers' plans. Instead the plans suggested only special cases where two objects only collided and preserved their one-dimensional motion.

Fourth, the principle of conservation of kinetic energy in elastic collisions as suggested by Christian Huygens as a solution to the historical experiment on hardwood balls, was

also left out from the teachers' plans. However, a hint was given about this principle in the "thinker" subsection of the chapter outline, but was never pursued further in either plans or actual instructions.

Fifth, just like other chapters no handouts were passed or serious attention was paid to the set of questions and problems at the end of the chapter. Though these questions and problems were given one day of work in the chapter outline, no handouts or suggestions appeared in the separate daily worksheets. As I mentioned before the teachers were absent on that day, and practically there was no significant consideration of these questions and problems. The almost total absence from planning and consequent classroom discussions of the textbook problems and questions was very characteristic of planning of all chapters. Let us remember here that one of the teachers' criticism of the textbook was directed against the nature of those questions and problems. Table (3) summarizes the related topics as they were dealt with in the textbook and by the teachers.

Table (3). A Summary of the Topics on Conservation of Mass and Momentum Discussed by the Textbook as They Were Included or Excluded from the Lesson Plans

Topics on Conservation of Mass and Momentum	Topics Included in Lesson Plans	Topics Excluded from Lesson Plans
1) The development of a mechanistic view of the world.		X
2) Historical development of the law of conservation of mass.	X	
3) Collision phenomena and the emergence of the idea of conservation of quantity of motion.		X
4) The development of the concept of momentum from the concept of quantity of motion.		X
5) The qualitative and quantitative definitions of momentum and conservation of momentum in the case of two-body collisions.	X	
6) The general mathematical formulation of the law of conservation of momentum.	X	
7) Factors that may interfere with the law like friction.		X
8) Elastic collision and the historical experiment on hardwood balls. Huygen's solution for the experiment.		X
9) Numerical problems and lab demonstrations on momentum and its conservation in one dimension.	X	
10) Collision in two dimensions.		X

I believe there was more than one reason that made teachers pay very minimal attention to those questions and problems. To start with, the teachers, though they relied heavily on the textbook as a source of knowledge for their planning and instruction, did make serious decisions and choices as to what to include and what to exclude from classroom physics knowledge. That would necessitate a new set of problems that would go with what was chosen. Several questions and problems in the textbook dealt with more than one issue simultaneously. The teachers, on the other hand, might have decided to exclude one of those issues. Under such conditions the textbook questions would become unsuitable for classroom discussions.

Another specific reason that I believe made the teachers exclude the textbook questions and problems had to do with their nature. As I examined those questions at the end of the chapter on conservation of mass and momentum, I found a wide variety of questions and problems which required different kinds of scientific knowledge and skills. Knowledge of scientific explanation, scientific prediction, and scientific reasoning in general would be required on the part of the student in order to answer some of those questions. Other questions required symbolic derivations, Out of the thirty-seven questions and problems, there were fourteen numerical ones. In contrast, the teachers' plans included mainly definitions, and over twenty-five numerical problems focusing upon two ideas only: momentum, and

conservation of momentum. As mentioned before the teachers planned to deal with momentum in one dimension only. Consequently, questions and problems appeared in their plans dealt intensively with these two ideas only.

In a variety of ways planning for this chapter had some features common to teachers' planning in general. Apart from the common format used, the teachers relied heavily upon the textbook as the basic source of knowledge to be organized for classroom discussion. In the case of momentum and its conservation, the textbook seemed to have played the primary role in teachers decisions about the sequnece of the chapter relative to other chapters, i.e., when to plan for these concepts in the yearly flow or sequence of instructions. The textbook seemed also to be the primary source of knowledge the teachers planned to teach. It should be emphasized, however, that the types of representations and the planning for the introduction of these representations were not all taken from the textbook. Some of the lab experiments and demonstrations were certainly suggested by the Project Physics learning materials other than the textbook. Demonstrations on collisions in one dimension that involved lab carts were certainly taken from the companion materials. But the way those activities were planned for together with some other activities like the computer simulation program had different sources in the experiential life of these two teachers.

Another common feature of the teachers' planning in

general which appeared in the planning for this chapter had to do with the changes or alterations teachers made about the subject matter to be treated. At the general level there were always some significant changes and alterations. On the specific level these changes appeared topic-related. In the case of momentum there was no planning to deal with the historical development of the concept. Planning in this case was focused mostly upon the mathematical manipulations and physical applications of the concepts to be discussed. In chapters five, six, and seven, where motions of the planets and other heavenly objects were to be discussed, planning did include, and in some detail, the historical development of several related ideas and concepts.

Why did that happen? Why did the teachers include the historical development of ideas related to planetary motions in their plans and exclude the same sort of knowledge in the case of momentum and conservation of momentum? A partial answer may have to do with the teachers' knowledge and judgements. As was indicated in the previous chapter, Mr. Stewart who played a major role in the planning process was very knowledgeable on astrophysics and astronomy. He taught that when he had been a college senior. But then he did know the historical developments of the concept of momentum. He hinted at that at the beginning of the first lesson on the subject. The detailed information about that was there in the book which he had been using for so many years. It is unreasonable to assume that he did not go over it several

times. Yet eventually he chose, and so did Mr. Davis, to exclude that from their plans. Again the teachers' judgement may be, tentatively, explained in terms of their knowledge they gained in their college years. Momentum and conservation of momentum are central ideas in several undergraduate physics courses. None of these courses, to my knowledge, would attempt to explain the developmental process that had gone into these ideas. In contrast, college astrophysics courses would explicitly talk about the historical development of related ideas about the motions of planets. Names like Ptolemy, Copernicus, Tycho Brahe, Kepler, Galileo, and Newton, together with their relevant works and reasoning would appear in college textbooks on the subject. Other examples similar to that of momentum and conservation of momentum where the developmental context of the concepts and ideas was excluded from teachers' plans were conspicuously clear in other chapters, particularly, 10, 11, and 12. Traditionally undergraduate physics courses do not incorporate the details of the historical context in which the scientific knowledge included in those chapters developed.

What would be the implication of that on teachers' knowledge? My tentative answer revolves around the knowledge teachers had gained through their formal college courses. Once more it seemed that what teachers learned during those formative years of college education persisted, even after twenty-eight years of experience, in their strong

influence on the teachers' instructional judgements and realities. I found that particularly interesting in the case of Mr. Stewart, who on several occasions, reminisced about his college years with some thoughts and hints reflecting his dissatsifaction with the way he was taught physics, and with his eagerness to follow a different path that would truly help a majority of students learn physics. To me, the content base in physics of these two teachers appeared, to a significant extent, to be significantly grounded in what they learned during their college years, whereas, they seemed less sure about the substantive base of socio-historical knowledge of physics which they had acquired on their own since they had been teaching HPP.

Teaching Physics: Overview Issues

As explained in a previous section the teachers had had a very accurate projection on what to cover during the semester. In the case of the HPP course, Mr. Stewart gave a very good description of what they would be doing during that period of time. In terms of the volume of contents in both courses the two teachers appeared to have covered about half of the subject matter included in each of the two textbooks: about four and a half chapters out of ten in the IPS course, and twelve out of twenty-four chapters in the case of the HPP course.

The range and variety of topics in the IPS coverage were not really wide when compared to those in the HPP

course. Furthermore the level of sophistication and abstraction required in the materials covered in the IPS was much lower than that required in the HPP. In terms of the sheer number of pages and a rough estimation of words, Mr. Davis covered materials that spread over about 100 pages of the IPS text; while in the case of the HPP course materials covered spreaded over 380 pages out of 740 pages. Furthermore, a full text page in the HPP would include around 570 words, while a full text page in IPS would include around 470 words only. This means that in terms of the literal contents of the two books the ratio of the knowledge bases that were to be somewhat covered in the HPP and IPS courses was around five to one. In terms of the informational or knowledge contents this ratio would still, I believe, be much higher if we were to measure the knowledge included in the contents of the textbooks in units that would consider the amount and sophistication of information included in those pages instead of the sheet number of pages and words. What I want to say here is that the scientific knowledge contents of, say a typical 1000-word passage taken from the HPP text, would far exceed, both in the informational content and its level of sophistication, the contents of a similar IPS passage. It is important to mention here that the two courses were the first encounters in high school science for the overwhelming majority of students who took them.

How did the teachers manage, and especially in the HPP

course, to cover such a very wide base of scientific knowledge? Anybody familiar with the topics included in various chapters, with the subtlety and sophistication of many of those topics would really raise such a question when told that the content coverage included what it did.

In the previous section about planning I mentioned that teachers did make significant decisions about what to include and what to exclude from their plans. As a result of that many topics included in the textbooks were completely disregarded. While this may apply to the two courses, deletion of topics was much more often done in the HPP course than in IPS. But that does not explain the whole story, even for the topics included in the plans were in themselves very numerous, very demanding as far as instructional time was concerned. Clearly here, I am using my own judgement as a physics educator who dealt with those topics for about fifteen years and on a variety of levels: college physics student, high school physics teacher, and college physics teacher. A more comprehensive answer will emerge as actual teaching episodes will be examined very carefully through the examination of various classroom recordings. Some of the teachers' pertinent conceptions, judgements, belief systems, and philosophies discussed in various interviews were also looked into in order to present a coherent and integrated picture of how the teachers treated the subject matter. At several points in this discussion I will show that that presentation was not the

researcher's perspective of what was going on, but was equally well the perspective of the two teachers in the setting. I believe there was a very strong convergence of conception, between the teachers' on one hand, and mine on the other.

Instruction Driven by Planning

Teachers knew very well the content coverage they would be making during the semester. Their daily plans in the form of chapter outlines and worksheets predetermined what would be discussed or neglected. They appeared to have decided in advance not only on the contents of classroom physics knowledge, but also on the way that knowledge was to be presented. The contents of instruction in both courses were driven by what was included in the worksheets. Appendix (B) includes some examples of some lessons whose plans appeared in Appendix (A). These examples are mainly literal transcripts of classroom recordings. Fieldnotes taken during my participant observation were also used, when necessary, in synthesizing the contents of these lessons.

In the IPS course, a typical lesson would start with the distribution of textbooks and worksheets at the beginning of the hour. Mr. Davis would then go over the questions included in the worksheets one by one. He would discuss each question separately with the class as a whole. Answers to those questions would usually be explained and very often with some details. Since most of those

worksheets dealt with experiments paraphrased or copied from the textbook, the teacher would go over every single step necessary for carrying out the experiment. He would assemble the apparatus, do the necessary measurements and calculations, and finally draw whatever pertinent conclusions he would deem important. Everything the teacher would do would be in accordance with the questions raised in the worksheets. In summary the teacher would demonstrate to the class as a whole how they would be required to answer all questions they would be supposed to go over during that lesson. The time the teacher would take for such literal, and sometimes detailed, demonstrations would vary from five minutes to more than one hour depending upon the nature of of the experiment particularly the procedural part of it where the teacher as well as the class had to assemble the apparatus at the beginning of the hour, and dismantle it at its end. The worksheet on experiment 3.10, for example, (included in Appendix (A)), took two periods to do. The first period as well as part of the second one were used up by the teacher to demonstrate to students what they were supposed to do. This appears in Appendix (C).

Students would then form into groups, two to three students in each group. Various groups would then move their tables to convenient locations where they would have easy access to various gas, electricity, and water outlets in the classroom. A student from each group would collect from a source table provided by the teacher whatever

equipment his group would need for carrying out the activity. They would, then, start working on the activity. By this time most students would have answered the introductory questions on their worksheets dealing with issues like the name of the experiment, its purpose, and the recall of any mathematical relations to be used.

While various groups would be busy working on their activities within the framework laid out by the worksheets, Mr. Davis would spend the time circulating around answering individual questions, making some suggestions, or voicing some cautions in anticipation of any hazardous steps or materials.

By the end of the hour students would be required to answer all questions on their worksheets, hand them in to the teacher who would grade them later. Finally, students would do the clean-up and the arrangement of their tables. Textbooks would be collected and kept on a table for the next class to use.

Following the literal guidelines of the worksheets was a characteristic of practically all lessons observed in the IPS class. Nowhere in my observations had Mr. Davis decided to significantly change the course of the lesson as planned for in the worksheets. No major digressions or alterations were observed, even when there was a clear and serious lack of student understanding of certain fundamental ideas or concepts. The following two examples would illustrate that.

Example 1

Prior to a lesson on how to find the volume of some beads by water displacement, I asked Mr. Davis if he thought that all his students would know the principle of constancy of volume in liquids since he was going to talk about pouring water in differently shaped containers. Actually my question was based on some previous observations in which I suspected that some students might have some difficulty understanding this idea. Mr. Davis's response to my question reflected a shared observation. He too thought that "some" students would have some difficulty with the idea. He then suggested that he would check on that the next class when he would be teaching the lesson on how to measure the volume of a number of beads using the method of water displacement. The following is a short vignette of how things went on during the introductory minutes of that lesson.

> (The class is looking toward the teacher who is standing behind his table scanning with his sight the class, and then casting a look on the table in front of him, on which a lot of paraphernalia were set: papers, beakers, flasks, a crucible with beads in it, an empty cube, and a graduated cylinder.
> The teacher then started his lesson by pointing to the graduated cylinder in front of him. He went on to explain how the markings on the cylinder could be used to measure the volume of water in it.)
> T: "The graduations, little markings on here (pointing to the horizontal marks), can be further apart and you can read the volume. The ones that are short and wide, their markings are very close together. This one here is a sort of compromise between the two kinds. This graduated cylinder will hold one

liter when filled to the top mark. And I want to fill this graduated cylinder with one thousand millliliters of water. How many liters that would be?"

S(A): (Student A): "One liter."

T: "O.K."

(At this point he asked a student to fill the graduated cylinder up to the 1000 ml mark.)

T: "While Ken is doing that let's measure the volume of this rectangular thing. (The teacher held the cube). What would I do with a rectangular solid like this to find the volume? How do I find the volume by measuring the length, width, and height?"

S(B): "Multiplying!"

T: "We multiply them together, right! I measure the length this way. (Started to use a ruler for that); I measure the height; and I measure the width over here. Now, if I measure the height, width, and length in centimeters, what unit do I get when I multiply them together?"

S(C): "Cubic centimeter."

T: "Cubic centimeter. Centimeter cubed. (The teacher turned his sight toward Ken.) I don't want it to be over. I don't want it to be under.

This container (pointing to the cube again) is ten centimeter by ten centimeter by ten centimeter. Ten times ten times ten is one thousand. What units that would be?"

S(C): "Cubic centimeter."

T: "One thousand cubic centimeter. Now we are going to have a check here. I want somebody, (noise started to rise) let me finish my sentence; what I want a person to do is to pour the liquid from this container, (pointing to the graduated cylinder) into this container (pointing to the empty cube), without spilling a single drop. I want the full amount from here (pointing to the cylinder again) into there (pointing to the cube); and if it drips you have to say happy birthday to me. (Much laughter and noise.) How many believe that the liquid in here (pointing to the cylinder) will fill into there (pointing to the cube)?"

Class: (Around half of the class raised their hands.)

T: "How many believe it wouldn't fit in that?"

Class: (Three hands raised)

T: "How many just don't know?"

Class: (Around half of the class raised their hands.)

(Mr. Davis asked Ken to pour the water into the cube. Ken did that but he spilled out

> some of it. He was then asked to repeat what he did. The student filled the cylinder just like before, and then very carefully poured the contents into the cube. The cube was full. That was followed by loud applause.) (Soon after the noise stopped Mr. Davis went on with his plan to find out the volume of beads by this method of water displacement.) [Fieldnotes: 9/17/86]

It was evident in this example that at least three out of twenty-six students did not know that an amount of water would preserve its volume in differently shaped containers, and at least half of the class were not clear about this issue. The two containers did not really represent the extreme variation in possible shapes. The cube was only shorter than the cylinder. Had the contrast in shape been more pronounced, more students, I believe, would have been confused about this issue. The teacher, however, chose to stop at that point and go back to do "business as usual" (Clark and Yiner, 1979).

Example 2

Let me present another example where some students' knowledge reflected, I think, a lack of scientific understanding of the concept under discussion, and how the teacher chose to go ahead with what he had planned before. The excerpt was taken from a transcript of a classroom recording in which the teacher, after he had in previous lessons discussed the concept of density, was explaining through a demonstration how hydrometers could be used to measure densities of various liquids. He then tried to apply the same principle to ships in different water.

T: "Where would a ship float higher: Would it float higher in Lake Michigan or in the Atlantic Ocean?"
Ss: (choral voice) In the Atlantic Ocean."
T: "Why?"
Ss (two): "More water...more water in the sea."
T: "More water is bigger, wait a second!"
S: "Higher density."
T: "Higher density! How many would say higher density?"
Class: (Fifteen students raised their hands.)
[Fieldnotes: 10/29/87]

Clearly, then, for some, perhaps the remaining eleven students, there was a confusion over the two concepts volume and density. For those students more water might have meant higher density. The teacher, however, went along with his plan and no further discussion of the issue was made.

The situation in the HPP course was fundamentally the same. In their various modes of instruction both teachers stuck to their plans. Though it is harder here to talk about a typical lesson because teachers used a variety of techniques like lecturing, lecturing with demonstrations, mathematical problem solving, lab activities and experiments, or simply seatwork; nevertheless, in all forms of instruction lesson plans determined to a very great extent the contents of classroom instruction.

An HPP lesson would start with the distribution of the worksheets for that lesson. The teacher would then make a brief introduction of what to be discussed in that lesson. He would then start discussing the first issue on his handout through a short lecture or a whole-class discussion in an attempt to elicit the required student response or

interaction. There was always some space left on the worksheets for the students' responses to a question raised regarding the issue under discussion. Students learned to fill into those blanks as the teacher would be lecturing or discussing the point with the class. In some cases the teachers took the whole hour to go over all the questions in the worksheets. On other occasions, however, especially when the plans included some lab activities or bonus problems, only part of the lesson would be used by the teachers for some demonstrations or explanations, and students would take the rest of the hour to do the work by themselves while the teachers would continuously visit at various group stations or individual students for any needed help or explanation.

At a pre-specified date students would hand in all their chapter handouts in order to have them checked and graded by the teachers. These handouts would be turned back to students who would be advised to go over their work in preparation for a quiz or a test.

Difficult, or even frustrating, classroom moments when a teacher would feel that much of his previous efforts in explaining to the class certain fundamental topics had been ineffectove are part of the classroom experiences of any high school and college physics teachers. Physics teachers experience that very often, perhaps more often than many other teachers. For many students struggling to understand physics, the experience may be so devastating that they may

opt not to study physics anymore. The instructional response of teachers in such situations may vary. In this study, both teachers, as will be explained later, constantly attempted to minimize or avoid these instances. However, on times when students reflected serious lack of understanding, or simply got stuck with an issue or problem, the teachers made no major concessions regarding their plans. They would offer one or two more additional examples to illustrate the difficult point students did not understand; they would add more details to their reasoning and discussions; but under no circumstances did they appear willing to make drastic alterations in their lesson plans. I have chosen four more examples, two for each teacher, that would illustrate that.

Example 3

In this example, Mr. Davis was trying through classroom discussions and reasoning to develop a case for Galileo's suggestion of constant or uniform acceleration in free fall situations. At the same time he was trying to show that Aristotle's famous argument that different objects would gain different speeds as they would fall freely was self-contradictory. Clearly, then, in this episode Mr. Davis was engaged in a key physics issues where commonsense knowledge and mere intuition were not reliable sources of description of how objects would behave in free fall situations. Inherent learning difficulties in such cases are well known to experienced physics teachers and students of physics as well.

(After some introductory comments on chapter two, Mr. Davis went into a historical introduction about the Greeks, their culture and some of their thinkers. He picked up at Aristotle and his ideas about motion. He then moved on to Galileo and his corresponding interests in the behavior of falling bodies. In this short lecture, around fifteen minutes, Mr. Davis stated directly both thinkers' conflicting ideas about motion of objects particularly in free fall situations. He then referred his students to Galileo's pertinent book, excerpts of which were included in the textbook which illustrated through an argument among three fictuous figures the self-contradiction inherent in Aristotle's views and the soundness of Galileo's. Mr. Davis then started his questioning technique with the class. The names Simplicio and Salviati refer to Galileo's fictuous figures in his book who supported the Aristotalian and Galilean views respectively.)

T: "Did you get the point, first of all, in the argument? The Aristotelian philosophy says that different materials fall with a fixed speed consistent with that particular material. When I ask you about falling objects; if we watch the object carefully, what appears to be happening to the speed?"
Ss: (Three together) "Increase!"
T: So the more time the substance is falling, the faster it gets!"
Ss: (Around five together) "Ah-huh!"
T: Then if that is true, go backward now, if you just released it how fast it was going, it just went?
Ss: (No response)
T: "If no time is gone by, how fast is it going?
S(A): "It is not going!"
T: "And so at the point of release the object is not moving at all, just at the moment of release. It's just kind of suspended there. I don't know if you agree on that. But, would you agree that after a period of time the object is moving faster than it started, that every moment the object is falling it gains more speed, and that the maximum speed is just at the point when it hits the ground. Aristotle then says that two objects made of the same substance, when released simultaneously, they should fall together. If we take the same material and make one much smaller than the other, what is he saying?"

S(B): "The heavier the object hits first."
T: "The bigger one hits first. The idea then the heavier object travels faster than the lighter object even when they are the same substance. This is self-contradictory. Galileo realized that objects when they fall they do change their speeds. But it's not dependent upon the kind of materials they are made of. Like clay lumps, and rocks and a chunk of iron, and a wood ball, if released they will all fall together regardless of their weight. They gain speed and Galileo showed that the gain is in a very predictable pattern as time goes on. So objects that fall, according to Galileo, fall together; they accelerate together. They fall together. Which is true?"
S(C): "I think if we drop a wooden bar and an iron bar, the iron bar will hit first!"
T: (Looking at student C who gave the answer) "You think the iron will hit first?"
(At this point there was a lot of noise in the classroom which I believe reflected the uncertainty about the correct answer.)
T: "How would you test the idea? How would you test the idea?"
S(D): (Started to talk but unclearly about two objects of different substances and then weights.)
T: "Good point she asks this question: is it the substance or is it the weight?"
Ss: (Three together) "It's the weight!"
T: "How would you test that ? How about taking two different weight objects and release them from the same spot. If they go bom...bom when they hit the ground the last bom will be the lighter object. What if they hit bom? What if there is only one hit?"
Class: (no response)
T: "How many of you think Galileo was right?"
Class: (only two hands raised)
T: "How many of you think Aristotle was right?"
Class: (A lot of talk and discussion going on, six hands were raised. However, the hour came to its end at this point.)
[Fieldnotes: 9/8/86]

On the second day Mr. Davis went over the next work plan in which he explained how to find out acceleration through graphing, velocity versus time graphs. Many

students, however, were still confused about whether heavy objects fall faster than light ones, or all objects would fall together with the same speed.

Example 4

The second example occurred in the context of another essential area in physics namely, Newton's laws. In this example, Mr. Davis was attempting to explain the work of rockets using Newton's third law of motion. This is a classical explanation which very often appears in the context of talking about Newton's third law. But before going into that example, let me say one important point about this law.

The law in its formal definition may be put as follows:

> "When two objects exert forces on each other, the force that object A exerts on object B is always equal in magnitude and opposite in direction to the force that B exerts on A."

This definition which is equivalent to what is included in the textbook, includes two fundamental ideas. The first is the mutual influence of the two objects upon each other: when one object exerts a force upon another, this latter one should reciprocate by exerting a second force upon the first object. So according to this definition we would be having two different objects with two different forces. The second point explicit in the definition is that these two different forces should be equal in magnitudes and opposite in their directions. Historically, Newton called these forces action and reaction, and the implication was that forces appear in

pairs. That is why it became very customary among physics students and teachers alike to summarize this law by saying "for each action there is an equal and opposite reaction." As we shall soon see in the following vignette Mr. Davis, while sometimes talked about two different objects in his explanation of the rocket motion, the rocket itself and the rushing fuel, he, nevertheless, regressed every now and then to the action-reaction definition.

What is fundamentally lacking from this condensed form of the law is an explicit reference to the two objects supposedly mutually influencing each other. During my observations I asked several students whether those two forces should cancel each other or not since they were equal in magnitude and opposite in direction. As I expected, all of them gave me the wrong answer: "yes", or "I think so". I believe the subtlety of this law in the realization that those forces were acting on different objects is a potential source of learning as well as teaching problems. That, I think, contributed to the teaching and learning difficulties encountered by Mr. Davis in the following vignette.

> (Mr. Davis started his lesson by a reference to a question he was asked by a ninth grader in the IPS course. The ninth grader asked how could the rocket in empty space travel forward or come back to the earth since there would be no air surrounding the rocket.)
>
> T: "Basically we are asking the question what causes the rocket to move. Is there anyone here who has thought about that? Is there anyone who has a clear picture about that?" [Wait time was eight seconds.]

T: "No one has that! That's interesting! Let me ask you: does the rocket move forward without the air? What do you think about this hypothesis?"
[Wait time was eight seconds.]
S(A): "It's wrong!"
T: "It's wrong! Does it push against the air?"
S(A): "Yes!"
T: "How does that work in space then?"
S(B): "It doesn't work!"
T: "So that hypothesis is wrong! What causes the rocket to go?" [Wait time was 3 seconds.] It does go. There is a force. One way of looking at Newton's third law: for every action there is an equal and opposite reaction. Now think about that in terms of the rocket. What is the action?"
[Wait time was 10 seconds, but no response was given.]
T: "What is a the action?"
S: "The fuel!"
T: "The exhaust, the fuel rushing out the back again. O.K.! What is the reaction?" [Wait time was two seconds.]
T: "The rocket going in the opposite direction. Now you put it out in space. You create an action this way and there is a reaction to it this way (drawing two arrows opposite to each other at the tail of a rocket sketch). Now on Friday we didn't try this, but imagine yourself on a skateboard, on a frictionless sort of a skateboard and you throw a ball this way, which way does the skateboard go?"
Ss: [Two students] "The opposite way!"
T: "That's the same thing as the rocket. You're throwing molecules of gas out that way, which way does the rocket go? That way (pointing to the opposite arrow). It doesn't push on the earth it doesn't push on the air. It's for every action there is equal and opposite reaction." [Fieldnotes 9/29/86]

Mr. Davis then went on in his discussion in order to make a connection with Newton's second law by discussing what would happen to the velocity of the rocket if the force acting on it remained constant while its mass decreased due to the loss of some fuel but none of the students was able to predict that the rocket would accelerate more. In his

final remarks on this issue, Mr. Davis raised the initial question again:

> T: "So what would be your answer to the ninth grader who raised the question?" [Wait time was three seconds, no response was given.]
> T: "For every action there's equal and opposite reaction. It is not the pushing of the air. It's just the rush off the back, and the reaction: the rocket going the other way."
> [Fieldnotes: 9/29/86]

The previous explanation came in the context of doing a lab activity on Newton's second law, and one lesson after all three laws of Newton were discussed. Though the specific contents of the discussion were not included in the worksheet, the issue was brought up as a revision of the previous lesson and an introduction to the new one. Eventually, no final changes were made on the lesson plan, and everything went on as had been planned before.

Example 5

This is an example that was taken from the context of a lesson on Kepler's laws. This was the second lesson on chapter seven. In the first lesson Mr. Stewart went over some pertinent topics mainly on the geometrical description of the ellipse including the definition of the concept of eccentricity. The worksheet for the second lesson (Appendix B) included a numerical discussion of Kepler's laws through a sketch for a planet orbiting the sun. Mr. Stewart went over Kepler's first law, law of elliptical orbits, and then started his discussion of the second law, law of areas. This law, after some simple mathematical manipulation was

formulated as follows:

$$\frac{V_P}{V_A} = \frac{D_A}{D_P}$$

V_P, stood for the speed of the planet at the perihelion point (the point where the distance between the planet and the sun would be minimum),

V_A, stood for the speed of the planet at the apihelion point (point with maximum distance between the sun and the planet)

D_A, represented the apihelion distance, or maximum distance between the sun and planet, and

D_P, was the perihelion distance.

The following vignette portrays the problems the teacher was encountering in his attempts to reason out a solution for a simple problem using the previous equation in which three values were known. Notice how the teacher was attempting to content himself with just developing an intuitive understanding of what sort of a reasonable answer the students should expect without even going into the simple algorithm needed for that. All values and expressions mentioned in the vignette were discussed during the first part of the lesson.

> "Let's go back to this equation that I showed you, where it comes from and see if we can apply that to find out how fast something is moving. Suppose we knew the speed at "B" is ten kilometers per second and this is equal to the speed at apihelion, isn't it? The speed at apihelion ten kilometers per second; what is the speed at the perihelion? It will depend on the ratio of the

distance. What is the ratio in this one? Let's take this equation and look at it to see if we can untangle it. [At this point the teacher started to look at the chalkboard where he had derived the equation]

V_P, That's my unknown, isn't it! The perihelion speed; that's what we want to find out. V_A, that's given: ten kilometers per second. [teacher started to write on the board] What else do we know?"

S: "D " and "D ".

T: "O.K. We know the distance to perihelion. What's that perihelion distance?"

S: "Two AU!"

T: "Two AU, good! And the apihelion distance? Six AU, all right! Now, can you tell me right now from that...let's say the ratio of the speeds is going to be the ratio of the distances, and the distances are six to two, so the ratio of the speeds is going to be one to three, or three to one: is it going to be three times bigger or three times smaller?"

S(A): "Bigger!"

T: "If I gave you the slow one, the fast one is bigger isn't it! Three times faster, so how fast is it going at perihelion?"

Ss: [about three students together] "Three, three kilometers per second!"

T: "O.K. Question, all right! This is just a hand waving go through. I am saying that the ratio of the distances, apihelion to perihelion is six to two or three to one. One is three times bigger than the other. The ratio is going to be three times bigger or three times smaller? In this case since I give you apihelion speed and ask you to find the fast one it means it will be three times bigger. So three times ten, because the speed increases as the distance decreases. Right! It's going fastest at perihelion and slowest at apihelion. So we're giving you the slow and asking you to find the fastest. O.K.!"

S: "So what is the ratio?"

T: "It's three to one. In this case it's three to one increase."

[Fieldnotes: 11/17/86]

Clearly then Mr. Stewart resorted to the logic of semantics in order to overcome the problem and move to the next item on his agenda. The reasoning he eventually used went as follows: ratio of distances was the same as the ratio of the speeds. Ratio of distances was three to one; and since the question asked for the higher speed, this speed, V_A, must be naturally higher than the given one, V_P, which was ten. So the speed to find must be ten multiplied by three. That is it! Clearly, a major source of confusion was the inverse proportionality between the planet's distance from the sun and its orbital speed. Notice also the teacher's remark "this is just a hand waving go through.", which indicated among other things, the teacher's intention not to be too involved or undertaken by it.

Example 6

The last example presents an event which I believe all physics teachers have encountered in one form or another, and experienced the bitterness and frustration it would leave on the sense of accomplishment teachers try to achieve through their classroom instruction. It is the case where after spending much time and effort trying to explain a certain topic or concept, a student or a group of students would raise some questions which reflect a great degree of ignorance of what had been going on for the past week or so. Though teachers' responses may vary from one situation to another, the effects such incidents may leave upon teachers

would very often be frustrating.

During his first three lessons on chapter nine Mr. Stewart discussed the conservation laws in general, and the law of conservation of momentum in particular. He solved at least seven numerical problems related to this law. The class had already done eight lab activities on the topic. Next, Mr. Stewart planned to solve ten more problems on the concept of momentum, and the law of conservation of momentum. The episode to be cited was recorded when he was attempting to lead the students to the solution of problem number three in the first of the two handouts distributed for that lesson. The problem asked for the speed that a 1300 kgm auto would have in order to achieve the same momentum as a 1950 kgm truck traveling at a speed of 20 meters per second. The problem is clearly a straightforward application of the definition of momentum in its mathematical formulation. All that was required was to multiply the mass of the truck by its velocity in order to find its momentum; and then to divide this momentum, which should now be equal to the momentum of the auto, over the auto mass. The result of the division would be what was needed. The teacher was also trying to use symbols and notations he explained previously.

T: "Well, we're saying that we have this automobile whose mass is nineteen hundred and fifty. Now we have to be able to talk to each other about these two different quantities and be able to keep them straight. So the way to do it is to use subscripts. What I am saying is the mass of the

automobile is thirteen hundred kilograms." [Teacher wrote on the board m = 1300 kgm] "I am going to put a little "a" as a subscript below the "m". So this is telling you that the mass of the automobile is thirteen hundred kilograms. How am I going to write the mass of the truck?"

Ss: [Three students together] Subscript "t"!

T: "Put a "t"! O.K.! The mass of the truck is nineteen hundred and fifty. Well, then I know that the truck has the speed of twenty meters per second. So how should I write that: speed of the truck is twenty meters per second?"

S: "V" "t"!

T: "V" sub "t" twenty meters per second." [Teacher wrote on the board V_t = 20 m/sec] "What about "V" sub "a"?" [He wrote V_a on the board, and then waited for 3 seconds, but there was no response] "V sub "a", the speed of the automobile is my unknown in this problem, isn't it! That's what we want to find out. What is the speed of the car?" [A student raised his hand.]

T: "Yes!" [pointing to the student who raised his hand]

S: "You must cross-multiply here only!"

T: "No, not cross multiply. What you have to do is to say, in this case it wants the momentum of the car to be equal to the momentum of the truck. So the momentum of the car is equal to the momentum of the truck. Momentum of the car is mass of the car times speed of the car, momentum of the truck is mass of the truck times speed of the truck. [During these utterances Mr. Stewart was plugging in the numbers in front of each symbol of the knowns in the relations on the board, and then bringing the numbers 1950 and 20 to multiply them to get the momentum of the truck.]

S(B): "Did we do this?"

T: [Stopped writing on the board and turned his face to the class.] "This stuff has already been covered. This is a review. We've gone through this before, right! You'd answered questions on it. We did it before. Momentum, you know it's straightforward. Just mass times velocity. O.K.! Let's look at that equation that we've come up with..." [Fieldnotes: 12/1/86]

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Mr. Stewart went on, solved the problem and the rest of the nine other problems just as he had planned before.

What Teachers Do When Things Go Wrong

It was explained that teachers had very accurate projections on the content coverage of the courses they were about to teach. It was also explained through specific examples how teachers stuck with their daily plans when teaching. In that sense their plans, in the form of worksheets, predetermined the physics knowledge discussed in classroom. This result is consistent with other research findings on the thought processes of teachers (Clark and Peterson, 1984; Shavelson and Stern, 1981; Putnam and Leinhardt, 1986). Shavelson and Stern described how a teacher would base the teaching of a lesson on a plan called "classroom teaching routine," while Putnam and Leinhardt called this plan a curriculum script." It was clear also that teachers tended not to make any significant changes in those plans during instruction even when there was strong evidence that a number of students were having some difficulty learning. In addition to my observations which continually confirmed this assertion I specifically asked both teachers what they would do in case a number of students did not understand the topic or topics under discussion. I asked the question in the context of the lessons on projectile motion which the teachers enjoyed teaching. They devoted more time for the discussion of this

topic than they usually would for other central physics topics. It happened that at the time I raised the question both teachers were finding out that students were doing very poorly on the quiz on that topic. Here is what each teacher had to say about that:

Mr. Stewart:

> "That's a question which we are faced with right now after as a result of the test I saw this morning. I think in the long run our solution is to look at the way we taught this material and try to analyze what we've done right and what we've done wrong, and next year do it differently so as the problem doesn't come up again. That's the long run solution. The short run solution of what we're going to do this year...now we've got ourselves into a dilemma. Look we went through four or five chapters. This is the first time that there is a large number of students that didn't do well on the quiz. Usually they do pretty well. But here is a quiz where they didn't. And so I am not going to throw everything in order to repair this damage. We may briefly allude to it. We are certainly going to get a mileage out of the lesson learned in terms of: how do you get ready for a physics test; what did you do to get ready for this physics test that when you came in and we gave you a problem like we've been working on, you couldn't do it. What was your preparation or what was your plan to get ready for the physics test that allowed you to make such an oversight?" [2nd Interview: 10/14/86]

Mr. Davis:

> "The policy that we've gone to is not the one I totally agree with, and that is to go on with the course with the intention in mind that the students know that here is an area where they didn't do well, and that in subsequent physics courses or subsequent science courses the topic comes up again, that here is something that your really have to zero in on. Our policy is not something that would stop the whole process to go back to rehash the material. To some extent we tried that. It didn't seem to produce much better

results that we did just going through it once". [2nd Interview: 10/14/86]

Neither teachers had specific plans to correct the situation with the specific students who made specific mistakes. They both talked about teaching students as a collective. Notice also that both teachers attributed, at least partially, the students' difficulties to the students themselves. While Mr. Davis thought that by telling students about those problems they would become alert to that when the topic would be discussed again, and that they would "zero in on", Mr. Stewart thought that the problem had to do with the students' preparations for the quiz. Both teachers, therefore, chose to go ahead with their plans and move on to new topics. Indeed there was no re-discussion of any ideas related to the topic in subsequent classes.

But what does it mean to score poorly on that, or any other, quiz or tests. Here I will not go into the details of explicating the nature of those quizzes and any implications for learning. But to the degree the quiz was a measurement of learning, I can say that there were learning problems regarding that topic. But to have learning problems related to projectile motion, a combination of two straight-line-motions one without acceleration and the other with a uniform acceleration, may very probably entail having learning difficulties with the fundamental concepts of motion discussed before like, velocity, acceleration, and Newton's laws. These teachers, as well as any experienced

physics teachers, would be aware of such situations in physics teaching where correcting a teaching-learning situation may require a regression toward square one in the students' knowledge of the object matter. Notice the last two sentences in Mr. Davis's quote: "To some extent we tried that. It did not seem to produce much better results than we did just going through it once." Naturally if the learning problems had to do with the understanding of the concepts of velocity, average velocity, acceleration, average acceleration, uniform acceleration, or Newton's laws, re-explaining projectile motion as such would do very limited improvement. The highly structured and hierarchical nature of physics knowledge is a source of concern if not frustration for any physics teachers who would attempt to eliminate such learning difficulties.

Another important accompanying phenomenon to the teachers' intention not to deviate from their instructional plans had to do with students' participation in classroom discussion. I had no research questions on this issue. But leaving the matter without a note on students may cast some shadow on this issue.

One of the striking observations I recorded on several occasions was the modest amount of interaction the students showed in classroom discussions. Furthermore, whenever that modest amount was displayed, it tended to be in a fragmented form and far from being cognitively challenging for the teacher's knowledge. Students' questions or answers tended

to be expressed in words, phrases or very short sentences. Extremely rarely were the situations where a five-minute sophisticated discussion about a difficult science topic between a student or a group of students and the teacher took place. Neither were any occasions when the teacher had to respond to a student question by saying something like this: "Well, you really could be right in your explanation or solution of that problem. But let me check on that and we'll come back to this point in tomorrow's lesson." It's true that the teachers were knowledgeable as far as the subject matter was concerned; but even with a lot of knowledge base and experience at their hands, physics teachers could very well be intrigued if not challenged by an inquisitive critical young mind striving to understand physics.

Classroom instructions was in accord not only with the teachers' plans but, I believe, with the classroom environment as a whole. The teachers never cut short or discouraged students' questioning. On the contrary they were constantly eager to raise questions. However, when receiving no response, or a wrong one, they would in turn offer their answer. Students would very simply accept that, and teachers would now move to the next item on the agenda, and so on. This was how the teachers' structured plans helped them move fast in content coverage.

Having said that, I believe it is improper, whether here or anywhere else in the rest of the findings, to ask

questions of the form "Which caused what?" Did the teachers' persistence to follow almost literally their plans cause the students to participate less in serious classroom discussions? Or, was the opposite more plausible? Any definite answer for either question may prove to be a careless or even irresponsible conclusion.

Forms of Instruction: The Teachers' Lesson Types

It was explained in the previous section that both teachers tended to implement their lesson plans without any significant deviations from their contents even when classroom communicative interactions showed clear signs of deficient learning or even lack of it. It was also pointed out that although lesson plans, in the form of worksheets, did not describe how to go about teaching a particular topic, teachers adopted the same instructional orientation toward them. In other words, they tended to use the same instructional strategy, or lesson type as was termed by them, for any topic they planned to teach. It seems there was a variety of reasons for that. Among these reasons was, undoubtedly, the co-experience they shared for so many years. A shared implicit understanding of the meaning of certain brief phrases, hints, and clues included on the worksheets had developed over the years. Words and phrases, like demo's, lab or lab exp., problem set #, bonus, and lecture, were among those words and phrases that were decoded by the two teachers into similar frames of classroom

acts.

Examination of the worksheets, transcripts of classroom recordings, and teacher interviews revealed several lesson types that were used by the teachers in both courses. However, and as pointed before, diversification in lesson types was clearer in the case of the HPP course than it was in the IPS one, where hands-on activity was clearly dominant over other methods. In the HPP course, the teachers had a clear intentional strategy to diversify lesson types pervaded various chapters.

As I go into the description of each lesson plan I will use the teachers' own characterization for these types whenever that was possible. There is, however, one key word I will use and which did not appear in the teachers' utterances. The word is "recitation". Under this concept of teaching I will include the lesson types in which the teacher would enter into a classroom discussion with the class in the form of interaction with individual students, or groups, or the class as a whole. The strategy under any form of interaction would be such that the teacher would ask a question or make a comment, and then wait for the class, or a specific student, to demonstrate his knowledge on the questions asked. The teacher would then check the answer, may be critique it himself, or ask somebody else to make comments on that. At one point in this process the teacher would make a decision to move on to a next question or topic. This strategy pervaded, in varying degrees, all

other lesson types used by teachers. They used it when they solved problems, made some demonstrations, or prepared for a hands-on activity. It was the dominant classroom interactional form that shaped much of the classroom interactions, put some limits and restrictions on the teacher-learning process, and gave much flexibility and leeway for the teachers' interactive decisions concerning micro-pacing: how much time to spend on a student answer, utterance, or lack of them, when to leave a topic under discussion and when to take up a new one. Just like pacing in general micro-pacing, manipulated through recitation, seemed to be consequently influenced by some major instructional objectives. Easy lessons, as well as potentially difficult ones were carried out within the pre-planned framework of time and activities. So were various chapters and units.

Another feature which appeared in many lessons was the usage of more than one technique or strategy within one lesson. It was very common for both teachers to use a mixture of two or more techniques during the same lesson. In some hands-on activity, for example, the teacher would precede that with a demonstration. Likewise, in a lesson planned for demonstrations the teachers would use problem solving techniques for parts or all of the demonstration, and so on. Indeed it is very hard to find a lesson where one technique only was used. However, lessons dominated by one technique only were often observed. In what follows, I

will describe with some examples each lesson type. Appendix (C) includes some examples on various lesson types.

Recitation - Discussion Type

As was mentioned before the word recitation was not used by the teachers in their description of their strategies. The closest teacher word for that was "review". The word discussion was also used but not in a definitive way. Traditionally, or perhaps grammatically, the word recitation denotes the speaking aloud, or the verbal demonstration of some forms of knowledge learned before. In education, however, the word is meant to describe the form of teaching-learning process in which the teacher asks his students some questions whose answers were previously explained to; or assigned for students to work on (Collette, A., and Chiappetta, E., 1984). In the actual classroom setting this is manifested through a question-answer interactional pattern.

In real classroom settings this pattern of interaction is usually used to check on students' understanding of certain concepts. But it could also be used, as was used in this setting, for further explaining and developing the concepts under discussion, or for setting the grounds for the introduction of new concepts.

So was the case with discussion. Though the ordinary usage of the word tends to be general, in education and particularly when talking about instructional methods its

usage connates an interactional pattern where the participants clarify their own values or understandings regarding certain issues. This interactional pattern requires, among other things, making thinking initiatives and novelties on the part of participants. In science classroom settings, it is very often the case, and in fact it is very much encouraged, that students called upon to discuss a concept would regress to what they learned in previous lessons in order to make their point. In that sense discussion overlaps with recitation. Appendix (C) includes an excerpt from a transcript of a lesson recording in which Mr. Stewart was attempting to review Kepler's first law in order to set the stage for the other two laws.

Lecture Type

Lecturing was used often by teachers. Most lessons and chapters were usually started with a short lecture in which the teacher would attempt to convey certain information for a variety of objectives. The historical information selected by teachers was conveyed to students through this technique. Almost all lessons and chapters were started with a short lecture in which the teacher attempted to elucidate some key concepts or demonstrate some lab skills to be used in a lab activity. In some cases a good part of the lesson was used in lecturing only. In the few cases when the whole lesson was used for a lecture, the teachers gave such a lecture in conjunction with a set of

demonstrations. Appendix (C) includes a transcript of one lesson in which a lecture was used to explain a multitude of concepts related to sound waves through a variety of demonstrations. The lecture, about 5000 words, conveyed an incredible amount of physics knowledge that was both central and sophisticated. None of my observations, and I believe none of the lessons in both courses, included a case where the teacher used up the whole hour lecturing verbally only.

Though lecturing somewhat implies a monodirectional form of activity, the teachers appeared always ready to stop at any point in their discourse to answer a student question or remark.

This form of instruction was always used for the class as a whole.

Hands-On Activity Lessons

This lesson type was used extensively in the IPS class, and less frequently in the HPP class. Teachers used to call it a "hands-on activity", or a "lab experiment". In such a lesson the teacher would demonstrate to the class how to do an activity using an apparatus. He would assemble the apparatus, when that was needed, carry out the activity, and do the necessary calculations and derive whatever conclusions he would be after. The class would then form groups of two to four students, and then start doing what the teacher had done. They would record their data, numerical or descriptive, on the worksheets for later

checking by the teacher. In the meantime the teacher would be circulating around answering questions and making suggestions.

In a few cases observed the lesson included more than one single activity. The teacher in those cases either demonstrated or simply described what and how to work. When further instructions were judged to be needed, they were written and left on various lab stations where students would carry out the activity.

The HPP lab activities tended to be of the verifying type, i.e. the teachers as well as the students were to verify a principle or a law through that activity. Others were purely demonstrational designed to elucidate a concept or a principle.

While some of the IPS course activities were designed to merely teach students some basic lab skills like various forms of measurements, others went steps farther than that. Explanation of certain concepts, verification of principles, and discovery or problem solving were all set as objectives in the design of some activities. However, the fact that the teacher always explained to the class, through the worksheets he distributed and the demonstrations he did, each step to be followed in the activity rendered such a work unqualified for the more rigorous definition of inquiry methods as described in science textbooks where students would be much more independent in designing their experiments and drawing their own conclusions regarding a

certain problem or phenomenon.

Appendix (C) includes two different examples on this lesson type. The first one was taken from an IPS lesson where the teacher asked his ninth graders to find out whether two metal cubes of the same dimensions, were of the same material. The class was progressing in their study of the concept of density. By that time they had to do a lot of different measurements including distance and mass measurements. Yet the teacher felt that he had to explain again how to make such measurements for the two cubes whose densities were to be investigated. Look also for his remark that in his previous hour some students were not able to find the volume of the cube. In fact, as I observed the class during that activity, I found that many students were not able to multiply three small numbers, not to talk about the next step of dividing mass by volume in order to find the density of the material. The didactic procedure the teacher went through in order to explain what the class was supposed to do is evident in the transcript. As I circulated around during that lesson I could observe several who still found it difficult to make the measurements or do the calculations.

In the second example the teacher, Mr. Stewart, was explaining to the class how to carry out an activity on Newton's second law: $F = ma$. Prior to the activity, Mr. Stewart explained Newton's laws; he also solved some mathematical problems on the second law. In a sense, the

activity was to verify the law.

Yet examination of the teacher's explanation and questions in the worksheets did not indicate that the teacher's goal was to teach the precise and rigorous, but yet simple, mathematical formulation of the law. In the final analyses what I found was that the teacher's specific goal was to let students develop an intuitive understanding of the law in a form that lacked the mathematical rigor and precision. At best, I believe, the activity attempted to teach the law in the following descriptive form: "As the force acting on an object increases its acceleration "a" increases too, if the mass is kept constant; and as its mass increases its acceleration decreases, if the force acting on it remains constants." In other words the mathematical meaning of direct and inverse proportionality embedded in the mathematical formulation of the law was not verified or tested by the activity. Of course students in problem solving sessions that preceded and followed the activity did use, clearly without being aware of that, the logic of proportionality but without trying to make the fundamental connection with what it meant in the physical world.

Problem Solving Sessions

Solving numerical problems was a lesson type used more often in the HPP course than in the IPS one. In a short presentation given by Mr. Stewart in the Fall Semiannual Meeting of the American Association of Physics Teachers -

Michigan Section, held in Ypsilanti on Nov. 1, 1986, Mr. Stewart stated without elaboration, three main objectives for solving problems in his physics classroom. They were: to help students develop their understanding of the logic involved, to clarify certain concepts, and to offer students an opportunity to exercise a mental activity or discipline. He then described a mnemonic scheme he had been using in teaching students how to solve problems. The scheme was the acronym "KUESA", where the letters had the following word sources:

"K", from Known quantity/ies,
"U", from Unknown quantity/ies,
"E", from Equal to (the equality sign "="),
"S", from Substituting, and
"A", from Answer.

In his explanation as to how to use this device in solving problems, Mr. Stewart emphasized the steps and their ordering as implied in the acronym: first, identify the unknown to be figured out; second, identify the known quantity or quantities; third, put the equality sign for the equation, fourth, find the appropriate equation to be used; fifth, substitute for the known quantities and do the algorithm; and finally find the answer.

That was a good descriptive framework of what happened in real problem solving sessions. However, there was nearly always an additional element of explanation and a form of discussion, though sometimes marginal, for almost all problems discussed. Appendix (C) includes a transcript of a

part of a lesson in which Mr. Davis was involved in solving three problems on acceleration.

Apart from the usual problem solving sessions devoted for various topics, there was always a session for bonus problems on each chapter. During this session students would have the option of solving an extra set of problems for an extra point or couple of points. Students during those sessions worked on their own. These extra points were potentially capable of raising the final grade of a student who worked for them, one letter-grade level, say from "C" to "B" for example.

As I observed those bonus sessions I had the impression that many students worked harder for the bonus than they normally would in the regular sessions. I asked Mr. Davis if he shared with me this observation. His answer was affirmative. When I asked him for his explanation of this phenomenon, his answer came as follows:

> "Maybe it can be used as a real worm to attract students to do something they normally wouldn't do". [2nd Interview: 10/14/86]

Examination of bonus problems indicated they were not different from other problems solved in prior sessions. While attracting students to do an extra exercise would be educationally sound, the real issue would still be: why would these students pay less effort in ordinary sessions than they would in bonus exercises? A hypothesis I contemplated was that the real weight of those bonuses in

defining the final grade was in reality more than was described by the teachers. It was true that the bonus points would raise the final grade one letter. This increase may be conceived of higher incentive under certain circumstances. If the students conceived of their ordinary grade as somewhat nearly constant, or secured, and above the passing mark, they would probably look at the bonus points as extra earning that would be added to their savings. A second case would be when a student would approximate his grade to be close to a critical position where a grade increment would really make a difference. Where that critical position is would depend upon a variety of things, but certainly one of them would be college entrance requirements for those students contemplating going to college.

As I looked into the final grades of students in the first semester I found them as summarized in Table (4) below.

Table (4). Students' Final Grades in the Two Courses Observed

Grade Category	# of Students in Different Grade Categories		
	Mr. Stewart's PP Class	Mr. Davis' Classes	
		PP	IPS
A	11	8	12
B	10	12	4
C	10	10	9
D		1	1

I even expected higher grades in the second semester. In one of the observations I had made in previous years

while working on the IRT project, I recorded Mr. Stewart saying to the class something to the effect that all of the students would eventually get "B's" or "A's" if they work for the course. It seems to me then, that a majority of students perceived the grade "B" to be very achievable with their ordinary work habits. An extra bit of effort might then push them to the "A" level, and that would be an extra big reward.

Demonstrations

Demonstrations in physics lessons have become a popular tradition that might be used for a variety of purposes. Both teachers used this strategy on several occasions where part, or all, of a lesson was used to demonstrate something in front of the class as a whole. The teacher, sometimes helped by one or two students, would do the demonstration while the class would be observing and supposedly taking notes. Frequently Mr. Stewart referred to demonstrations as "observational activities". More often, however, they were called simply demonstrations, or "maxi demo's" where something bigger than usual was planned for.

Examination of various demonstrations carried out by the two teachers revealed some different situations where those demonstrations were used. The most frequent one was the case when the teachers wanted to elucidate a concept through a phenomenon that could be observed. Under this category, a multitude of demonstrations on waves and various

related concepts like wave front, frequency, and period, were carried out by the teachers using various means including the ripple tank. Another set of demonstrations that took a whole hour to carry out was related to various concepts on sound waves. During that hour Mr. Stewart used both lecturing and demonstration techniques. A complete transcript of that lesson appears in Appendix (C). The contents of the transcript shows the wide knowledge base Mr. Stewart employed in this lesson. He covered, once and for all, some of the very basic and profound concepts and principles in physics, like, forced and natural vibrations, resonance, superposition principle, standing waves, and terms like nodes and antinodes.

Another situation where demonstrations were used was when the teachers wanted to show a working model for some machines. That was clear in their demonstrations of a variety of models for steam engines. Principles of operation for those machines, together with various characteristics and shortcomings were explained. There was another case when a machine was used to explain a fundamental and subtle principle. That was the case with the epicycle machine, which was used to illustrate the retrograde motion of planets as suggested in Ptolemy's geocentric system.

A third case was when the teachers introduced a new topic. For example a whole lesson was used to present a variety of demonstrations that somewhat reflected or

demonstrated the new concept of inertia.

Finally teachers used some demonstrations to formulate and solve some problems. Demonstrations on conservation of momentum cited in a previous chapter would fit here. In those two demonstrations, "Shoot the Kitty", and the "Cannon", the problem formulated was how to find the speed of something moving very fast, like a bullet or a hard rubber ball fired from a cannon. The teachers did the demonstrations and carried out the necessary calculations.

Other Lesson Types

A few other lesson types were used occasionally. My observations included two lessons in which the teacher, Mr. Stewart used programmed instruction to discuss waves and some wave concepts. During those two days Mr. Stewart distributed special booklets on waves for the students to read and answer some questions. Essentially what the students did was to go over the concise illustrations, and then answer the questions. Mr. Stewart did not do much during those hours for the answers were also included in the booklets and students seemed to look at them whenever they wanted. During those two days Mr. Davis was absent. However, his classes used the same booklets under Mr. Stewart's instructions.

Mr. Stewart did not seem enthusiastic about how things went during those two days. During a conversation with him, he told me that had Mr. Davis been present, he, Mr. Stewart,

would have made certain changes in the way things were run during that period. He still would have used the booklets, but would have augmented that with some demonstrations. But since Mr. Davis was absent, doing what he did was the way he thought fair enough for all classes, his and Mr. Davis's, to receive equal instructional treatment.

On about three other occasions, films and videotapes were screened, and at lease one visit to the library was made. Such activities used to take place mostly on Fridays, which I often, but not always, skipped in my observations.

Some Remarks on Lesson Types

There are some general remarks which may be drawn out of this description of the teachers lesson types.

First, there was a clear intention on the part of the teachers to diversify their lesson types. In the next section, I will discuss various possible factors that could have influenced the teachers' decision to choose a particular form of instruction.

Second, the teachers' lesson types were directed mostly toward the whole class. In recitation, lecture, problem solving, and demonstration lessons, the instructional interactional patterns were whole-class oriented. In hands-on activities students were divided into groups but still with a clear intention on the part of the teachers to have their pacing class-oriented rather than group or individual-

student-oriented. This lends support to similar findings by Tobin (1987), and Tobin and Gallagher (1987 b). The two researchers reported that a majority of high shool science and math teachers they studied taught using predominately "whole-class" activities.

Third, the bonus-point issue I discussed can be seen within the motivational strategy used by the teachers. It could be argued that that strategy was used not only to enhance the students' participation in classroom activities, but equally well to promote a popular image for the physics course. The idea of promoting a popular image of physics or perhaps "marketing" the physics courses (Gallagher, personal communication), was clear in the teachers' usages of catchy terms like "maxi demos," their advertisement of their courses, and their selection of some teaching examples that appealed to or provoked their students' imagination (see the two examples on "maidens" and "astronauts" discussed on a following section on 'concretizing and destructuring').

Whatever the case may be, the bonus-point issue seemed to bring under focus the significance of the teachers' reward structure in influencing students' participation in classroom activities. This conclusion confirms Doyle's (1983) argument about the need to pay more attention to the reward structure operating in class, and to Tobin and Gallagher's (1987 b) assertion that the assessment system in high school science classes was used to motivate students.

Fourth classroom activities seemed to follow a weekly repetitious rhythm. I noticed, for example, that the first three days of each week were devoted for activities which reflected more participation on the part of both the teacher and the class. Friday, on the other hand, was mostly taken for quizzes or less rigorous activities like films, videotapes. Thursday was circumstantial; it could go either way, but mostly belonged to the first group, and occasionally used for some bonus activities. It was as if Fridays belonged to both directions of the week days: work days and weekends. That is why, I did not expect big things to happen on Fridays. In fact, that was the important factor that convinced me to drop most Fridays and some Thursdays from my observation schedule since I could not afford going on a daily basis. As far as classroom work was concerned, I think that students' perception of this day was different from their perception of the preceding four days.

What is also interesting about this observation is the high contrast between the two types of activities given on Fridays: film and videotape, and quizzes, if discipline is to be pushed into this picture. In film and videotape sessions students would have more freedom to talk together, make comments, or even daydream. Though the two films I happened to observe were relevant to the subject matter discussed in the classroom, students did not appear anxious to follow their literal content, and there was only very brief discussion of some of the contents. There were no

test questions related to these activities. Quizzes, on the other hand, would dampen many potential behavior problems. In so doing the teachers appeared to have used two contrasting management styles to deal with the same situation: a day characterized by some laxity and thus potentially problematic as far as classroom control was concerned. While one style tended to curve with, or resonate with, the anticipated circumstances, and thus lessen any potential friction with the students, the other style attempted to halt totally such a trend, at least for an hour, by creating a highly structured classroom environment where students would have one choice only: to take the quiz. Any evasive or undisciplined student actions in such a context would be costly on the part of students exhibiting such actions.

Factors Influencing the Teachers' Choice of a Lesson Type

In previous sections I explained, through an example, how the two teachers made important decisions about what knowledge to exclude from their plans and consequently from classroom instructions. In following sections, as I will discuss the teachers' guiding instructional objectives in dealing with the subject matter, this issue of knowledge inclusion or exclusion together with more specific details on how the teachers dealt with the subject matter will become clearer. To some degree, talking about choosing a lesson type is related to the teachers' treatment of the

subject matter in general. Therefore, talking about the factors that influenced such a choice is interwined with the more general issue of teachers' instructional goals and objectives. In this section, however, and for organizational purposes I will try to limit my talk to lesson types. As will be soon clear, isolating the two issues is artificial and is only done for organizational purposes.

What were the factors that were possibly considered by the teachers in deciding a lesson type in their physics instruction? I will discuss this question mostly in the context of the HPP course because, as was stated before, these lesson types appeared mostly in the context of dealing with this course.

In his articulation of what and how to teach, Mr. Stewart mentioned five major constraints that influenced both the contents and methods of instructions: the nature of the subject matter, time, availability of equipment, class size, and teachers' professional experience.

1. Nature of the Subject Matter

As for the nature of the subject matter Mr. Stewart explained that if a concept is one "for which there was no payoff down the road", then it could be ignored. As to how he would judge that, Mr. Stewart referred to his experience.

2. Time

Time was a constraint partly because teachers wanted to cover the whole book. As Mr. Stewart explained "We want to

be able to take about a week and a half per chapter throughout the course in order to get the total picture of physics." This would, consequently, influence the lesson type for some topics. As explained before, in one lecture only, the teacher covered a wide variety of central and sophisticated concepts like, resonance, standing waves, and the superposition principle.

3. Availability of Equipment

Availability of equipments, would also impose some limitations on not only what to teach, but also on how to teach it. A small group lab experiment may be replaced by a large-group experiment, which in turn may still be reduced to a mere demonstration when a physics teacher operates with a shortage of lab equipment.

4. Class Size

Class size would seriously influence lesson types. With thirty students, or more, it would become very difficult to use techniques that would require monitoring students' work on individual basis. Lesson types in large classes may tend to emphasize strategies like lecturing or demonstrations where the whole class would be dealt with at the same time.

5. Professional Experience

It is interesting to see how Mr. Stewart saw their professional experience and knowledge as a constraint, but "a strange" one as he put it, to what and how they taught physics. Let me quote him describing that constraint.

> "...still another [laugh] kind of strange sort of constraint. "Ken" and I have taught together for a long time. We've tried a lot of wild ideas. Every construction that came down the road! Every plan! Every teaching gimmick! Teaching angle that we could think of, that we could find out, we tried! And over a period of time we said, we found: well, this didn't work very well here, last year we did it in a different way and that seemed better. Then we come around next year and look at that. We subtract, throw out the ideas we tried and they don't work. And so there is a convergence over a period of time of things that have bubbled to the top as been the best way to approach a certain idea. These things have filtered to the top and we've thrown out the ones that didn't work so well". [1st Interview: 9/23/86]

So this process of "evolution by subtraction", as Mr. Stewart called it on another occasion, resulted in adopting the best methods of physics instruction. Indeed it is a constraint, and a major one, on any desire to look for better methods! From this perspective, there would be no better methods anymore. I will describe this as a pitfall of experience.

As I attempted to make a coherent interpretive picture of these factors several implausibilities appeared. For example, on several occasions both teachers described their physics course, in part, as a preparation for college physics. As was discussed before the topics they chose were mostly college oriented. How, then, did the teachers judge some of the fundamental physics concepts as ones "for which there was no payoff down the road?"

Time was cited as a constraint. But it was so only because the teachers had decided in advance, in their lesson

plans, to allocate a fixed period of time for each chapter, and to cover all the chapters included in the textbook. Time and coverage could have been manipulated in different ways.

Class size could have also been manipulated or influenced by the teachers had they chosen to. As it will be seen both teachers encouraged, and in different ways, students to take their courses. High enrollment was one of their important concerns. To work for high enrollment and then cite class size as a constraint on teaching implies a circularity in the teachers' thinking or mere rationalization of what they were doing.

Even the process of "evolution by subtraction" which Mr. Stewaart thought resulted in the best methods of physics instruction seemed only to justify or rationalize the status quo in physics instruction at the school. I once asked Mr. Stewart, after a thorough interviewing about how he taught physics, whether or not he felt that he was betraying the physics he learned at college by treating it the way he did. His immediate answer was: "yes". After a few seconds, however, he added: "but that depends upon which physics you mean": implying a distinction between physics of the physics community and physics of the public at large which he advocated every now and then.

Mr. Davis, on the other hand, confessed to me on more than one occasion that he yearned a lot for those days when both teachers were experimenting on "wild" ideas.

What would that mean? Among other things, this would mean that the teachers' decision to diversify their lesson types, might be connected with other contextual issues acting on the setting in more fundamental ways than did other factors related to time, nature of contents, or availability of equipment. In examining the interview transcripts, I came across two other factors which seemed to me more fundamental in their ways of influencing the totality of the teachers' decision to diversify their instructional approaches.

The first seemed pedagogical in nature. Mr. Stewart made the connection between their decision to diversify lesson types and their understanding of how students learn.

> "Project Physics course is going out (inaudible) is that different students learn better by some media than others. You know, Charlie in the front row might learn better from experiments than Suzy. She might do better by doing mathematical problems. And somebody else in the room might do better by reading in the text. So...(it was...) the feeling of the people who put together Project Physics, a course should have, should present several avenues for a student to understand a concept". [2nd Interview: 10/14/86]

So the teachers appeared to have attempted to go along with the course's suggestion to provide "several avenues" to understand a concept. In many situations they did present several lesson types within the same chapter that used to cluster around a small number of concepts. It is also clear that Mr. Stewart considered that a plausible pedagogical principle that had to do with student learning. The

relevant question here, is whether or not, Mr. Stewart or Mr. Davis, made any attempts to know whether "Charlie in the front row" might really benefit more from experiments than from lecturing. As will be seen in the next section, they did not; and they did not intend to do that. Their instructional target was the class as a whole, and not individual students.

Any physics teacher would agree, I believe, that there is an element of fun in teaching physics. How enjoyable to a physics teacher are those moments when he demonstrates to himself first a certain physical concept, say standing waves, which he long knew or dealt with intuitively or mathematically! Such a demonstration, especially when it is done for the first time, would be a great source of satisfaction and fun. It would be a physical embodiment for otherwise fuzzy, evasive, shaky, and uncertain understanding for something he struggled hard to perceive. A successful demonstration or experiment would make a great difference in teacher and student attitude and conception toward physics and the attempts to understand it. Conversely, every physics teacher, I suppose, tasted some measure of frustration, disappointment, and embarassment when his demonstration or experiment did not work. Striving to understand, to quiet our inner inquisitions about certain physical manifestations, to unleash the reins of our imagination in its attempt to model our rational thinking about nature, are, I believe, a driving force for many

people pursuing physics and science in general. Nurturing this human dimension could, and I believe should, be one fundamental criterion by which we can measure the successes and failures of our physics teaching.

So without physical representations or embodiments in some form or another of the physics stuff teachers discuss in classrooms, physics may be conceived as boring and irrelevant to many students who may consequently turn their backs to physics and science altogether. Both teachers knew that very well. In that sense, diversification would be a requirement embedded in the nature of physics knowledge without which something fundamental would be lacking. In other words not to diversify in our approaches to teach a physical concept, would be equivalent to leaving out one of the vital and stimulating dimensions of our physics knowledge. Let me now introduce a quote from Mr. Stewart that put all these things together, plus something else.

> "We select lessons that involve a variety of lesson types. That it's not lecture every day; it's not problems every day; it's not experiments every day, but a number of different things. And we provide that variety as much for our own survival as anything else. So the class is different every day. Yes, it would be very boring for me to teach a math class where, every day, you spend the first fifteen minutes going over tomorrow's work, and the last minutes of the class working on homework, and that's the way a day after day. I wouldn't like that. I like the fact that we are doing a demonstration lecture today, we're doing historical lecture tomorrow; something else, an experiment, problems, and so a variety of things. So I think the kids get from the way we select the lesson, plan a lesson, thus get a good of variety of views of a concept, not only from an experimental point of view, but from lecture,

> demonstration, perhaps that can put some of the data, some of these relationships in a context. They read it in the book they do problem solving, and supposedly, hopefully, the understanding if not from one method of approach in that idea, another perhaps, or one reinforces the other". [1st Interview: 9/23/86]

So what appeared as a pedagogical belief turned out to be strongly connected with the nature of the subject matter. But eventually, however, Mr. Stewart appeared more concerned about their survival. Diversification of lesson types seemed to be more strongly related to the teachers' strategies to cope with their work conditions.

The second factor that seemed to have influenced the teachers' choice of a lesson type was revealed to me by Mr. Davis during my observations for my previous research work with the IRT (Abu Isneineh, 1986). At the end of my observation of an open air activity in which students launched little rockets, I started to ask Mr. Davis what physics knowledge or skills he had in mind to teach through that activity. Mr. Davis responded by explaining that some activities, like rocket launching were very attractive to students. He then went on to point out that they had in the past stopped that activity for a couple of years and enrollment went down. Consequently, they decided to try it again.

In a sense, promoting high enrollment, could be seen as just another dimension in the wider issue of survival. As will be seen in the rest of this chapter, this issue seems to underlie many of the teachers' decisions not only about

the forms of instruction, but equally well, about the its content. Various researchers have described such teacher behaviors as "coping" (Lacey, 1977; Hargreaves, 1984; Sikes et al, 1985) or "survival" (Woods, 1984) strategies.

While it is true that teaching in general and physics teaching in particular may be very stressing for many teachers, the issue of "survival" should not be exaggerated. Neither should we allow it to conceal other issues whose appearance in the teachers' articulation of their problems is less potential. Let me conclude this section with an elaboration of the idea of survival in the context of Mr. Stewart's articulation to see how other important issues related to the subject matter were confounded in that seemingly primary concept, survival.

Previously in this section, I noted how Mr. Stewart conceived their instructional techniques as a "convergence toward the best". I called that a pitfall of experience. In the last quote Mr. Stewart talked about boredom and survival. It seems as though what Mr. Stewart was saying amounted to something like this: after trying a lot of techniques, and taming so many wild ideas, we have reached a stable experiential plateau where we knew what was best to do. After reaching such a stage, work becomes mere routine, which though may prove efficient in saving time and energy, it would still connate boredom. To survive this feature of their work, teachers seemed to have diversified their techniques.

How and why did a dynamic and interesting human knowledge like physics become boring to discuss repeatedly. While I do not pretend to have a satisfactory answer for such a complicated question, an element of such an answer appears plausible in the light of what has been discussed.

Before going into that element, however, let me introduce Mr. Stewart's perception of the changes that occurred in his physics knowledge over the years and since his graduation. Mr. Stewart explained to me through a drawing, a copy of which appears in figure (3), how his deep vertical knowledge extensions in various physics areas, like

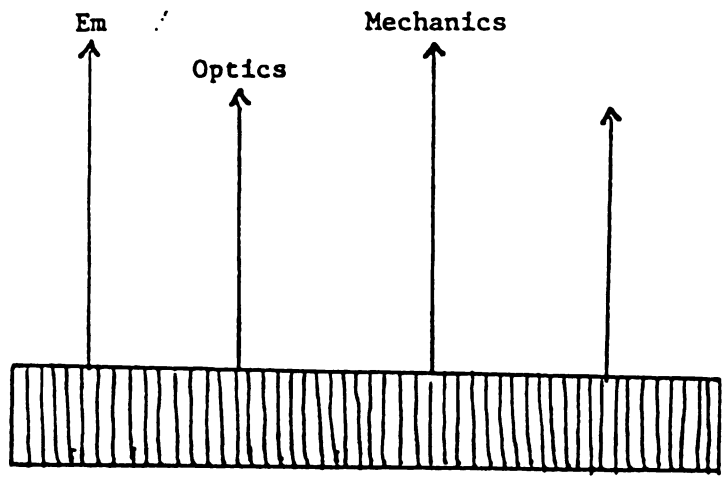


Figure (3). Mr. Stewart's Representation of His Physics Knowledge

optics, electromagnetic theory, and mechanics, which he learned during his college years had leveled out with time into a horizontal layer of integrated knowledge of physics or science in general. The vertical lines in the figure represented his knowledge of various areas of physics just after graduation. He described that knowledge as

conceptually unclear, and unintegrated, i.e., no clear connections among these knowledge structures. With time, these deep vertical knowledge structures gradually disappeared and were replaced by much less deep knowledge structures, the shaded area in the figure, which were conceptually clear and structurally integrated. At this point, he referred to what he described before as "interlocking" physics knowledge.

It seems to me that what I called a pitfall of experience represented a state in the teachers' professional life where their experiential knowledge of physics and physics teaching has reached a steady state which can hardly be changed by any external knowledge fluctuations. It is as if this experiential knowledge had become resistant to changes or reformations. In a sense, this is what Mr. Stewart meant when he described the process of evolution in their methods of physics teaching as a constraint on what they did. It is as if those vibrant and pulsating years of teaching physics, for which Mr. Davis yearned, and to which Mr. Stewart referred frequently, had finally formed a stable and inflexible form of experiential knowledge of the subject matter and the way to teach it. Such a form of knowledge would show resistance to change; it would grow minimally, if at all.

Compare this state of knowledge with what is going on in the world of physics or science in general. Surely, the contrast appears very sharp. Physics, like other scientific

fields is in continuous change. Human knowledge in various science areas is in a process of continuous reformation and development. Can we, then, conclude anything about what has been lost or absent from the teachers' knowledge structures?

My answer to this complex question is partially speculative and incomplete. I believe one missing element has to do with the sort of interplay between what the teachers knew and what they did not know, between their knowns and their unknowns. Just after graduation from a physics department, a college graduate would know a lot of basic physics knowledge. He would, supposedly, have studied a lot of classical mechanics, electromagnetic theory, electrodynamics, thermodynamics, optics, quantum mechanics, and relativity. However, no one can claim that his knowledge of the topics and concepts he studied was as precise as it was presented in textbooks or by professors. To a varying extent, his knowledge would be permeated by uncertainties and fuzziness about many of those concepts. His knowns would be connected, though thinly, with the realm of the unknown. He would, for example, go back to his notes and books and study again Maxwell's equations, a topic which he knew fairly well, in order to build on that an understanding of these equations when used in realtivistic terms, something which could have been left as a mystery or unknown in his college years. He may also be in a position that would enable him to build on his introductory knowledge of optics to contemplate the mystery of the concept of

coherence in light, and possibly understand the mathematical complexity involved in the theory of coherence of light waves. Such a state of knowledge, though full of uncertainties and equivocation would, I believe, be stimulating and far from boring for one simple reason: it would engulf within its structure, or touch up its limits or boundaries, some mysteries which challenge his mind and imagination. Physics knowledge in such a state would be such that the realms of the known and the unknown overlap and entangle over a wide area, or a wide range of concepts and themes. I will borrow the concept 'entropy' from thermodynamics to characterize this state of knowledge. The implication would, thus, be such a state of knowledge is characterized by high entropy. In such a state, there would be a considerable confusion about certain concepts, and many mysteries to ponder and reflect upon.

What happened to this state of knowledge over the years of teaching? During those years, the teachers would have plenty of time to review, teach, and reflect upon some of the concepts they had learned in college. This, undoubtedly, would elucidate some concepts and, thus, would fix the teachers' understanding of them. Many concepts that passed into their knowledge structures as understood would turn out problematic upon the first attempt to teach them. When I asked Mr. Stewart where he learned physics more, in college as a student, or in high school as a teacher, I was not surprised by his "in-high-school" answer. Understanding

meaningfully many physics concepts would require a long period of socialization with those concepts at various levels. Occasional reflection upon such concepts, what they mean physically, how they relate to other concepts, their applicability and limitations, is very much needed in order to assimilate them into prior structures of knowledge. Undergraduate courses do not provide, I believe, enough opportunities to reflect upon what is learned. There is simply not enough time for that, taking into consideration the very broad coverage of physics areas that are usually attained during college years. So what would happen during the years of experiencing physics teaching would be such that the teacher would master the understanding and manipulation of some concepts. But here he would become very selective in his understanding and manipulation of those concepts, for high school physics is certainly different from college physics. Mainly, those concepts that would be dealt with in high school textbooks would become the focus of his interest and socialization.

In selecting some concepts for more treatment, and leaving others as they had been learned in college, a physics teacher's knowledge structure would start to change. The new changes would be characterized by a constant process of selection, emphasis, and more profound learning of some concepts, and abandonment or neglect for the majority of others. This process, I hypothesize, disentangles or disengages his two realms of thinking: that which belonged

to the known, and that which contemplated the unknown. As time goes on with the teacher doing the same activities both realms pull apart, and a sort of polarization would take place. In this state, the teacher would have a thin layer of mastered and well understood and integrated knowledge, and another fading shadowy area were the remnants of all his unused college learnings are thrown in almost complete neglect. He would still remember some words and phrases he struggled with for long like: Schrodinger equation, Maxwell's equations in relativistic forms, theory of relativity, Fourier transforms, spin resonance, etc. Beyond what would be a mere recall of words and phrases which may still have a shadowy structure, would lie topical areas of physics formerly studied but now very remote to the teachers. The polarization of the known and the unknown and their disentanglement would be characterized, as I imagine it, with a higher degree of order, and thus less entropy, mainly because of the systematic alignment in the teacher's structure of certain mastered knowledge.

The detachment and polarization of the shadowy and problematic areas of knowledge and their weathering out and fading, together with the constant and continual preoccupation of the teacher with the same concepts over the years, would leave very little to stimulate and incite his imagination. Many mysteries would have already been solved within the new structures of knowledge. Others, unsolved, would be just thrown in that ineffectual shadowy area of his

knowledge structures. They would not, anymore, incite his thinking and trigger his imagination. With time, his instruction would be limited to the realm of the well understood, mastered or known, which, though very complex in itself, would become so highly organized, tuned, and aligned that its transmission by the teacher would become habitual with little or no reflection at the contents of the signals transmitted or their channel of transmission. Whether conscious or unconscious of any uncertainties in his functional knowledge, the teacher would adapt to that in his instructions and in various ways. With time he would become less sensitive to those uncertainties.

Physics knowledge that was once stimulating, interesting, and challenging, would become mere facts, skills, and tables of artificial data perpetuated by teachers. No wonder then that some teachers would resort to emphasizing different techniques. Emphasis on techniques, though educationally sound, was in the case of Mr. Stewart, a means of surviving another pitfall of experience, namely, the polarization in his knowledge of the subject matter between: what he knew and very well mastered, and what he deserted in the back yard of his thinking and imagination. I will come back to this issue in the concluding chapter.

Once again the issue of survival, though now in a different sense than before, has bubbled to the surface of the teacher's thinking as an important factor influencing the classroom events dealing with the subject matter.

So what can we conclude about the factors that influenced the teachers' decisions about their lesson types. A review of these factors indicates that they do not necessarily conflict with each others. Teachers did work under some constraints which could have influenced their choice of a lesson type. They, at the same time, saw in diversification a means of satisfying a large number of students with a wide range of individual differences. Furthermore, diversification seems to have broken, or at least eased, what otherwise could have been a boring monotone of events over the work days and years. The teachers, however, did not raise all these issues within the same context of discussion. Neither did they give them the same significance and consideration.

Teachers' Conceptions of Their Lesson Types

In this section I will bring together several points that were raised in previous sections which will present us with a picture of how the teachers, particularly Mr. Stewart described some aspect of their pedagogy that dealt mainly with their classroom instructions.

In the previous chapter, when the teachers' views on the textbooks were discussed, it was pointed out that Mr. Stewart saw in the HPP course an "impedence match" between a variety of contextual factors. Since in his approaches to classroom instructions he attempted to be consistent with the course, these approaches in turn were also conceived as

an "impedence match" between those factors that ranged from the student body, to lab equipment, and school district rules and allocations.

In the previous section, Mr. Stewart described the long process of evolution in which their instructional methods went into, and, finally, reached the stage of being the "best" ways to approach various ideas. He described the process as evolution by subtraction. On another occasion he emphasized the same idea by another metaphorical statement.

> "What we have now is essentially a distillation of many different styles, many different attempts, many different philosophies that have survived the battles". [3rd Interview: 11/26/86]

As to the sources of their approaches, Mr. Stewart cited their high school and college teachers, educational books and magazines, physics teachers meetings, previous NSF summer institutes, informal discussions with other teachers, and society at large.

Both teachers gave a variety of factors that influenced their choice of a lesson type. Among those factors was one that touched directly upon the teachers' conception of student learning. Mr. Stewart believed that different students would learn more effectively in different ways. The relevant and important, question that was raised before, as to whether or not the teachers made any efforts to know which students would learn optimally through which methods, is due now. There was no indication in my fieldnotes or classroom recordings of any affirmative answer for that.

What I found, however, in an interview transcript was an emphatic no-answer given by Mr. Stewart. I asked him whether or not he attempted to know who would learn more by which method. His answer was as follows:

> "No! No! No! It's scattered on a shotgun kind of approach. Sometimes we do it one way, sometimes we do it another way. I don't make any attempt to find that out. And so in the way we do it, one of the things that "Davis" and I have found, for our own survival; you know for our peace of mind, is that we got to change the mix. We got to have a variety for our own self. And so some of the things we do, frankly, are just to provide variety to do a different way." [3rd Interview: 11/26/86]

So it is "scattered on a shotgun" approach, with no efforts of aiming at particular students or group of students, or no matching between one approach and individual learners. No emphasis on diagnosis or individualizatiion often suggested by educationists. This quote gave even a stronger indication that the major, and perhaps the only, motive behind the issue of diversification had originally been survival and "peace of mind." Under such an assumption Mr. Stewart appeared to have accepted the pedagogical principle or objective he cited earlier as a rationale for the diversification issue, only to the extent, and in the form, that would agree with his primary objective or motive, namely survival. This, therefore, would be another instance of the case where Mr. Stewart would agree, or bring to the forefront of his discussion, a plausible belief or research finding, but only when it would go with his primary goals or

intentions. As Doyle and Ponder (1978) argued, teachers were most receptive to suggestions that would fit with their practices. The personal coefficient in their knowledge (Elbaz, 1983; Munby, 1984; Clandinin, 1985; Lantz and Kass, 1985) seemed to have a considerable influence on what the teachers did.

Teachers' Decisions About Treatment of The Content of Their Lessons

In the previous three sections I described a variety of instructional forms, called lesson types, that were used by the teachers. I also presented the teachers' rationale for using those forms, as well as their conceptions of them. In my attempts to interpret the teachers' choices of their lesson types two important issues, among other factors, surfaced as a potentially interpretive frame for much of what the teachers did and how they did it. They were student enrollment and teacher survival. In the light of all that, let me now turn to some decisions, as articulated by the teachers, that would explain much of the specifics of teachers' acts on the content of the lessons they taught.

These decisions tend to be general or generic in their formulations by the teachers. Under each decision statement, a variety of specific instructional acts on the content of the subject matter was found. These decisions, as will be seen, overlap in a variety of ways. That is why my categorization of them is only for organizational purposes. After all, and as indicated previously, we are

dealing with teachers' narratives of their own knowledge and practices, which ideally, would appear for each teacher as a coherent mesh of instances, events, anecdotes, and stories. In my attempts to see and interpret the totality and the specifics of these narratives, I, unavoidably, made a lot of segmentations and cuttings; and attempted to look at various segments from the reference points of teachers' knowledge of the subject matter, and the way they dealt with it in classroom.

Engineering Success

Engineering success was one of the phrases that Mr. Stewart used to characterize a variety of instructional decisions concerning the subject matter. He used it in his discussion whenever he sensed a question of the type why this, and why not that. It first came into our discussion when I asked him why they deleted from their discussion the concepts of instantaneous velocity and acceleration, and limited their treatment to the concepts of average velocity and acceleration. Engineering success was the context of his explanation. Since the phrase was then repeated I asked him to explain to me what he meant by that. Here is part of his answer.

> "Well, as we've talked about it before, we try to deal with a broader range of students in physics than typically take a high school physics course. Thus being the case, if we'd recruited the students to come to us for a physics course, we can very easily blow them away by making the course mathematically too demanding, intellectually too challenging. We can make the physics

course as hard as we want to. And of course in so doing, we can limit the number of students by making it more and more difficult. We can get any number of students we wanted to. Now by getting more students in the class, we don't want to mean that we make the course easier. But what we want to do, is to be sure that the students that we have encouraged to take the high school physics course that they have avenue to success. How this translates, is that we want to set up the experiences so that they can bypass some of the traditional difficulties the students encounter in physics classes. For example, and I can give you lots of different examples: we never use English units; we never use cgs units; and we never ever mix units. That eliminates one potential hazard, a roadblock that you can roll in front of students. You can say well, you shouldn't do that, and that may be true. But the point is that, that gets into the way of learning the concepts of physics.

Other ways that we can do this, is to use graphical solutions only for vector addition. We would show students one way to add vectors graphically and stick to that. We all know there are other ways of doing it, and a lot of physics courses point out these different ways, and spend time on each one, and that sort of thing. But we want to set it up that they can successfully add vectors without a lot of clouding of the issue.

In handling trajectories, we've separated the horizontal motion from the vertical motion, and horizontal course is constant; velocity type of thing is constant. The vertical component accelerates. We touch each of these things separately, and then we add them together and see how we get trajectory.

We engineer success by limiting the variety of problem types on an area that we are going to ask the students to do. We clearly stated at the beginning when we started to study this material in the chapter covering this week, what we are going to teach them. We spend time developing these skills; and then those are the skills we test. So the class is very straightforward in the sense there in no mysteries. The students know what to expect of the test." [2nd Interview: 10/14/86]

Before making any further interpretations of the teacher concept of "engineering success," let me make few

comments on the examples cited by Mr. Stewart in this quote. First, using the MKS (meter, kilogram, second) system of units has been the trend in college physics and other science books that plan to prepare students for college science. The British system is not used in such books anymore. The derived (cgs) system is also hardly referred to. So, another possible interpretation of using the MKS system, would be the teachers' knowledge of the college physics requirement in such a case. Let us remember an assertion made earlier that the topics selected for classroom treatment were oriented more toward college physics than anything else.

The second example on vector addition represented a topic which both teachers treated in a similar way to that of the textbook. Both treatments explained the graphical method of adding two or more vectors. Both emphasized the "head-to-tail" technique and avoided the parallelogram method and the mathematics that is usually involved in that. The two techniques are basically the same, however, heuristically, the "tip-to-tail" method is more convenient. However, students ought to know that the two techniques were equivalent, for that would save them time on some problems. This, nevertheless, is not so urgent, because with a bit of thinking and reflection on that, students may discover it by themselves.

What is important, I believe, as far as the structure of physics knowledge is concerned, is the significance of

the instrumental nature of these constructs and definitions: vector, vector addition and subtraction, vector products, both dot and vector products. They operate mathematically on a variety of physics and science topics that soon, perhaps during the college freshman or the sophomore year, physics and engineering students will find it too hard for them to organize and comprehend good parts of what they learn without a real mastery of these constructs and their rules of operation. This difficulty would become much more serious in later years of college learning. The textbook was certainly aware of that. Vectorial treatment was invoked whenever it was needed. It was used, for example, all through the chapters on the concepts of motion, as well as in chapter nine on the conservation of mass and momentum. The teachers, too, were aware of the importance of these theoretical constructs, for otherwise they could have skipped them, been explained only in a couple of pages in the text. In spite of the teachers' awareness of the future significance of these concepts, both teachers avoided applying them to pertinent physics topics.

It is true that the teachers referred to concepts like force, velocity, and acceleration, as vectors; but they never treated them with constant consideration and awareness that they were so. This resulted in the treatment of physical laws and relations in their particular or special cases only. In such cases, the direction of the vector was predefined and assumed constant, and its magnitude only

changed. Under such circumstances teachers, for example, talked about velocity, but, in fact, what they used was speed. And so was the case with other vectors, where their directions were always absent from treatment, while attention was focused on their magnitudes only. While the speed and velocity of an object have something common, namely the numerical magnitude, they are still fundamentally distinct physical concepts.

The place where it became impractical to talk about the subject matter without considering vectorial treatment was momentum and conservation of momentum. The planning for this topic was explained in detail earlier in this chapter. Though the teachers did mention that momentum was a vector, they did not use that in their later treatment of the subject. However, when it came to some specific examples on the law of conservation of momentum, they seemed to be pressured by the nature of the topic to allude to momentum as a vector. Examination of various worksheets on the topic, (Appendix B), indicated that all examples and problems given, were indeed special cases in which the motion of the two colliding objects was in one direction only. There were, however, three somewhat different examples in which motion in opposite directions was involved: the cannon demonstration, and problems two and three in the bonus worksheet. Here, only the simple algebraic implication of the vectorial treatment was used to explain those problems. This implied using the signs "+",

and "-", to indicate the opposite directions of motion on the same straight line. Further analyses showed that problem number two, was not a real mathematical problem on the law of conservation of momentum. It was intended to show a numerical verification of the law. And while Mr. Stewart did by himself the cannon demonstration, Mr. Davis went further and solved the third one. In none of the problems, or examples did the teachers use the formal symbolism to go through the necessary steps to solve those problems. Of course, there was no need for that since their treatment was limited to special cases only.

The third example on "engineering success", that Mr. Stewart gave, was on how they handled projectile motion. To my knowledge, all educational physics books approach this topic the way the teachers did: decompose the motion into two components, horizontal with constant velocity, and vertical with constant acceleration. The two components would be brought together, and the path (trajectory) would follow a mathematically defined curve called parabola. Both teachers did some hands-on activities on the graphical plotting of trajectories. What the teachers did not do in this respect was the mathematical derivations included in the textbook in order to show the mathematical model of the trajectory. The concept of parabola was not invoked, neither was the mathematical model of such a curve, though they were discussed with some details in the textbook.

The three examples given by Mr. Stewart on "engineering

success", were, thus, among the traditional concepts studied or encountered in college physics. In each case, it was seen that a potentially more difficult part was left out of the picture. While it may be argued that what was left from the first example was principally an arithmetical nuisance, since there would not be much to learn from converting from one system to another except for some practical purposes as I pointed out, the other two examples were more fundamental. In fact both teachers avoided going into the realm of any abstraction in both situations. As will be seen in the rest of this chapter that was very much a characteristic of their treatments of the content.

A couple of sentences in the previous quote still need more examination. The first is the teacher's statement: "What we want to do, is to be sure that students that we have encouraged to take the high school physics course, that they have avenue to success." The teachers encouraged students to take their courses. Therefore, they felt morally responsible to provide avenues for success. The word success was later defined by the teachers as student achievement. As was shown earlier in the chapter the grades were clustered almost evenly around "A", "B", and "C". It seems as though the teachers fulfilled their responsibility.

The second statement in the quote is "...the class is very straightforward in the sense there is no mysteries. The students know what to expect on the test." Very true! Indeed it was a straightforward course where test questions

were all examples discussed in the classroom.

Where Engineering Success Led Teachers

In the sub-section on hands-on activity, I described how the students carried out an activity on Newton's second law, F = ma. A transcript of the classroom recording for the teacher's lesson instructions, as well as the worksheet for that are included in Appendix (C). The worksheet suggested doing the activity in two steps. First, one group of students would vary the mass of a lab cart and its load, that was to be pulled on a table by a suspended mass attached to the cart and passing over a pully, and then this group would measure acceleration by measuring the varying spacings among dots left on a paper tape, that was attached to the other end of the cart, and was marked with these dots by a ticker-timer, while being pulled by the cart with the same speed. Students were to calculate acceleration under four different situations, four different masses of the cart. The point to emphasize here was that, neither the numerical values of those different masses used, nor their proportional estimates were considered. As the handout showed, they were given ranking numbers. So was the case with the second group where they had to change the pulling force, weights hanging down the cord, by adding more weights without considering their true values.

The main idea, as the questions on the worksheet indicated, was that students would conclude, through a class

discussion, that as mass increased acceleration decreased when force was kept constant; and as force increased, so did acceleration when mass was kept constant. The mathematical law which had been explained by the teacher before the experiment was to be invoked again after the activity was done but without any elucidation to the precise meaning of direct and inverse proportionality. The law was thus represented by descriptive, incomplete, and imprecise statements.

A similar, but yet more complicated, activity was done on centripetal force which was given by the equation $F = \frac{MV^2}{R}$ where, F represented the centripetal force on an object moving in a uniform circular motion; M, its mass; V, its orbital velocity; and R, the radius of its circular path.

Students in three groups were to describe three derived relationships for an object that was moving in a uniform circular motion while being pulled to the center. These relationships were: (1) between mass and force, while the radius and the period of revolution were constant; (2) between radius and force, while mass and period were constant; (3) and between period and force, while mass and radius were kept constant. In each of these relations students were to describe it in words only, i.e. to say whether one variable would increase or decrease as the other variable increased. Once more the mathematical definitions of various proportionalities embedded in that formula were

neglected. Consequently, as we shall see in Mr. Stewart's response, some students seemed a bit confused when they found out that the centripetal force increased as the radius of the circular motion increased, while both mass and period were kept constant.

I asked Mr. Stewart specifically about these two cases: why he treated them the way he did. His response for the first case was as follows:

> "Well, that would be another case of where in the attempt to make a point about an understanding or a feeling of what the second law is all about. It can be a snag if you say from the proportion "a" is proportional to "F" over "m", to "a" is equal to "F" over "m", that you must add a constant "K" of proportionality, and then we choose the set of units so that value of "K" is one, and then you know the acceleration is equal to force over mass. Now that's an example of something the kids can get hung up on. And when they get snarled on that, they were snarled on something that is not a critical issue, right! So it doesn't take anything away from the process to say: well, all right, we see an example, and you can see other examples: when you ride your bicycle, when you throw a baseball, or you play basketball, or in the riding of your car. You can see examples everywhere that acceleration is proportional to force and inversely proportional to mass. That is, to make force big it makes big acceleration; and to make mass big it makes less acceleration. We see this in the experiment in the laboratory; and it comes from this equation that allows us to put quantification on that: "a" is equal to "F" over "m". And we jump over that further. In fact we hide it from students. When they get more sophisticated mathematically, when they see a study in physics that's in greater depth and detail, then they can get some new answers. But what we are worried about in Newton's second law, is that Newton's second law, not the snarls that picking the right set of units to make "K" equal to one. So it's a question of dodging something that gets into the way of learning. It's an example of, maybe, engineering success." [2nd Interview: 10/14/86]

As for the second case on centripetal force, Mr. Stewart stated:

> "That's even cloudier than that on Newton's law. And we realize that was really cloudy to write the equation for centripetal force having done some of those. And I noticed one or two students raised the question: "Wait a minute. That equation for centripetal force is MV square over R. But yet when we made "R"bigger, we got a bigger force, how is that?" And only a couple of students raised that question. And of course the answer is that "R" is not only in that equation there, but the "R" is related to "V" also. And if you look at it in both cases, you can see that it's really if the force increases, it is "R" increased before other things, if you hold your period constant. That requires you increase your speed and that comes to that. That's a pretty cloudy thing. But then again we wanted to give the students a visualization of what we were talking about on pencil and paper; and we wanted them to see how this swinging takes place and how there has to be that force acting toward the center. And you know, we leave a lot of stones unturned as we plow through this material. That's a good example of something that we didn't say, that we just [Ken] and I talk about waving our hands over an issue, magically passing over an issue as though it doesn't exist, and go right through it hiding the issue, hiding the issue in a cloud of smoke. We do that from time to time and those examples you quoted out are just examples." [2nd Interview: 10/14/86]

In my question about those two cases I made it clear that the mathematical definition of direct and indirect proportionality was not made clear through the activities as they were done. He could have done that through graphing, something he did in a simpler case of a distance-time graph, without going into units. His own conception, however indicated that he saw no need to go through the whole process of verification or discovery of the law. Instead,

after students observed a descriptive trend of changes in those related variables, the mathematical formulation which had been explained before, was assumed to be verified or even re-discovered.

Let us now look at his answer to the students who wondered how they got a higher force when they made "R" bigger since the equation seemingly predicted a smaller force. As Mr. Stewart indicated, to increase the radius and keep the period constant would require increasing the speed. In other words the variable "V" in that equation would also increase. But even that would not give a satisfactory explanation as to how "F" increased. For a precise explanation the direct proportionality as such, first, between "R" and "V", and second, between "F" and the square of "V" should be invoked.

There are, I believe, no better words to describe what the teacher did, other than his own words: "magically passing over an issue as though it doesn't exist and go right through it, hiding the issue in a cloud of smoke." What was hidden in these two cases was both theoretical and observational: the clear explication of the mathematical meanings and interrelationships among various variables in the two relations, as well as the conventional process by which a certain physical phenomenon could be described mathematically, or alternatively, the process by which we may find a physical confirmatory instance for a general or theoretical relation were both left out from the teachers'

discussion.

Let me elaborate a bit on these two issues which were left hidden by the two teachers since both of them did what had been planned for on the worksheets. There was a couple of sentences in the previous vignettes that would shed more light on the "hidden" issues, or the "unturned stones". In the first quote, and in the context of talking about how bigger forces would imply bigger accelerations, Mr. Stewart described how he used the lab activity and the formula to introduce the concept: "We see this in the experiment in the laboratory, and it comes from the equation that allows us to put some quantification on that." What I think interesting to look at is the first "this" in the sentence. What did the pronoun refer to? The preceding two sentences made it clear that the teacher was talking about Newton's second law. The sentence, then, meant that that law could be "seen" in the equation, he was referring to. Therefore, and according to the implication of that sentence, there were essentially three entities: the meaning and implication of the law denoted by the pronoun, the experiment, and the mathematical formula. The teacher appeared to have used both the experiment and the law as two separate means of arriving at the same destination, namely, the conceptual meaning of the law. And indeed, with some examination of what the teachers did, the above interpretation would become more plausible. In each of the two cases on those laws, the teachers first introduced the

meanings of the law through the mathematical formulation, then went back to the lab activity, carried it out, and invoked the mathematical relationship again. This would be equivalent to telling students that, here was an idea "A" that we could arrive at through two separate routes: route "B", an experiment, and route "C", a mathematical formula. Or, alternatively, here was an idea "A", and here were two instantiations of that idea: instantiation "B", an experiment, and instantiation "C" the mathematical formula.

If this interpretation is granted, then two related conclusions ensue. First, Mr. Stewart perceived the meanings of those phenomena as knowledge entities that were distinct in themselves and separated from both theory and observation. This would be another confirmatory instance of the assertion I made in the previous chapter that the teachers' physics knowledge was in highly objectified or reified forms. Second, the relationship between theory and experiment, seemed as though they were distinctly separate from each other. In fact, the sentence cited reflected an understanding of theory and experiment as two potential confirmatory instances of the same idea or hypothesis. They were indeed used as such in dealing with the contents. The teachers, therefore, who maintained a conception on physics knowledge as objective entities or realities, taught it as such. They introduced to their students lab activities and mathematical formulas, pertaining to the same phenomena, as two distinct and separate routes of arriving at the same

reified reality out there in nature. Indeed, this is an important instance where the teachers taught the way they knew. Among other things, the dynamics involved in the process of using our mathematical knowledge as a tool in organizing our observational data, which is in essence part of the general issue of theorizing in science, was kept "hidden" from classroom discussions. While science educationists may disagree on the amount and concentration of the pertinent "pedagogical dose" of rigorous scientific theorizing that they would prescribe in various science curricula, some real taste of that would be advocated by all concerned; for without that, science knowledge, as constructed by the scientific community, would be fundamentally lacking in its instructional presentations.

It should be made clear here that, although Mr. Davis did not articulate these issues in detail, there were essentially no significant differences between the two teachers as far as their practices were concerned. There were, for example, some instances when Mr. Davis, just like Mr. Stewart, sounded concerned over what he often termed as "hang-ups". He often talked about minimizing those "hang-ups." Other signs of convergence in the teachers' conceptions and acts would be expected out of their working together: they used the same lesson plans, the same setting, the same pacing, and so on. This of course created a lot of overlap not only in their instructional strategies, but in their multi-dimensional conception about what they

were doing.

The teachers' conceptions of theory and practical activities as two separate sources that students can use either in their learning of the same concept, had apparently helped the teachers "go through" the subject matter. They seemed to have adapted their treatments of the contents of instruction in such a way that, whenever possible, only one of these sources was used. Teachers seemed to have opted for the source that proved less difficult for students to manipulate. In this respect I will cite three main categories of classroom subject matter encounters.

In the first type of encounters, teachers seemed to have found that "snarls", and "hang-ups," would be minimized if teachers would rely mainly upon the mathematical manipulation, and pay less attention, or even overlook the conceptual approach in their treatments. Teachers seemed to have developed the experiential knowledge (Elbaz, 1983) that would inform them when to do that. I will call this case, math-biased treatment. Among the topics that would come under this category I would include acceleration, Newton's second law, centripetal force, momentum and conservation of momentum, and density. In each of these examples there were certain subtleties involved in the construction of the concept that made it a bit difficult for students to deal with. However, mathematical definitions of these concepts were made very manageable. Stripped of its historical, contextual development, the fundamental concept of momentum

was made manageable through its mathematical definition, P = MV. All the students had to do was to multiply or divide in order to solve related problems. So was the case with the law of conservation of momentum after deleting the cases that required vectorial treatment. As Mr. Stewart put it, it was a "book-keeping" matter. The concept of centripetal force was among the most difficult concepts dealt with. This concept would evade the imagination of even the brightest students in class. Yet when put in a formula, "F = MV^2 /R" it becomes reasonably manageable. The similar thing could be said about Newton's second law, and the concept of density. In all these cases, and many similar other ones, there was a clear emphasis upon the mathematical component in the teachers' treatment of the subject matter, and less, or no emphasis at all, upon the physical meanings of these concepts. Furthermore, the math involved in these examples tended to be amenable to classroom treatment, which did not go beyond finding an unknown value in a relation with other variables whose values were given. It should also be pointed out that emphasis on math did not mean emphasis on theoretical bases. Teachers used that often in cases where simple mathematical definitions and relations were used such as momentum, density, kinetic energy, and conservation of momentum. With no emphases on the underlying theoretical procedures, or the meanings of physical concepts involved in the mathematical forms used, what was left was mostly algorithmic manipulations with the

ideal case of finding an unknown value in a mathematical relation.

There were other situations when the mathematics involved did not appear manageable by students, or malleable enough for classroom treatment. In these cases the mathematical component was either ignored or alluded to, but not made required. The main ideas or concepts involved were thus explained either through verbal explanation or demonstrations. The path of a projectile was done through hands-on activity, while the theoretical basis, explained in the text, was avoided. Derivation of Kepler's third law from Newton's laws was only referred to in classroom, and students were told that they would not be asked to do such things. Standing waves, resonance, and interference patterns were all demonstrated to students without going into some explication of the theoretical assumptions of these fundamental phenomena. In this category there was not a common way of dealing with various topics. What was common was the teacher's deliberate avoidance of the theoretical underpinnings of the concepts. I called this, the "theory-avoiding" treatment.

In the third class of encounters the teachers kept away from the concepts or topics in all possible forms, the "nil treatment." Most of the topics excluded completely from classroom discussions tended to be of theoretical or abstract nature. Examples on this category would include instantaneous velocity, instantaneous acceleration, Galilean

principle of relativity, simple harmonic motion, the second law of thermodynamics, and many theoretical predictions of the kinetic theory of gases.

It should be clear from this description of the teachers' treatment of the subject matter that there was a tendency to shun any theoretical intricacies, and deal more with the concrete aspects of the subject matter. Under such an interpretation we would expect both teachers to be primarily concerned with "facts" of physics per se. This was the case as was first shown in the preceding section. The last quote also implied that, as Mr. Stewart asserted: "But what we are worried about in Newton's second law, is that, Newton's second law, not the snarls that picking the right set of units to make "K" equal one."

The teachers' treatment of the subject matter was highly skewed toward special cases, "facts", and concrete knowledge. They not only emphasized the concrete aspects of physics knowledge, but also presented particular cases as if they had been representing the abstract concept or idea under discussion. One example on that would be the way they dealt with the velocity-versus-time curves in order to find average acceleration. First, they limited their discussions to a straight line, a special case of a curve. And then, to find the value of $\frac{\Delta V}{\Delta t}$, they picked up two points: one of them was always the origin, which was another particular case of choosing a point, though of course it would not have mattered anyway since they picked a straight line and, thus,

no variations in the slope existed. (More details on how both teachers dealt with that concept were included in Abu Isneineh, and Contreras, 1987. The two teachers appeared under the fictitious names: Mr. Simon, and Mr. Morris). I called these trends of drifting toward the concrete in the subject matter, and particularizing abstract knowledge: "concretization" of the subject matter.

The way teachers perceived and treated theory and observation as two distinct and separate instructional and learning sources, together with "concretizing" the subject matter content had, I believe, serious consequences on the nature of physics knowledge presented in classroom. Combined together, they would amount to more than fragmentation in the physics knowledge presented to students. As I stepped out of my role as a phenomenologist, I perceived the two teachers involved in a process of deconstructing the structure of physics knowledge in their attempts to teach it. I termed this process: "destructuring" physics knowledge.

I took my perception to both teachers in order to see how much we shared such a perception. Before that, however, I had had a true surprise. The term "concretizing" which I used to describe some features of their treatment of the subject matter had appeared in my notes during my early observations. To my surprise, the same expression was used by Mr. Stewart to describe what he, and Mr. Davis, were doing with their physics courses. So, I will take up the two issues together since they are strongly related to each

other.

Concretizing and Destructuring

Let me start this section with two events that took place on Nov. 1, 1986, during the Semiannual Meeting of the Michigan Section - American Association of Physics Teachers in Ypsilanti. The first event was the one I cited before about Mr. Stewart presenting his "KUESA" method for solving numerical problems. What I did not mention, however, was Mr. Stewart's own description of their own method of teaching physics. The key word in that description was concretizing. He asserted that both he and Mr. Davis would usually attempt to "make the abstract things concrete".

The second event occurred when Mr. Stewart got involved in a dialogue with another high school physics teacher. The issue discussed was the word 'body' that was extensively used in the HPP textbook. The teacher, appeared unsatisfied with the generality implied in the usage of that word, explained that he would always replace it with something specific. Mr. Stewart then elaborated on this issue by invoking Newton's second law of motion, F = ma. He went on to point out what he perceived as a sort of confusion in his understanding physics.

> "What I am confused about is that when we start abstracting? Where is the interface between the formula and the concepts? I usually raise the question Am I really teaching physics when I teach: "F" is equal to, "m" times "a"?" [Fieldnotes: 10/1/86]

When a formula and its referent concepts are held as two distinct and separate entities, and dealt with as such, the interface between them would simply disappear, or at best become too thin to be visible. Let us for a moment think of the extreme cases where we have nature with all its phenomena on the one hand, and mathematics as one product of human rational and theoretical thinking on the other. Nature has always been independent of human rationality or irrationality. The fact that mathematics has played a crucial role in our attempts to understand nature does not really tell us much about why it has been so. The grand success of mathematics in explaining physical phenomena is still a source of intrigue for philosophers and scientists alike. Whether there is a reasoned explanation for this success, or it is merely a fortunate occurrence of our existence is still debatable.

Less debatable, however, is the correspondence scientists make between the theoretical and observational concepts, at least in classical physics. When Newton theorized about motion and its causes, he made such a correspondence between Euclidean basic mathematical assumptions, and his own observational terms. An object, be it a grain of sand or a planet, stood for Euclidean geometrical point. The distance between the centers of two such objects stood for the Euclidean straight line. Other observable terms such as mass and velocity were defined quantitatively. Describing certain physics behaviors, in

terms of mathematical formulations, enables us to describe, explain, and predict related events. An event, a physical phenomenon, could be one of an infinite number of events that could be operated upon by the mathematical formulation of the law. Once we attempt to explain or predict, as when we teach applications of the law, we temporarily create a dialogue or an interplay between the general, the law, and the particular, the event. The general collapses momentarily into the particular in order to explain, or predict, it.

Newton's second law, therefore, was intended to explain and predict an infinite number of physical observations ranging from terrestrial phenomena to celestial ones. The mathematical form used is both simple and concise, and had been known for centuries before Newton. The matching Newton constructed between the form and observation was of his genius. But so long as it would be held in complete isolation from observation, the law would be closer to a general mathematical formula than to a physical law. It is only when we maintain the interplay going on between the general law and the particular events that the form could be called a physical law. What Mr. Stewart appeared confused about, I think, was how to maintain this constant dialogue or interplay between the general and exact mathematical form and the particular inexact physical events. The closest they would come to each other would be in the processes of explanation and prediction.

There is, I believe, another dimension to Mr. Stewart's confusion. Let us for a while think of the way physicists would theorize and make their theories useful. Quantification is a necessary step in this process. Physical terms have to be quantified in order to be mathematically operational. Quantifying these terms would necessitate going into the mathematical reasoning and procedures which Mr. Stewart literally called "the snarls of picking the right set of units". Those "snarls" which the teachers "hid" from students represented another point on the plane of potential contact, or "interface", between the mathematical form and the physical phenomenon. Once that point is established it becomes inherent or embedded in the relationship between the general and the particular. It reflects our attempts to exact our description of nature.

In an interview I asked both teachers whether or not they would share with me my conceptions about "concretizing," loosening the structure, and destructuring the physics knowledge structures they attempted to teach. As Mr. Stewart was listening to my question he kept nodding and uttering the word "yes" several times. For a few seconds after I finished my question Mr. Stewart appeared to me unwilling to give more than his "noddings" and "yes's." However when I asked for more than that, his response came as follows:

> "Well, as far as structure or looseness, yes. The thing that I really disliked about the PSSC was that it was telling me how to do it. And that if I ran into difficulty, which I constantly did, and kids understanding this so that we can go on to that. There was a constant battle over what pace should I go in PSSC. If this point is dependent on this point, which is dependent on that point, how much time should I spend on the first point? What kind of success do I heed in class? Is it fifty percent, or thirty percent, or ninety percent, before I can feel as a class we can go on to the next point on which that is based? And that was a constant struggle! And it was frustrating for me and I know it was frustrating for students, because we couldn't do last week's work, then there is no chance of doing this week's work because it's based on that. So I didn't have a lot of success with the PSSC. I think I gave it a very realistic honest shot in a lot of different ways. I tried changing the formula, changing the mixing in a lot of different ways but it didn't work." [3rd Interview: 11/26/86]

Some moments later in the interview I ran out of tape so I started to summarize the rest of his response.

> "So, for the loosening issue, yes, we do that deliberately. As for concretizing we feel many students have not reached that sort of Piagetian stage where they can think in terms of abstraction".

Clearly then, Mr. Stewart deliberately avoided abstractions, concretized the subject matter, and loosened its structure, if not deconstructed that. As I was listening to his response describing his experience, clearly a painful one, with the PSSC, and trying to compare his past struggle with the subject matter with the sort of continuous, uninterrupted flow of physics instructions both teachers were having, a question arose at the spur of that moment. I explained to Mr. Stewart that I sensed a change

of tradition in physics teaching as he shifted from his past approach with the PSSC toward doing what he was doing with the HPP. To me, I should confess, Mr. Stewart appeared, not breaking with a tradition in physics teaching influenced by the nature of the hierarchical structure of the subject matter that would not make it possible for the teacher to move from one topic to a second one, that is dependent upon the first, without making sure that the majority of students had already understood the first. By such a break, he also appeared to fail to make clear, weaken or even destroy the connections within the formulation of individual topics or concepts. In other words, the concretization and loosening processes were done at two levels: inter-topical, and intratopical levels.

As I indicated, a question came to my mind, while I was listening to his response and contemplating my own ideas. Would not Mr. Stewart feel that he really betrayed his own physics learning by doing what he was doing? I should point out here, that I would have worded my question differently had I not hastened to ask him about that, instantly after he finished his response.

So I asked Mr. Stewart if he had this feeling of betrayal to his own beliefs of what physics is, and how it should be taught. Mr. Stewart's answer came quick, and, I think, candid.

> "Yes, that's right!" [He stopped for a few seconds and then went on to say:] "But you know we have to look at other factors. It also depends

> which physics you are talking about." [3rd Interview: 11/26/86]

As pointed out in a previous section, the implied reference in the last sentence was to college physics and physics for the public.

Mr. Davis seemed also to share with us the conceptions of concretizing and loosening the structure of the subject matter. His answer, as will be seen, reflected another dimension which had to do with relevancy and contextualization of the subject matter.

> "I suppose the destructuring or the idea of loosening the structure of the topic is our attempt to take the physics topic and describe it. This is my philosophy as I look at it. How would I describe it to somebody that I knew based on something that he would understand without going back to the book. I just say hay! I better start from something where everybody understands you so we can know at least where we will be going with those topics. Loosening the structure, I never thought about that! I suppose it's our attempt to make it more human. The concretizing makes it possible for some of the bottom end of that spectrum that we have in the room to deal with it, with the topic. Admittedly it takes away from the top end, or it doesn't push the top end, but it pushes the middle and keeps the class that size that it has. By concretizing, it's supposed that it allows more people to be successful, use your format to follow. It becomes a computer program and all you do is plug in the numbers. It has some good points and some bad points." [3rd Interview: 12/2/86]

So, by loosening the structure, Mr. Davis wanted to create a connection between what students knew and what he wanted to teach. It sounds as if Mr. Davis wanted to build on students' prior knowledge, or to contextualize the

subject matter and make it relevant. Furthermore, like Mr. Stewart, Mr. Davis thought that concretizing would help students at the "bottom end" of the class to understand the topic. Finally, Mr. Davis saw in concretizing a way of allowing more people to "be successful". They would simply use a clear format: "It becomes a computer program and all you do is plug in the numbers!"

As will be explained later in this dissertation both teachers admitted to have decided to change their standards and expectations of students in order to secure their jobs. The teachers' concretization and destructuring of the subject matter seemed to be in line with that decision. Once more the teachers' coping with the situation seemed to have influenced the very structure, very vital in this case, of the subject matter they taught. If students are likely to find learning easier in an environment which emphasizes memory and procedural tasks (Doyle, 1983), then it would seem ery plausible to conclude that teacher seemed to have solved some of their problems in ways that sacrified the acquisition of academic knowledge (Feiman-Nemser and Floden, 1984), made the acquisition of knowledge easier (Sedlack, et al., 1986), and reduced the cognitive demand of their work (Gallagher, 1986).

Making Physics Relevant

Making physics related to students' experiences was another feature that appeared in Mr. Davis's last quote.

It was also emphasized on several occasions while talking with both teachers. However, to come up with a coherent picture of how teachers did that required going beyond the teachers' surface meanings as experessed directly in their discourse. Indeed, a difficult, yet interesting, aspect of doing interpretive research, I have found, is to present both the manifest or surface meanings of narratives and vignettes as well as their possible latent or hidden meanings and contexts. This could be achieved through the examination and interpretation of teachers' statements and assertions on the one hand, and their practice on the other. Mr. Davis's quote, taken out of context, may convey a certain message, the manifest meaning, that could be fundamentally different from the latent meaning when his words are put into the content of his practice.

There were constant efforts, on the part of the teachers, to make their examples not only concrete and tangible but, as well, known to their students. Their worksheets did not talk about "objects" as such. Instead, they tended to talk about things from the students' experiential life. An examination of the problems and examples on momentum and conservation of momentum would explain that. Problems talked about cars, snow-scooters, rockets, billiard balls, bumper-cars, and astronauts. But how much difference would it really make in a student's learning if, he or she, were to find the momentum of a Mustang instead of finding the momentum of the meaningless

word "gnatsuM," whose masses and velocities were known, if that student could not, at least, differentiate between the concepts of momentum and mass on the first hand, and momentum and velocity on the other, not to talk about the theoretical development of the term.

As another example, both teachers did several concrete demonstrations on the fundamental, subtle, and tricky concept of inertia. Each teacher took a whole hour to make ten related demonstrations. Each teacher attempted to explain each demonstration in terms of inertia. However, not one single student in the classes observed, was asked to use his own words in an attempt to explain any of those demonstrations. Even the quiz asked nothing about that. Anybody familiar with those demonstrations would know quite well that they would be interesting to see but subtle to explain. Likewise, several interesting demonstrations were done by the teachers on some fundamental wave concepts, like standing waves, and resonance. They were only demonstrated to students with no theoretical explanation whatsoever. How much did students really learn about those concepts could be anybody's guess. A student observing a concrete example on standing waves without any attempts to understand the theoretical underpinnings of the phenomenon, would in no way be in a better position than a layman looking at a rainbow, or a housewife baking in her new microwave.

On other occasions, furthermore, the concrete examples might have lost even their claimed direct effects upon

student learning. Let us look at the following problem that was given as an exercise on acceleration:

> "Some primitive societies were known to throw young maidens into "bottomless" pits. A young maiden dropping into a bottomless pit had an initial velocity of 0.0 meters/second. After 3.0 sec of fall her velocity is 30 meters/sec. What is her acceleration?" [Worksheet: 9/16/86]

The wording of the problem provoked a lot of giggling and joking among the students, especially the girls. Instead of thinking and talking about acceleration the class seemed more inclined to joke about maidens thrown into the "bottomless" pits.

Another example which could have been counter-effective, was related to a popular problem on the law of conservation of momentum. Analysis of that particular problem could have been used to demonstrate the vectorial nature of momentum. In that sense, the problem was somewhat different from the other straightforward ones. I am referring to problem three in the set of bonus problems on momentum. It was about two astronauts, who, while floating freely in space, push each other. The problem gave their masses, and the velocity of one of them before the push, and asked for the velocity of the second one. Let us now see how Mr. Davis concretized or contextualized that problem as he started to discuss it with his adolescent students.

> "I'll tell you a story here. Astronauts may have been in space for a while." [Teacher started to draw sketches of two astronauts on the board.] "Their names are Sam, and Martha. Women are part

> of our space program too, I suppose! And these people are working on a project out in space, and they've become madly in love with each other. They're romantic and all this type of thing!"
>
> Class: "Oooooh!" [A lot of laughter and noise.]
>
> "And while in space, while working on the space station, they decide to take time out for a (Howard) wander group kissing in the hallways."
> Class: "Oooooh!" [laughter]
>
> "Okay, they decide to take time out for just a little hug and kiss; and so they're madly in this embrace, I cannot draw them closer than they're physically right now. But, imagine during this dodging of their moments something is said that Martha doesn't like. And she says to Sam, in only the astronaut language, she says: "get yourself away from me!" [At this point the teacher made a pushing with both hands.] "And Sam goes one way and Martha goes the other!"

By the time the teacher ended his story the students' attention was clearly drifting far away from momentum and its conversation. Laughter and noise persisted until the end of the hour.

In this section I have been talking about two issues together: concretizing and contextualization or relevancy of the subject matter. It seems nobody would disagree with the idea of presenting students with concrete examples that would illustrate some abstract or theoretical ideas or concepts. But when concretizing becomes almost an end in itself, or when the abstract is fragmented into eventual particulars and taught as such, then there is, I believe, a strong case for the claim made earlier that concretizing would fundamentally change the structure of physics knowledge taught. In saying that, however, I deeply feel

the tension, or even the irony, that such an interpretation creates. For on the one hand, I feel deeply committed to my interpretive methodology which, among other things, views the particular as central in our attempts to understand phenomena; while, on the other hand, I look with an equal respect and commitment to our scientific knowledge that, among other things, possesses certain structuring that involves a lot of abstractions and generalizations which could not really be discerned by learners through their mere encounters with their concrete fragments or representations.

The other issue I talked about in this section has been contextualization or relevancy of the taught knowledge. Once again, it seems everybody would agree that teachers should build upon their students' experiences and knowledge. We have seen how both teachers attempted to do that through some concrete examples or representations they provided in their lessons. However, I feel compelled to note here that this seemingly sound pedagogical principle should be defined and manipulated carefully in physics teaching. Let me cite an example where students' past experiences may not help them learn the concept under discussion.

In explaining circular motion, and other related concepts, it is very usual for physics teachers to draw a circle like the one in the figure below, and then designate an object "O" traversing a circular path at a certain speed which is constant here. Teachers, each in his own way, would start talking about, or reasoning out, related

concepts like orbital speed, centripetal acceleration and force. Indeed, this was what both teachers did when they wanted to discuss the concept of centripetal force.

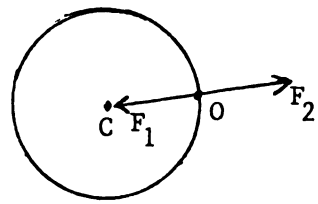


Fig. (4): A Representation of the Circular Motion of an Object "O" Around the Center "C".

Among other things, Mr. Davis introduced two concepts the centripetal force, which was pointing radially inward, represented in the graph as "F_1", and an imaginary force that pointed radially outward, represented by the arrow "F_2".

I knew from experience that the topic was fraught with potential learning and teaching problems at the high school level. Even college physics and engineering students would encounter a variety of problems in their attempts to conceptualize the meaning of centripetal and contrifugal forces. The latter is often described as fictitious, imaginary, or pseudo. Many physics books do not discuss that in any length; they only refer to it. The HPP textbook did not mention it.

Notwithstanding the relatively difficult nature of the concepts, I expected some reference to some concrete examples from students experiences that would elucidate the

two concepts and would distinguish between them. The concrete examples I had in mind were the many circular rides which students certainly experienced in amusement parks, or simply a ride in a car travelling in a curve. Such concrete examples were not raised in that lesson on centripetal forces. I should add here that there was a problem on the "rotor", which was supposedly solved during a subsequent lesson which I did not observe. However, that problem asked students to calculate: circumference, centripetal acceleration, and centripetal force. There was no suggestion as to how to analyze that student experience in the light of the formal structuring of physics knowledge.

What worried me about representing the two forces in two opposite arrows as they appear in figure (3) was that students may conceive of those forces as acting on the same body, and since they were equal in magnitude and opposite in direction they would cancel each other. The net force on the body might, thus, appear to be zero. Both the representation and the conclusion would, therefore, be incompatible with the scientific formulation. I was somewhat surprised that none of the students in the two classes I observed raised any questions about that. Neither did the teachers during those hours.

However, when I raised the point with Mr. Stewart, I discovered that he had gone through that in one of his sessions. I asked him first if he used the concept of imaginary forces. In his answer he explained that he used

the term centrifugal instead of imaginary, because students who experience such forces in various circular rides thought of those forces very real and not imaginary. He then went on to explain how he explained those two force concepts in the case of a student riding in a rotor, as Newton's action and reaction forces. Let us look at his answer in full to see how such an intricate concept may elude the thinking of an experienced and knowledgeable physics teacher.

> "Yes, and that question was raised by a student in one of my sections; and we talked about it briefly. I didn't use the term imaginary force, because there again, that's a snag that they can say: wait a minute, that's not imaginary! That's real! It seems very real to them! But what I said is that you have to focus in on the force that is on the object that is moving on a circle. And the example I gave: a lot of them have been to the local amusement parks and have ridden on various kinds of circular rides. And there is one that involves a circular wall that they stand next to. And it revolves, and they are plastered against the wall, the rotor. Now, I used that as an example of what I was talking about in those forces. I said there is a force on your back, that you feel pushing toward the center. And this is the centripetal force that we are talking about. In order to keep a body moving in a circle requires the centripetal force. I said, now, as we found out from Newton's third law that forces exist in pairs, and there is certainly a force involved in pushing on the wall of the rotor thing. But we are not concerned with that. We are concerned with the force that is on the body that is moving in a circular path, in other words your body. And that force is toward the center. This is the force that we look at. So what I try to do is to direct their attention to the force that we're concerned with, and that we had described and was consistent with, and not worry about centrifugal force." [2nd Interview: 10/14/86]

The content of the answer would still be confusing. In a sense it is not compatible with the accepted physics explanation. Before going into that, let us remember that the example was cited in order to show that students' past experiences, though they may be very real for them, may not necessarily be congruent with the physics knowledge construction. This example is, I believe, fundamentally different from other situations where students might have misconceived certain phenomena and thus formulated knowledge structures that were incompatible with the scientific explanation. To some extent, the inverse seems more plausible in this case. There is a good reason for students to believe in what they experienced to be real. However, the way that experience was constructed by the scientific community tells them something else.

Physicists call any force that would cause an object to follow a circular path, a centripetal force. There is nothing particular about this force. It is simply like any other force that could act on any object. As pointed out previously this force is always pointing toward the center of the circular path, and is given by the formula discussed before. I should point out right now that this definition is viewed from a frame of reference that is stationary with respect to the circulating object. From the view of a stationary earth for example, the moon is under the influence of a centripetal force; in this case it is gravitational. This view would not consider what the moon,

herself would be saying, not about the earth, but about herself. To make it a bit technical, if we attempt to describe the same motion from a rotating reference frame in which the moon appears at rest, our view will change fundamentally. In metaphoric terms, this would be equivalent to allowing the moon, or something else in her very context and displaying the same pattern of motion, to describe her motional experiences. But not quite; for physicists never allow the subject, the moon, to speak for herself. Instead, they imagine such a frame of reference to be centered on the earth and rotating once every 27.3 days with respect to a fixed star.

From this rotating frame of reference, the moon now appears to physicists to be under the influence of a force that is pointing radially outward, i.e. just opposite to the direction of the centripetal force constructed from the stationary frame of reference. However, this new construct, called technically "inertial force," seems to be without origin, unlike other forces like gravitation which we experience through interaction with the earth, or electromagnetic and nuclear forces. For this reason inertial forces are described as imaginary. And for this reason too they do not obey Newton's third law.

But, otherwise, these forces are just fine. We can verify their presence in the same way as other "real" forces. What is important to emphasize is that for anyone in that rotating frame of reference these forces are as real

in their existance as any other "real" forces like gravitation. They do produce physical effects that could be measured. A student plastered against the wall of a rotor does feel his body pressing against its wall. That would be real for him as Mr. Stewart explained, though from the view of a non-rotating frame of reference, there is no such thing as a centrifugal force. There is simply no need for that in the construction of a physical reality consistent with the laws of nature. The only "real" thing from that frame of reference would be the centripetal force.

But Mr. Stewart's reasoning does not eliminate that potential problem. Neither would it be compatible with the scientific explanation. Starting with the second paragraph of the quote, Mr. Stewart assumed the existance of two forces together: a force "pushing toward the center, the centripetal force", and an opposite and equal force pushing on the wall. In other words, he invoked Newton's third law in order to explain the imaginary force. This explanation, though may be accepted for engineering purposes, would not be adopted by physicists and physics books for theoretical reasons. The two forces, centripetal and centrifugal should not appear together. The former would appear only when we look at a circulating object from a stationary frame of reference, while the latter would appear to a viewer in a rotating or accelerating frame of reference. Put it simply, the two forces do not appear together for the same observer in either frame of reference. So there would be no sense,

from a physicist, or a theoretical point of view, of talking about action and reaction according to Newton's third law. The origin, or the agent of the centrifugal force is not known. More confusingly, unlike all other forces that physicists talk about as "real", centrifugal forces do not produce the centrifugal acceleration as defined by Newton's second law. So, to preserve the format of Newton's second law of motion in various frames of reference, this force, not the only one by the way, was labeled imaginary, in spite of the fact that the force is not less "real" to an observer in the rotating frame, than the "real" forces would be for an observer in a stationary frame of reference, as far as their physical effects were concerned.

But let us look more carefully upon the teacher's words again. He assumed that a student in such a circular ride would feel a force on his back pushing toward the center. While this is true, the feeling of being pressed against the wall would also be true and "real" for such a student. This would even become clearer as his head or hands become free in such circular rides. In such cases the absence of direct centripetal forces on him would make him feel as if his hands and head were going to fly away from the center. These experiences are real for the student, yet in our conventional physics laws forces that would cause such influences are labeled fictitious. But Mr. Stewart learned, and repeatedly, from various sources, physics courses and textbooks, that, conventionally, there would be no such

forces as centrifugal. In a sense, he was attempting to preserve that learning, while, at the same time concede of the "reality" of his student's pertinent experience.

Let us look again at Mr. Stewart's explanation to see where it eventually took him in his reasoning. The wall pushes the body toward the center, centripetal force; and as a reaction to that the body pushes the wall in opposite direction, the centrifugal force. So the centrifugal force, after all, would be on the wall and not on the revolving body of he student which concerned us right from the beginning. Eventually, then, Mr. Stewart twisted the description of the student experience in order to make it congruent with his formal knowledge contstructs.

That should be too confusing and bewildering for a student. Mr. Stewart adopted an explanation that would not agree with the theoretical formulation laid out in physics textbooks. However, that was not where the confusion originated. The fact that physical phenomena can be made, through our physics knowledge constructs, to appear differently for observers in different frames of reference, renders, not only our commonsense knowledge, but also some of our experiences that could be seen in terms of some physical consequences and effects, of conflicting effects upon our attempts to learn those knowledge constructs.

Furthermore, not all of our scientific knowledge constructs correspond to things in our experiential world. Quantum and relativistic physics is full of concepts that we

do not experience. Light phenomena are explained by employing two models which we think of as paradoxical. In explaining interference patterns we imploy the wave model, and totally, or even absolutely, forget about the other model, the particle model. However, in certain other light phenomena, like, photoelectric effect phenomena, we resort to the particle model and never ever in the course of our treatment invoke the wave model. But the physical attributes of particles and waves are simply opposite to each other. A particle is an entity with a definite mass and volume and other derived concepts; while a wave would theoretically extend from minus infinity in space and time, and go to plus infinity in both dimensions. It possesses no localization or mass. In our experiential world and reasoning we had never thought of that until we attempted to describe, explain, and predict light phenomena.

What does that mean to physics teaching? Simply put, teaching for creative imagination and alternatives, teaching for the unexpected, for the future, for the unknown. What about those who do not plan to go to college? That is a silly question, for who would dare saying that life and the individual are so simplistically divisible!

Teachers' Long-Term Instructional Objectives

Close examination of the teachers' instructional planning and practices at the course and lesson levels revealed certain major objectives which the teachers had

achieved in the past and were keen to maintain.

There were, I believe, two global instructional goals which the teachers were persistent to attain and maintain: dealing with a broad range of subject matter topics, and maintaining a high enrollment in their physics classes. Teachers tended to be inclusive at two levels: the subject matter level, and the student level. They planned to teach as many topics as they could, and practically ended up teaching from the book cover to cover, and for as many students as they could attract in their courses. Interestingly, no where in the written literature about the course, like the course description, or chapter and lesson plans, prepared by the teachers, was there any mentioning for these major goals. They there revealed only when I directly asked the teachers some pertinent questions.

These two major objectives could also be used as an opening upon the teachers' relevant and important beliefs, theories, and interests that motivated or even dictated upon them to do what they did in classroom. As I discuss these major objectivess, it will become evident how it is difficult to characterize various classroom instructional acts and behaviors in the absence of the teachers' unspoken goals or intentions. As this discussion is over it will also become clear, I believe, that any characterization of the teachers' implicit goals or intentions would be totally or partially misunderstood, like being biased toward or against the teachers, without putting them in the wider

setting, or milieu. Furthermore a snapshot description of the milieu may prove of only limited help in this characterization. In the setting under study, I have found, as will be explained later, that a dynamic description is needed. Should the word milieu be preserved here, it should be qualified to include the relevant past as well as any future projections or expectations. In the next chapter I will show how the history of the setting influenced the teachers' major instructional objectives or intentions.

Exposing Students to the Sweep of the Subject

The pace of instruction was set by the teachers with the aim of covering as many topics as possible. As explained before, in both courses, about half of the chapters of the textbooks were covered in varying detail during the first semester. In the IPS this coverage tended to be inclusive in the sense that the teacher went over almost every section and activity in the part discussed. In the HPP course the situation was different. While the nominal content coverage included about half of the textbook, the real coverage was much less than that. As was explained before, many concepts, and whole sections were deleted. In some chapters, 11 and 12, only some fundamental concepts were chosen for brief descriptive treatment. But the assumption on the part of the teachers seemed to imply that students had some important and needed exposure, to

those concepts, though admittedly brief. Let us now see how both teachers expressed their views concerning this major objective.

Mr. Stewart argued for a wide content coverage on three bases which were related to: the nature of the course, the future needs of students taking the course, and his philosophical views on the nature of science. He saw in the physics course an introductory one, that was taken by students experiencing physics for the first time. Consequently, there was a need to expose them to very many topics, and a limit to how deep you could go into these topics.

> "Any introductory course is limited by the depth in which you can cover....In our attempt, in our physics course, to see the entire picture of physics in all aspects, atomic physics, nuclear physics, as well as mechanics and optics, and so on...We have to go very rapidly touching bases on some critical issues and leaving many alleys unexplored. But overall, we try to give them a complete picture of what the field of physics is and to expose them to some of these ideas in a logical framework that they carry with them to college." [1st Interview: 9/23/86]

The same ideas were emphasized on another occasion in the second interview.

> "It seems to me what we are after, in a beginning course in physics, is to give the students exposure to the structure and the sweep of the subject that fit it. We don't, and I don't propose to have mastery of any one of the topics, or at least a broad and deep mastery of optics, for example. But it's important for students in a beginning course of physics, and you have to realize that the students that we have at [Howard] High School, coming in with almost no physical

> science experience at all in any of their elementary and junior high school experiences. These concepts are brand new to them". [2nd Interview: 10/14/86]

As for the future needs of students, Mr. Stewart saw two basic categories: college needs, and vocational needs. He saw in the introductory physics course a preparation for college work as well as a technical vocational training.

> "The students that would go on to a career in science would find that what they do in college will plug right into what we've done here. We tend to develop a course laterally and cover a wide area but not going deeply. In college they tend to pick up narrow fields and go in more details of it. But that's the nature of physics. Another aspect has to do with pre-vocational training. There are some kids who may have interest in mechanical things: it might be mechanics or technicians, or T.V. repairmen. And I think what they will see in their careers has a foundation; and they'll see in life what they saw in physics class." [3rd Interview: 11/26/86]

As explained in the previous chapter Mr. Stewart conceived science, or physics in particular, as a structure of "interlocking ideas". A goal of an introductory physics class, according to Mr. Stewart, was to expose students to this structure. This would necessitate going over a wide range of topics. That was clear in the first sentence of the second quote in this section: "It seems to me what we are after in beginning course in physics is to give students exposure to the structure and the sweep of the subject." This idea came up often in the teacher's description of what he intended to do in classroom.

> "I think probably, we worked the way the course actually worked..... It's sort of like working a jigsaw puzzle as you put the pieces together, and soon some patterns and pictures begin to emerge, and you get the large view." [1st Interview: 9/23/86]

But was Mr. Stewart aware of the consequences of his sweeping pace of instructions? Did he try other different methods? The answer to both questions is yes. Talking about the payoffs involved in different pacings of instruction: slower pacing when using inquiry methods, and his rapid pacing, Mr. Stewart noted:

> "The pay-off in one case, is you learn more process of science. What the pay-off in the other, is that you get a whole picture of the science physics is all about. And you pay one, and you make the choice. Our gamble is that it's better to see a picture of what physics is in its totality, rather than be lost in the minitour of developing an experiment that allow you to come up with the conservation of momentum. That stuff has been done, and to rediscover the wheel is, may be valuable as a process, but, certainly, not its content. It's a waste of effort. [2nd Interview: 10/14/86]

So Mr. Stewart seemed to realize that what he was doing was a "gamble" after all. He knew the grounds on which he could be criticized. However, he sounded confident in what he did, for after all, he had tried other rates of pacings. This last quote could be looked upon as an opening upon the history of the setting in which Mr. Stewart has been working for so many years. I will take up this issue of history in the next chapter in order to put the teachers' major instructional goals and their classroom practices into a

wider perspective.

Mr. Davis echoed that same major goal. However, in his rationale or justification for the pacing followed, Mr. Davis referred to what he saw as potential consequences of following a different pacing that would emphasize mastery.

> "Our total goal is to present a picture of physics, at least from the private physics textbook, from cover to cover. Looking for mastery in all areas with this cross section,...we would be totally frustrated! We would be destroyed!" [2nd Interview: 10/14/86]

In his description of a past experience where they tried to teach for mastery, Mr. Davis stated the following.

> "We've tried that, we got overwhelmed in paper work, one time dealing with students on a re-take of a quiz on a retake basis. And we tried that, where students, let's say if they don't understand the thing they could take the text again and again. That provided paper problem, where we couldn't tell which test from which in the changing of things. That broke down credibility. So, we just had to just say the best we can do is one shot." [2nd Interview: 10/14/86]

Once again the history of the setting appeared to have played a significant role in the emergence of this instructional objective in the classroom life of teachers.

Like Mr. Stewart, Mr. Davis seemed to realize the dangers involved in pursuing such a goal persistently. On another occasion, he stated, not only his reservation on what they were doing, but the deep conflict or tension such a practice has left in his conviction or conception of how he should treat the subject matter.

> "I'm in partial agreement that you should get from one cover to the other cover. But in the process of doing so, I agonize over concepts not being developed, not really developed. I agonize on that." [3rd Interview: 12/2/86]

When I asked him about the trade-off for such an agony, his response came as follows:

> "The agony got compromised over time. The benefit that comes out of it, is that we stay together. And staying together means that we can share the load on all kinds of things: classroom set-up, development of today's lesson. It helps in doing so to take some of the preparation time, and helps to think about the physics and not the preparation, you know, of getting all the physical stuff here and there. Kind of buy some time by that." [3rd Interview: 12/2/86]

Working together did really "buy" some time for both teachers. However, Mr. Davis did not seem to be fundamentally different in the IPS course, where there was no team work, as far as the content coverage was concerned. In examining the teachers' lesson plans, as well as some specific classroom practices, both teachers in both courses made consistent efforts to achieve wide coverage.

I think that both teachers did agonize at one point or another over that issue. I also believe that their agony "got compromised over time", as Mr. Davis talked about his case. The matter represented, I think, a point of tension between the realities of the setting, including the nature of physics knowledge, on the first hand, and the teachers' ideals about what they had been supposed to do as physics teachers, on the other hand. Overloaded with those

realities, both teachers seemed to have adapted to them and sacrificed many of their ideals. As I go through the history of the setting, it will become clear how larger issues came into play. Within the wider historical milieu of the setting both major goals will appear as they had been situationally dictated over time. To some extent, more in the case of Mr. Davis than it was with Mr. Stewart, the whole issue seemed to have left a scar on the teachers' memory of their teaching experiences, which is sensitive, even painful, for any scratching: inquiring about it in this case.

Making Physics Inclusive

The second major objective which both teachers worked to achieve was to have high enrollment in physics classes. As was explained before, they adopted some classroom practices to stimulate enrollment. They kept a display of photographs of students and teachers working together in the lab, with other occasional pertinent printed materials in a visible spot adjacent to the physics room. The latest poster I saw in that space read: "HERE ARE REASONS WHY YOU SHOULD SIGN UP FOR PHYSICS".

Mr. Stewart first brought up this issue in the context of comparing the PSSC and HPP projects. The implication was always that the HPP was designed as a physics course for a wide variety of students. His historical decision in the seventies to use the HPP as an introductory course, and

later keep the PSSC for the advanced one, meant, for him, that he should teach physics to everyone. In order to teach physics for everyone, Mr. Stewart felt that he had to design his lessons with an eye on the class as a whole, and not on a specific group of students. As we saw in previous sections that was exactly what he did.

> "And you know our decision that we try to teach physics to everybody, which means that we have to compensate for the fact that some kids have an innate ability to pick up physics concepts quickly and going to them in great depth; and others it's a slower process. And so we want on every day, we want to relive that philosophy that we have overall, that physics should be inclusive and not exclusive. We want to be sure that everybody is with us. So we try to select lessons that fit into the class hour." [1st Interview: 9/23/86]

Making the necessary changes in one lesson, or "compensating" in favor of the kids who did not have an "innate ability to pick up physics concepts quickly" boosted enrollment in physics classes. High enrollment meant a lot of things for Mr. Stewart. It meant that many students were finding the course relevant and useful in their lives.

> "And the fact that our enrollment stayed high consistently, I think, is an indication that what we're giving to the kids is something that they think useful and valuable, not irrelevant; and that it's taught on an accepting level: where we accept the level of where they are. We aren't trying to make them into something that they are not. And I think in that sense there is a match between what the students are and what the course is." [3rd Interview: 11/26/86]

High enrollment also meant success for this elective physics course in its competition with other much easier

elective courses been offered to students.

> "I think the fact that we have maintained a solid enrollment for a long period of time means: here is another indication that we are competitive, Physics is successfully competing with the kids who wish to take it, or the kids with the elective courses. The school district has an enormous number of courses from which the students can elect. Physics is among that pool". [3rd: Interview: 11/26/86]

Furthermore, high enrollment was not an educational service to the student body and public at large only, but, equally well, to the very field of physics itself, according to Mr. Stewart. However not all people inside physics would agree on that, as he mentioned.

> "Now, you read some of the reports, the studies which have been done in science education. Recently, one of the points they lament is the small number of kids that take science courses. And nationwide overall percentages are very low. Alarmingly low! Scary! Something like, I read two different studies: I think one was three percent of the high school graduates will take a course, nationwide average, in physics; the other is seven percent. Now I don't know which figure you want to believe; but it's very low. At "Howard" thirty or forty percent, depending on how you calculate it. So we've done about what somebody's study said what we're supposed to do." [1st Interview: 9/23/86]

Five minutes later in the same interview he noted:

> "And I have come to the conclusion that I believe I best serve the field of physics by serving a large number of kids in the school. I know that the people inside physics itself: some agree with that, and some don't. Probably more don't agree with that".

But the tension in the teachers' thinking that I talked about in the previous section between the realities of physics teaching and the ideals and expectations of others, including both the teachers and the physics community, appeared in the continuation of the last quote.

> "They would like to see, for their purposes; they would like to see high school physics students come out extremely well prepared to plug in their college courses, and to be trained research physicists. That, that's what they see my job is: but I think, I think, uh, uh, uh you know, it's a question you never resolve completely in mind; but as always: you weigh it which direction should I be going! And I think, maybe over a period of time we've done, we've done, may be the best of both worlds". [1st Interview: 9/23/86]

What I found interesting in this quote was the repetitive words and phrases, hesitation about certain utterances, and the usage of words that denoted uncertainty about the soundness of his decision. In practice, however, he appeared determined to go along to achieve his objectives the way he believed possible.

Mr. Davis was also concerned about high enrollment, though less than he had been several years ago.

> "I think years ago we used to watch it quite carefully. We used to worry about it. We used to really get concerned. We do concern ourselves with enrollment. But I haven't put it on the same level as in the past." [1st Interview: 9/23/86]

When asked about why he had been concerned about that, Mr. Davis gave the following response:

> "In the past I only taught physics. It was Mr. "Stewart" and myself who were teaching physics. There weren't any other courses in the curriculum; and they were not putting any new courses in the curriculum. And so if our course level is low, I wouldn't work because of seniority. And a few times I did get to teach biology, and I did have to teach some other types of materials in chemistry, two different types of chemistry. So I was like a travelling salesman for a while when enrollment dropped in the late seventies. But at present time, the enrollments are high, and so one doesn't put that a priority anymore. But, you know you still worry about it because I lived through it." [1st Interview: 9/23/86]

When I asked him if he had to make any serious changes in the way he taught in order to influence enrollment, Mr. Davis went into some details to describe how their grading system changed in such a way that:

> "...the objectives that we have are not as high in terms of the level of hierarchy of the objectives that may be set aside in some physics programs". [1st Interview: 9/23/86]

On another occasion Mr. Davis added another element in those changes that maintained high enrollment. He described how some "manipulation" of physics, like doing exciting demonstrations, was necessary in order for students to stay in the course.

These quotes shift the attention to another sphere of influence on teachers' instructional practices. Both major instructional goals appeared to have developed, or evolved out of a dynamic process in which the teachers' interests or "survival", as Mr. Stewart called it later, went into an interplay with the various elements in the milieu over a

period of time. In the next chapter, I will attempt to trace the evolution of those objectives through a narrative of the history of physics teaching at the school. I will also discuss, briefly, other important elements in the setting in order to present a comprehensive picture of the teachers' treatment of the subject matter.

AN INTERPRETIVE STUDY OF TWO EXPERIENCED HIGH SCHOOL PHYSICS TEACHERS' KNOWLEDGE, CONCEPTIONS, AND CLASSROOM TREATMENT OF THE SUBJECT-MATTER

Volume II

By

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CHAPTER VI

ADDITIONAL RELATED ISSUES

The previous chapter was intended to answer the second research question on how teachers treated the subject matter. I started that with a detailed description of how they first planned to teach. I attempted to show how they were persistent in their classroom instructions to follow their plans even when students encountered learning problems. Both the form and the contents of classroom instructions were analyzed. Two global instructional goals were, finally, discussed. Those major goals: very wide coverage, and high enrollment, influenced the teachers' treatment of the subject matter in fundamental ways. Indeed, it appeared as though that treatment had been, for the most part, driven by these two objectives.

The teachers' practices, therefore, were very compatible with these goals, and vice versa. But since the focus of the study was the subject matter and its treatment, other important issues were left out. To put the descriptions presented in the previous chapter in a more meaningful picture, three more pertinent questions need answering. First, what were the teachers' role conceptions, as far as the subject matter was concerned? Second, what were the teachers' knowledge and conceptions of their students? Third, what were the teachers' conceptions of learning? Though these questions were not central in the

study, some related information appeared in the data.

The Teachers' Role Conceptions

In a related study (Abu Isneineh, 1986), both teachers were asked specifically about their roles as high school teachers. The study explained, among other things, how teachers envisioned their roles as primarily related to students,and to the subject matter. "You are an engineer, a creator of their (students) experiences with your subject", Mr. Stewart asserted. Mr. Davis also echoed the two dimensions about his role. "Leave students with some facts about the subject matter." While the implications of the two statements are different, both of them, however, emphasized the teachers' concerns about the same two issues: students, and subject matter.

As for their physics instructional roles they had the following descriptions:

Mr. Stewart: "Humanist, on the side of the student, both of us are going to explore physics rather than a physicist challenging students to bring themselves to me."

Mr. Davis: "I try to teach skills, data, numbers, patterns. Skills like using equipments, batteries. Understanding technology is also important."

What is interesting about those responses is the little emphasis they put in their roles on pedagogical matters. Mr. Stewart saw himself as a "humanist" not a science or physics educator. The words: education, pedagogy, and

their derivatives did not come into teachers' speech utterances as frequent and spontaneous as words like science, physics, technology and their derivatives. Even when they referred to their educational background, they tended to make conspicuous the science component of their education, while the pedagogical dimension was raised only when they were specifically asked about it. Furthermore, when asked about the ways in which we, researchers, can offer any help for them, they tended to talk about attending seminars in which physicists would discuss certain topics of interest to them. They did not ask for a science educationist or a pedagogist. Ironically, they asked for the help of the people whom, at least in the case of Mr. Stewart, they did not try to emulate!

The incongruence between the physics teacher role conception, humanist and not a physicist, and his conception of his role enhancement, listening to and interacting with a physicist, not with a humanist may have more than one implication. First, it reflects a teacher awareness of authority in science. Physicists are ultimately the people who would define what physics knowledge is. Second, it may reflect the personal dimension in what the teacher would eventually do in classroom, for in spite of their recognition of the authority of the scientific community, teachers should not be expected to follow that community's suggestions and recommendations blindly. That was very clear in a previous quote when Mr. Stewart talked about two

kinds of physics, that of the university, and that of the public. This personal dimension is in agreement with the research reviewed on personal knowledge, Elbaz (1983); Clandinin (1985); and Lantz and Kass (1985). Third, this conflict may be linked to what was alluded to in the previous chapter as a tension in the teachers' conceptions of their actual treatment of the subject matter, and their ideals about how such treatment should be. This issue will come up again in the last section of this chapter when it will become clearer how both teachers compromised some of their ideals about physics teaching in order to cope with physics classroom realities.

The Teachers' Knowledge and Conceptions of Students

Both teachers taught long enough in the school to know much about the population their school drew its student body from. Both spoke of the diversified nature of various aspects of students' social and cultural backgrounds. All of these students were potential takers of the science courses the teachers taught.

Both teachers, accordingly, saw very wide individual variations running from "the very highly motivated kids that go to places like University of Chicago and Kalamazoo College, MIT, and Harvard, to the lowest kind of unmotivated near criminal element that is just about as low as the human race go", according to Mr. Stewart; or from "the kids that do not value education at all, all the way up to those who

really value it", as seen by Mr. Davis.

Individual differences were also expressed in terms of their academic abilities. Mr. Stewart talked about kids who had "innate ability" to understand physics concepts more than others; while Mr. Davis talked about students who possessed more of mathematical skills than others.

All students were seen as potential takers of the science courses the teachers taught. However, Mr. Stewart thought that they still did not do "a good job with the lower half of the student body", which he referred to as the "unwashed masses." So students enrolled in science classes tend to come from the upper half of the student body. Mr. Davis described such students in different terms, they were those who were "looking for an elective that is not just mickey mouse!"

As for the consequences of the type of students enrolled in these courses, it was mentioned how Mr. Stewart planned to compensate for those with lower abilities. He also indicated that the methods that succeeded were those that "reflected student biases, attitudes, satisfaction, spans, and current levels of interest." However, this resulted in some students who were labeled as "mismatches" for the course, according to Mr. Davis. These students did not work enough for the course, and there was "no way in the system to get them out of the course."

Another important aspect of the teachers' conceptions of their students was related to their work habits and

learning. Mr. Stewart thought that the present generation is oriented more toward some sort of quick gratification, rather than toward detailed reasoning over a long period of time. As I asked him for an example on that, he went on to describe his daughter's behavior when he tried to explain to her in detail how to solve physics problems. While he attempted to explain each step in detail, she wanted only "shortcuts" and quick answers. When asked if that had influenced the way he taught in classroom, Mr. Stewart asserted that over time it did skew the way they did things in classroom.

Mr. Davis also talked about what he called "cartoon syndrome." He mentioned that in the context of describing how his IPS class did not have the patience to sit still and watch him doing demonstrations. That was why he did not like to do demonstrations in that class.

An interesting feature of the teachers' knowledge and conceptions of their students was the collective way in which they tended to think of them. Teachers talked in terms of groups of students, or classes, or the student body as a whole. As I pointed out before, they did not consider individual students in their planning for instruction. They seemed more concerned with the plural rather than with the singular. Their methods were "scattered on a shot gun" as Mr. Stewart once described, and indeed, insisted on saying that he would not try to know which student would learn by which method best. My first

hypothesis about that was that both teachers did not have significant knowledge about individual students. Later, however, I made an observation which refuted that conclusion.

> "During today's session in which students were engaged in solving bonus problems on conservation of momentum, Mr. Stewart kept circulating around in the classroom for about forty minutes. During this period of time he made over forty visits to various students' desks and answered at least the same number of students' questions. Most of those short trips were made upon students' requests. I followed him in almost each trip he made, listened to the students' questions and to his answers. What I observed was interesting, for the same student question, Mr. Stewart gave different responses to different students. For some students he would instruct them to the very operations needed to find out the answer. He would even solve the problem for them. For others he would give a hint, or two, as to how to go about the problem. For a third group he would simply discuss it very briefly by raising a question or elucidating a point, and then would leave the student to work on his own. In all cases the teacher's responses were quick, short, and very specific." [Fieldnotes: 12/3/86]

After the class ended, I explained to him my observation. His response indicated his knowledge of individual students. "For some I needed to give the answer straightforward; for others, I held it and asked them to think again, gave them some hints to how they would solve it." In the midst of all that interaction and moving around Mr. Stewart was even aware of students who did not ask any questions at all.

So after all, the teacher did know about individual students. That knowledge seemed to inform the way in which

he interacted with them. In fact only a very knowledgeable teacher, of both the subtleties of the subject matter and the individual students, could do what Mr. Stewart did in that session. However, the teacher concern did not seem to lead to effecive teaching or learning.

It is interesting to bring into discussion at this point the idea of "compensating" for the slow students which Mr. Stewart mentioned in the context of making physics inclusive. His implication was that, they compensated for the slow learner by making the subject matter less difficult. The quote above may also be seen along the same line of compensating for those who did not know the solution for problems. The teacher simply gave it to them. That helped him maintain the same pacing of instruction across the variations among individual learners. In other words, "compensating" for individual variations seemed to have helped the teacher achieve both of his major instructional objectives.

The Teachers' Conceptions of Students' Learning

Two points are worth mentioning here: the teachers' conceptions of how learning would take place, and their conceptions of the level of learning their students achieved in their courses. With the exception of one question only, about how learning occurs, there were no direct attempts on my part to elicit the teachers' responses toward these ideas. However, on various occasions the teachers did talk

about their students' learning.

Both teachers saw learning a complicated process that would occur over a long period of time. Both of them saw that exposing students to the material, together with some hands-on activities, were needed for students to learn. However, not all students would learn optimally through the same means, according to Mr. Stewart. While some may learn through more presentation of the materials to be taught, others may find lab experiments or mathematical formulations more helpful.

Both teachers emphasized the idea of making physics knowledge meaningful to their students. They talked about formulating their instructional examples in terms of students' experiential world, and making connections with students' prior knowledge.

Taking into accounts students' prior knowledge, and emphasizing the interactions of the learners' cognitive structures with new forms of knowledge may be considered as fundamental requirements for cognitive restructuring. Related research within the cognitive psychological perspective emphasize learning as dependent on prior conceptions that may facilitate or hinder the acquisition of new structures of knowledge (Anderson and Smith, 1986; Hashweh, 1985). In that sense, the teachers seemed to hold cognitive views on learning. Another piece of evidence that would confirm these cognitive views was the teachers' descriptions of individual differences among students. As

these differences were referred to previously, they tended to touch upon the students' cognition and thinking. Often teachers referred to variations in students' reasoning and thinking abilities.

However, on other occasions the teachers sounded differently, and seemed to hold non-cognitive or behavioral learning ideas. Mr. Stewart, for example, when asked about the signs he would consider indicators of learning, mentioned the following: test scores, but only to a very limited extent, expressions on students faces and their behaviors during instruction "what are they doing with their hands and pencils," the way they follow you as a teacher when you walk around form one side of the class to the other. These and other similar behaviors were thus considered, by the teacher, reliable clues that learning was taking place. Mr. Davis, still used different expressions. Sometimes he talked about concepts that did not "sink in," which meant that students did not learn.

How can we possibly interpret these seemingly conflicting conceptions? I think a key idea in such an interpretation would be connected with the nature of the subject matter they taught. The HPP course presented physics knowledge as a case of conceptual change and evolution. The dynamics involved in this historical process of conceptual change was depicted throughout in the course. The cognitive dimension in that process was, simply, central. Teachers' knowledge of the nature of such a

process might have contributed, unconsciously, to what I called cognitive views on learning. The other non-cognitive views might have come from their formal educational courses many years ago. They could have also developed as part of their practical knowledge of students and student learning.

I should repeat a point mentioned earlier about the teachers' knowledge of pedagogy. Both teaches were conversant in their subject matter. They used its technical language, knew much of its history, and a lot of biographical knowledge related to various scientists. They, to some extent, showed an interest in reading some pertinent recent materials. In contrast these teachers appeared unaware of what is going on in fields like psychology and sociology of learning. It is true that I did not probe much into their knowledge about learning, but then there were several occasions where they could have employed such a component of their knowledge, had it existed, in their articulation about teaching and learning. Even on the few occasions when I asked specifically about learning and teaching, I was left with the impression that they were unaware, or perhaps uninterested in what is going on in such fields. From all these fields, only the name of Piaget and his stages were invoked very briefly, once, and by one teacher, during all of my observations.

The teachers' lack of interest or knowledge of the theoretical underpinnings of learning squares with some of the remarks made earlier that teachers seemed to think of

learning as mainly a student responsiblity. Under such a circumstance teaching would hardly be informed or constrained by what learning theorists would have to say. One consequence of that would be that teachers would have more leeway and autonomy in dealing with the subject matter. They would, as it was the case in this study, easily modify their pace of instruction in order to achieve whatever objectives and intentions they had in mind.

But let us look at the second point I mentioned at the beginning of this section, namely, the teacher's conceptions of the level of learning their students achieved in those courses in order to see if the teachers' pertinent remarks may change or modify the interpretations and potential conclusions mentioned above. Examining students' grades would not tell us much about learning as such. What does it mean, in terms of learning, to find that the class was divided into three grade categories "A's", "B's", and "C's", with an almost equal number of students under each category? More meaningful, I believe, were the teachers' related remarks uttered occasionally in our discussions, for here, too, I did not ask directly about those conceptions.

I believe that both teachers had no illusions about what their students learned and what they did not learn. Very often Mr. Stewart talked about learning in unspecific terms like "seeing the structure of physics," "developing a feeling for what physics is," or "visualization of what we talked about." So did Mr. Davis, who occasionally explained

to me that though he was not sure how much of a particular concept or topic students did learn, their test results would show that they learned something anyway. At the end of an interview Mr. Davis expressed his doubts over his students' learning:

> "I don't know how much they would get out of this wide exposition. Much of what we taught is watered down." [4th Interview: 5/13/87]

Furthermore the teachers, particularly Mr. Stewart, talked often about people criticising him for doing what he did. In this respect, he asserted:

> "I've had my share of criticism of being too flexible, of trying too much to compromise my values. Accused of watering down the course and giving away grades, etcetera etcetera! [3rd Interview: 11/26/86]

His response was that those people did not understand the nature of the course and how it had originally been designed. Mr. Stewart also talked about two other groups of teachers and administrators who agreed with him. However, one group said that though they agreed with him, still they would not do it in their classes for a variety of reasons, while the other group indicated that they would not hesitate to do it, or they were indeed doing something similar to that.

But did the teachers know other alternatives of teaching physics? This point will be looked at again in the following last section of this chapter. As it turned out,

the answer was: "Yes."

What does this mean to the interpretations and conclusions I suggested earlier about the teachers' conceptions of learning, their knowledge of learning theories, and their classroom practices? One possible meaning or implication would be that both teachers had really known about learning and its theories, but for various reasons chose not to abide by the recommendations and implications of such a body of knowledge. Simply said, they might have found it impractical; and with time, lost interest in it and developed instead their own methods that would meet "their and their students' biases", as Mr. Stewart repeatedly said.

Saying so does not mean that the teachers might have known much about learning. It only suggests that what they had known in the past was not maintained in their immediate awareness and concern. It might have subsided far away from the focus of their attention, and thus stopped growing and became much less effectual on, or relevant to, the teachers' practices. This in itself should be a source of worry for educationists, for it would have serious implications on what is going on in classrooms under similar circumstances.

History of Physics Teaching: A Narrative of Struggle for Survival

Occasionally, the concept of survival popped to the surface of the teachers' thinking. It first appeared as the

teachers explained how they were attempting to maintain high enrollments in their courses. It appeared again as they talked about their lesson types. As I pointed out before, this issue appeared to be a primary teacher concern of an overarching nature. Bringing the issue under focus, would, however, require going beyond the present in the life of the setting under study. Its past, as will be seen, was of great influence in shaping the present. In what follows I will narrate the relevant parts of that past as I heard them from both teachers. I will try, as much as possible, to preserve their key words and expressions. Embedded in this narrative, as will be seen, were the concepts of struggle and survival in more than one sense.

Mr. Stewart started teaching physics at the school in 1958 when there was a growing concern over American education in general and science education in particular. So, in a sense, he started teaching physics at a "starting date" for science education. He started using what he described as a "very traditional physics course": "Modern Physics", authored by Dull, C. et. al., and published by Holt, Reinhart and Winston. The book, as described by Mr. Stewart, had "very traditional, straightforward approach to physics." It, however, had a "strong section on electronics and another strong section on electrical circuits." Since Mr. Stewart's background was strong in these subjects, he explained, for he had spent some years as an electrical engineering student, he liked the course a lot. "It gave me

a chance to show up my knowledge," he asserted.

Coincident with the beginning of his career there was the "Sputnik business," which reflected a great concern over science education. Then, the PSSC materials started to come out largely of the MIT along with the NSF sponsored summer institutes for physics teachers. Mr. Stewart participated in those activities. In 1960 he attended an institute for the PSSC in the University of Washington in Seattle. Describing his first attitude and responses toward the PSSC Mr. Stewart stated:

> "And I was quite taken with the PSSC course. It stripped away a lot of the material that was in the Dull, Metcalfe and Williams', extraneous materials that was not pure physics. And the original philosophy of the PSSC was to almost an inquiry approach to learning physics, where you went to the laboratory, asked a question, and then you came back, read and discussed and solved problems; somehow assimilated the ideas that you discovered in the laboratory. This was intriguing." [1st Interview: 9/23/86]

Mr. Stewart started using the PSSC right after that institute, in addition to the other traditional course. Although enrollment increased in the PSSC course, that, according to Mr. Stewart, did not mean that the course was successful. The students' conceptions about that course in comparison to the traditional one, was his explanation for that increase in enrollment.

> "It became not so much a success in the course itself. But since we were teaching physics on two different levels in the school, a PSSC course, the new course, versus the old course, it became a scheme among the student peer to get into what

> they thought the elevated course, the advanced course, the premium course, the PSSC!" [1st Interview: 9/23/86]

By the second year, Mr. Stewart started to conceive of the PSSC course as a "very restrictive, monolithic method" of teaching physics. He explained how the textbook sequencing of topics was so structured that if a certain idea or experiment was missed or not understood, then understanding of much of what would follow would become too difficult. "The PSSC was a structure you have to buy the whole thing or it did not really make much sense at all," he asserted.

Another problem which Mr. Stewart perceived with the PSSC was what he called "elitism."

> "The PSSC was a little elitist, frankly, in the difficulty of the problems it presented and the assumption that students would be able to make the jump in inference from what they saw in the laboratory to physics ideas generally." [1st Interview: 9/23/86]

By 1964 it was clear to Mr. Stewart that the PSSC sections were not going well. He explained how students had "great dissatisfaction" with the course. So, eventually, he started to bypass some chapters where students found major learning difficulties. In particular, he referred to a chapter that explained how some forces that are on our human scale, surface tension for example, do not mean much; but, on a microscopic scale, they do. These concepts were "foreign" to students. The struggle with the PSSC course

went on in the midst of growing dissatisfaction with the course on the part of students.

Mr. Stewart then recalled that about 1966-67 he read an article that talked about the development of a new physics course that would "better address the needs of contemporary students" than the PSSC was. He, through the school science director, communicated with Jim Rutherford at Harvard who was in charge of that process, and expressed his willingness to participate as a trial site for that course, which became known as the Harvard Project Physics.

Mr. Stewart explained how enrollment started to "clumber" because of the difficulties with the PSSC course. So the HPP looked like the course that might bring "life back" into the physics enrollment. He remembered how enrollment jumped from less than sixty students in 1966, to over three hundred students in 1970, three years after they started using the new course. During those years he spent around a year working with Jim Rutherford as a teacher consultant for the course.

The HPP course was finally adopted and since then it has been in use in the school. The teachers' views about the course were dealt with in the previous chapter. As was explained in that chapter Mr. Stewart saw the book as an "impedence match" among a variety of things that included teachers' as well as students' biases.

Mr. Davis joined in with Mr. Stewart to teach physics in the early seventies, after the HPP course was established

at the school. Physics was the only course that the two teachers had to teach, since the curriculum had not yet included the advanced physics and the physical science courses. During those years enrollment was watched quite carefully. A few times, Mr. Davis had to teach biology and chemistry. As was explained previously, he saw himself as "travelling salesman" during that period of time. This became a real threat, at least for Mr. Davis when enrollment went down again after mid-seventies.

The following years seemed difficult and threatening for both teachers, and certainly more for Mr. Davis than for Mr. Stewart for seniority reasons. Mr. Davis described that point in time in their history:

> "We were to the point where we, both of us, had three physics sections. Then the principal suggested we do math tutoring. We had a math tutoring room here. We had also a course that we called "Living in a Man-Made World." We had environmental study. We, (laughing) tried everything just to stay afloat." [1st Interview: 9/23/86]

Mr. Stewart, too, recalled with bitterness that turning point in their history:

> "Our enrollment went down and down. When we got to sixty, the principal came to me and said: we can't give you physics classes for these hours in the day. So these hours in the day, you're going to be teaching remedial math, or something. I realized that my career, my future, was going down the drain with this direction. And I had to do something surprisingly, astoundingly different!" [4th Interview: 5/13/87]

A lot of other consequential decisions were, therefore, also made. Mr. Davis described how they "very seriously" concerned themselves with their evaluation and grading system. Their decision was to set objectives that were not "as high in terms of the level of hierarchy of the objectives that may be set aside in some physics programs". This decision left the teachers, according to Mr. Davis, "with some room for the majority of students to do well in the course." To satisfy as many students as possible they even experimented on testing. Let me leave the description of what they did on that for Mr. Davis:

> "We tried two tests. We would give one side of a test that was rote memory, or direct sort of multiple choice, true false, this type; and the other side of the test was problem solving, or whatever. And we had the students, then, make the choice of whether they would work on one side or the other side of the exam. Then we tried to encourage them, then if they are going to college, they would be majoring in science or some area then they would choose the side that had problem solving. That would be more in line with the traditional format of physics. We ended up making two tests and the students could do one side, do the other side, combinations of them. And then we would take these scores. Oh, gosh! We had a curve. We developed a mathematical curve that, for the number of tries that they had and we go up and read across the corresponding score on the particular thing. IT WAS A DISASTER! [Laugh] But we did try to account for different levels. But it took too much time!" [1st Interview: 9/23/86]

To "stay afloat", Mr. Davis explained that they also had to make important decisions about the contents, what to include and what to exclude, and how to be very specific about their choices.

But the struggle with the subject matter of physics to overcome the inherent difficulty in physics teaching and learning, is a reality which physics teachers and students know very well. This struggle would become only more exhausting for the teacher's nerve and energies when it is perceived as a threat to his school academic status as a physics teacher. Both teachers clearly had their share of this struggle. Let me just add one more example on such a struggle which the teachers had lived. As I emphasized in the previous chapter, the teachers avoided abstract concepts and ideas that were central in physics knowledge. I gave several examples on that, among them was instantaneous velocity. I asked Mr. Davis if they, in the past, had tried to explain this concept. His response was as follows:

> "I think we tried it. It didn't come out well, I suppose. What we had done in the past is to take the distance-time graph for the motion of a uniformly accelerated object. We then ask students to choose points on the curve and find the instantaneous velocity at that point. Well, at that, we got ourselves trapped into taking slopes for many many points. And we found ourselves in just a mess of students' ability, inability! IT WAS A DISASTER. So we decided to stay away from it at least for a while, and to go with the case where, if we're looking at a speed situation that the average speed could be pretty much the same, at least in a simple graph like that." [1st Interview: 9/23/86]

Eventually, then, the teachers dealt with the special case where the average speed would equal the instantaneous speed, and thus avoided the "disastrous" situation. If this is "disastrous" under normal teaching conditions, one

wonders how it would be perceived by teachers struggling to protect their job that is endangered by such difficulties. Quotes from both teachers' discourse that reflected past struggle with physics teaching and learning were many. I would like to end this point with the following one by Mr. Stewart.

> "...and I look back on those days when we were teaching PSSC and the kids were so frustrated in their inability to get some of the ideas to be able to express them mathematically to solve the problem. It just there wasn't any way for them to go in physics, except out!" [1st Interview: 9/23/86]

So his past decision "to do something surprisingly, astoundingly different", finally, gave him satisfaction in his work.

But when Mr. Stewart talked about struggle and survival he went much beyond the immediate elements in the setting like the subject matter, students, and administrators. He included the milieu at large, where other societal and cultural elements seemed to contribute to that struggle. Furthermore, the unexpected changes in those elements over time may work against teachers, who, therefore, should keep vigilant for any new societal trends that may touch their careers in one way or another. Mr. Stewart described all that in his answer for what he meant by survival. From that lengthy answer I chose the following excerpts:

> "I talk of survival in the sense of, of, of getting through the school with your head intact, with your pride intact, and surviving on a longer

period of time just as a teacher. Let me give you some examples of what I was referring to. We've seen in this building teachers that have, literally, taught themselves out of the job! Okay, they start off with a job in the building, and by their actions or inactions, or by the decisions they make, relative to how the class progresses, and how they were meeting the needs of the kids, as the kids perceive it, they got themselves in situations, where fewer and fewer kids take the class. Pretty soon, they have a job, but no students. And then, they don't have a job. So in that sense, they taught themselves out of the job! And we've seen example after example in this building of viable programs killed by teachers that they didn't survive because they didn't make the necessary decisions and commitments. They didn't have the flexibility to change to the time.

The other survival I talk about has to do with the stresses and strains of being a public school teacher. There are monetary limits and controls. And there is politics that's going on...social pressures from outside. Surviving in that sense.

A school teacher takes, well, for the last six years....has taken an emotional bashing in the newspapers, in magazines, and in the media; from people who try to tell us that we're doing all the wrong things. And they cite all the evidence that school are going all the way down the tube to rack and ruin. And so survival has also the connotation that you have to live through that all, and still somehow have your confidence intact....

Because things continue to change, and I think, as a teacher, you better have your finger on the pulse of what's happening in terms of what the students want, and what the taxpayers want, and society in general wants and needs. And I think you have to somehow address that....

I think the surviving teacher is the one who responds to that, and if possible, can glean something and turn that to his advantage!" [3rd Interview: 11/26/86]

CHAPTER VII

SOME CONCLUDING IDEAS AND DISCUSSIONS

It has become a tradition in research reporting to end up the process with a concluding chapter in which the author summarizes his/her work, and advances some concluding remarks, suggestions, and recommendations for either the dissemination and utilization of the findings or the doing of future related research. In this work, I have found this task to be particularly difficult, and may be unfair to the actual setting which has been depicted in this thesis.

The source of difficulty is at least three-fold. First, the portrayal I have presented is, at best, a proximal fit of the subject-matter narratives of the two teachers. I have, for example, used only a fraction of the information embedded in my data which I judged to be related to the subject matter. Those data, in turn, were only part of what actually went on in the classroom. To present another reduced version of the already reduced one may render such a presentation of little relevance to the setting. Second, the study has been mostly an exploratory one. Its main course has been characterized by labyrinths and sideroutes that appeared potentially significant, but for practical reasons were not explored fully. Third, in a sense, this study has been a case study of the subject matter knowledge and treatment held by the only two physics teachers working at a high school. Consequently, no

generalizations beyond what was studied were sought. In that sense, it is improper to talk about generalizable issues, which are usually documented in different types of research, and are targeted by many research readers. Furthermore, an ideally successful interpretive research would present us with an intelligible and articulated depiction of the setting studied. In that sense, the meaning of the word "findings" does not necessarily connote the revelation of something that had not been expected or known before. For that reason, at least some of the "findings" in this research may be left for further "reading into", or "interpretation" by the reader of this dissertation. A reader interested in policy issues may interpret this work in ways that do not need to be congruent with the conclusions of curricularist or philosopher of sciences. Notwithstanding all these restrictions and difficulties, I will proceed to recapitulate the main highlights of this work. I will also discuss what I saw as implications, and limitations and opportunities this work has presented. Other readers are also entitled to draw their own conclusions and suggestions.

Recapitulating Some Highlights of the Study

This work started with a proposal to study one physics teacher's personal practical knowledge of physics. For both theoretical and practical reasons, I decided to look at two main issues: knowledge of the subject matter held by the

two physics teachers working at the same school, and their treatment of that subject matter. Discussion of these issues was included in Chapter I.

Chapter 2 dealt with the theoretical framework of this research. The few studies that touched upon the subject matter were reviewed. They were done, mostly, from a cognitive psychological approach, and with a focus on teacher effectiveness. Research on teacher thinking was, then, reviewed as a wider framework for this study.

I started Chapter 3 with a description of the context within which the research was done. The teachers were introduced with some biographical information about each teacher's background, education, and professional experience. That was followed by a description of how the research was done, together with an allusion to some pertinent theoretical underpinnings. In this description, I presented the techniques of data collection: participant observation, and interviewing. Both techniques were described with some details. Data analysis was also explained. The processes involved in selecting codes or repeated categories, organization of those codes, and the reduction of that list of codes into a smaller one, were explained.

The dilemma of how to look at the physics knowledge, the commonplace, was discussed in this chapter. It was decided to simply define it as it was originally defined in related physics textbooks. Looking for the teachers'

knowledge of the subject matter required looking for those explicit physics constructs and meanings, as well as any implicit or subjective related aspects of that knowledge.

In chapter 4, I attempted to answer the first research question about the teachers' knowledge and conceptions of physics. However, before going directly into that, I introduced the two textbooks the teachers used, Introductory Physical Science, and Project Physics, with a summary of their contents. Both teachers' related views on the textbooks were presented. Among the highlights of those views were three issues that need to be restated here. First, it was clear how Mr. Stewart devoted much time for dealing with some of the HPP contents which he, himself, criticized as being over-treated by the book. The interpretation given for this observation, focused on Mr. Stewart's background. It seemed that he allocated more time for the unit on astronomy, a topic he extensively had dealt with at college, in spite of his recognition that the unit should not really be given so much effort. A second issue was my analysis of Mr. Stewart's comparison between the HPP and the PSSC courses. At the end of that analysis, I concluded that, in spite of Mr. Stewart's frequent criticism of the PSSC, he did not seem willing to abandon it completely. A third issue was the strong and positive attitude which Mr. Stewart had toward the HPP course. On several occasions he described it as "impedence match" among many factors influencing the context of physics teaching at the school.

Two levels of description of the teachers' knowledge of physics were presented: a macro-level, and a micro-level. The macro-level description was intended to cover the teachers' knowledge over all the taught contents. Four major clusters of knowledge structures were conceptualized in this general description. They included knowledge of vocabulary terms of physics, knowledge of higher-order relations, mathematical knowledge, and philosophical and historical knowledge. Teachers organized their knowledge in large chunks which consisted of various elements from those major knowledge categories. Very often Mr. Stewart talked about his knowledge in terms of "interlocks" which were internally consistent and externally coherent with other "interlocks" in the total picture of physics knowledge. History of physics ideas was also utilized by both teachers in sequencing and organizing their knowledge structures.

The micro-level description of the teachers' knowledge focused on one topic, namely, conservation of mass and momentum. In this analysis it was shown how the micro-level description agreed in its presentation with the macro-level conceptualization.

In my attempts to probe into the implicit dimension of the teachers' knowledge of physics, the philosophical component of that knowledge appeared potentially revealing. It was found that both teachers acquired philosophical knowledge structures that could be ascribed to the two incongruent views on the nature of our scientific knowledge,

namely, the traditional view, and the more recent one (sometimes called the relativist view). Further analyses, however, showed that both teachers' views converged in their conception of physics knowledge as a highly objectified, or reified, form of knowledge. In order to trace the origin of the teachers' dual conceptions, some analyses of the textbook's pertinent ideas was done. It was explained how the textbook, directly and otherwise, possibly influenced the genesis of those conflicting ideas. Eventually, however, it was suggested that in spite of so many years of experience with the HPP course that presented physics as a human enterprise whose knowledge constructs were influenced by social and cultural issues, the two teachers seemed to have preserved, from their college years, their learning of the objective nature of their physics knowledge.

Chapter 5 attempted to answer the second research question: how the subject matter was treated in classroom by both teachers. The chapter can be conceptualized as including four major blocks or components: teachers' planning for their lessons, teachers' instruction, teachers' decisions about the treatment of the subject matter, and their characterization of some aspects of that treatment, and finally, what the teachers had achieved through the whole course of their treatment of the subject matter. Each of these components was a story in itself with its separate implications. However, they all seemed to cohere with each other to give a meaningful whole. This should have become

clear as I approached the end of that chapter.

The sections on planning described how the teachers planned for their daily lessons in both courses. Formats used for that were described. It was stated that the teachers had had a prior mental picture of what to cover during the school semester.

After giving a general view on planning, some focusing was done on how the teachers planned for a specific topic: "conservation of mass and momentum." Knowledge organization and contents of each of the seven lesson plans prepared for that topic were discussed. Knowledge deleted from their plans was discussed. It was found that the deleted knowledge included, among other things, the historical contextual knowledge in which the concept of momentum was developed, as well as some theoretical aspects of the concept. Planning for this concept was found to agree, in various ways, with the general description of planning. However, the teachers' deletion of the historical development of the concept stood in contrast with their emphasis on this historical dimension in concepts dealing with astronomy. The interpretation given for this sharp contrast revolved around the teachers' formal college learning where the developmental histories of many physical concepts would not come into the discussion, unlike the fundamental concepts in astronomy whose history of evolution would usually be included in college textbooks.

Classroom instruction was then described and analyzed.

It was clear that both teachers appeared determined to follow their lesson plans no matter what! Several instructional episodes from both courses were cited in order to show how both teachers adhered to their lesson plans even when there was strong evidence that some students were having serious learning problems. What both teachers said they would do, however, was to talk to students about those problems in order to pay more attention to such topics when they would be discussed again in future lessons or courses. They also talked of revising their lesson plans for the coming years in order to avoid such problems. The hierarchical nature of physics knowledge and its possible relation to the teachers' instructional policy not to deviate from their plans, was highlighted. The modest amount of student interaction in classroom discussions was another related factor in that picture.

Lesson plans defined most of the content of instruction, and part of its form. Various lesson types, as forms of instruction were documented. They included: recitation-discussion, lecture, hands-on activity, problem solving, demonstrations, and others. As for the factors influencing the choice of a lesson type, the teachers mentioned five of them: the nature of the subject matter, time, availability of equipment, class size, and the teachers' past experiences. In my attempts to explicate the nature of the last factor, a variety of important issues appeared. First, Mr. Stewart conceived of his methods as

the "best" ones that could work in that setting. I termed this conception a pitfall of experience. Second, there seemed to be a tension in both teachers' thinking about their ideals of what they conceived of as physics and physics teaching, and the realities they faced as physics teachers. Third, this tension shifted the focus of the interpretation of the diversification of lesson types to other contextual factors in the setting: teacher survival, student learning, and enrollment.

The issue of teacher survival was amplified a bit in order to see some of its subtle meanings and connections with the subject matter. In doing so an important issue was revealed. This issue had to do with a description of the changes in one teacher's physics knowledge that occurred over the years. It was suggested that physics teachers would start their careers with unintegrated or differentiated knowledge structures of the subject matter. These knowledge structures were described as permeated by conceptual fuzziness and uncertainties that would sustain and interplay between the known and the unknown in the teachers' thinking. That state of knowledge was described as entropic. An entropic state of knowledge was assumed to be stimulating for teacher thinking and practices. Over time that state of knowledge would become more integrated over various physics or science topics. Many of the uncertainties would disappear and would be replaced by the emergence of a stable and inflexible layer of knowledge

structures of well understood and mastered concepts of the subject matter. This steady state of knowledge was described as less entropic than the previous state. The assumption that teachers, over the years, tend to limit their discussions, and thus mastery and understanding, to certain specific concepts of the subject matter was hypothesized to be related to what the state of polarization between the known and unknown in teacher thinking about the subject matter in this experiential state of knowledge. In such a state of knowledge, teaching the subject matter of physics may become boring for them. To evade, or minimize, such boredom these two teachers seemed to emphasize diversification of their teaching techniques.

As for student learning, the teachers believed that various students learn better through different experiences. Diversification of lesson types was, therefore, thought to meet student individual differences pertaining to learning. However, those individual differences were thought of and considered in collective terms. Both teachers did not attempt to find out which students would learn best through which methods. Their approach in using various lesson types to meet individual differences was described by Mr. Stewart as "scattered on a shotgun."

The third factor that seemed to have influenced the teachers' diversification of lesson types was enrollment. It was found that some lesson types were used by teachers to boost enrollment in physics classes.

After discussing the forms of the teachers' instruction, its contents were, then, focused upon. I should emphasize, however, that the distinction I make between form and content is very artificial. It is only used for organizational purposes. In the teachers' narratives, however, there was no intentional distinction between the two. For example, when Mr. Stewart characterized their ways of teaching physics as "engineering success," he was practically referring to a variety of decisions they made about what and how to teach, though the phrase first emerged as I discussed with the teachers their treatments of some specific topics or concepts. Later usages of the expression by Mr. Stewart were related mostly to decisions about the contents.

"Engineering success" was an important opening upon a variety of such decisions. It was clear how Mr. Stewart used this characterization of what they did to explain how and why he treated specific topics the way he did. Among the topics referred to were: the unit systems, graphical solutions and vector addition, projectile motion, Newton's second law of motion, and centripetal acceleration. Analysis of the last two topics showed how the teachers intentionally avoided some of the pertinent theoretical issues. It was argued that such a treatment was consequential on the structure of the subject matter they taught.

It was found that the teachers dealt with the

mathematical formulas and the lab activities pertaining to the same phenomenon as two separate ways of attempting to understand it. This was interpreted as a separation between theory and experiment. It was also suggested that the teachers dealt with the meaning of phenomena to which both theory and experiment would refer, as separate entities isolated from both theory and experiment. This was seen congruent with the finding cited in the previous chapter when it was concluded that the teachers conceived of physics knowledge as mostly objective. The conclusion made was that the teachers, in that respect, taught the way they knew.

The teachers' treatment of theory and experiment as two separate routes that would lead to the same destination, namely, the meaning or explanation of a certain phenomenon, seemed to have helped the teachers in their wide content coverage. In this respect, I talked of three types of treatment of the subject matter: math-biased treatment, theory-avoiding treatment, and the nil treatment.

Further analyses showed that a common factor in various ways of classroom treatment of physics was the teachers' flight from what was abstract and theoretical. More examples from classroom discussions were further explored. It was inferred that both teachers deliberately concretized and, somewhat, destructured the physics knowledge they were attempting to teach.

In the teachers' explanation of their intentions to concretize the taught physics knowledge, the idea of

contextualization of taught knowledge surfaced their thinking. It was suggested that although contextualization might have helped students relate what they learned in classroom to their prior knowledge and experiences, some discussed examples could have been counter-productive. The issue was probed further through the examination of a particular example on the definition of centripetal and centrifugal forces. It was shown how teaching and learning such definitions should make us careful about any suggestions regarding contextualization and its relation to learning. Much of our scientific knowledge would not, necessarily, relate in clear terms to our daily experiences or common knowledge and language.

While the teachers defined their objectives for each lesson through their lesson plans and worked to implement those daily plans, other long-term objectives appeared as the holistic perspective on what they were doing started to take shape. Two of these global objectives were laid out in the last part of this chapter. They included: wide content coverage, and high enrollment. Teachers' views on these major goals were depicted. Once again the tension between the teachers' ideals and their classroom realities appeared in their narratives. Clear in those narratives too was a life-long-term intention or objective. This one had to do with teacher socialization not only in the school setting, but in society at large. The teachers described that as "survival." Exploring this overarching intention required

going beyond the immediate context of the setting. It demanded going into its history. This is part of what I did in the next chapter.

In my portrayal of the ways the subject matter was treated in classroom, I alternated my perspective between the "wide-angle" (the general), and the "close-up" (the particular) views. I also used the teachers' own descriptions and characterizations of their own work whenever that proved possible. In other cases, when I expressed my own views, I made that explicit to the reader.

In chapter 6 additional issues, which were not planned for in the study, were discussed in order to present a comprehensive and coherent picture of the setting. They included various teachers' conceptions about: their roles, their students, and their students' learning. A final section on the history of physics teaching at the school was included.

The teachers' envisioned their roles as primarily related to students and the subject matter. When they talked about their roles and what they did at school they emphasized the component of their work that had to do with science. The pedagogical dimension was never spontaneously brought into the discussions by the teachers.

As for their conceptions of their students, both teachers talked about wide variations among their students in various aspects from academic differences, to social and cultural home differences. The teachers' conceptions of

their students seemed to have influenced the way the teachers taught physics. Teachers talked of compensating for the less able students in the class. However, in their classroom practices as well as in their description of their work, the overriding emphasis was on the group or class though there were some instances in which the teachers' interaction with students reflected their knowledge of individual students.

As for the teachers' conceptions of students' learning two points were raised: how learning would take place, and the students' achieved level of learning. Both teachers expressed both cognitive and non-cognitive views about learning. Possible sources of influence on the teachers' views were the textbook and their formal education. Both teachers described the students' learning level in general terms that reflected uncertainty about how much their students did really learn.

Finally, a summary of physics teaching at the school was narrated from the perspective of the two teachers. In this narrative both teachers talked about two dimensions in their struggle to teach physics. First, the struggle with the difficulties of teaching the subject matter, physics. This was highlighted by Mr. Stewart's narration of how he changed from one curriculum to another, and how he perceived the PSSC and the HPP curricula. The second dimension had to do with enrollment and its connection with job security. It was clear in the narrative of that history that there was

indeed a turning point when both teachers decided to do something "surprisingly, astoundingly different" from what they used to do, as was pointed out by Mr. Stewart. In their descriptions of those days when they made such a turn, both teachers sounded as if they had turned their backs to some of their ideals about physics teaching.

Embedded in the history of the setting was the genesis and development of the long-term instructional objectives of the two teachers. When brought together, these major objectives seemed to have alleviated the work pressures on the two teachers, and achieved some form of job security for them. They were also part of the life-long-term teachers' socialization at the levels of both the school and society at large; a process characterized by what Mr. Stewart described as "survival."

Further Reflections and Implications

Several implications could be drawn out of this study. I will discuss these implications under the following six major topics.

Personal Knowledge Revisited

It was pointed out in chapter one that for theoretical and practical reasons the word 'personal' was dropped out from the description of the teachers' knowledge sought in this work. This resulted in a wider research perspective on the teachers' conceptual knowledge. Very recently the term

'personal knowledge' has been discussed by a number of researchers (Clandinin and Connelly, 1987; Elbaz, 1987; Marland, 1987; Munby and Spafford, 1987). These recent discussions, however, made no reference to Polanyi's original work related to the concept which was cited as a basis for earlier works by various researchers. In the recent discussions, Clandinin and Connelly seemed to stretch the meaning of 'personal knowledge' to cover practically all terms that claim to conceptualize individual teachers' thoughts, such as 'teachers' conceptions,' 'teachers perspectives,' 'teachers' understandings,' 'teacher beliefs and principles,' and 'teacher practical knowledge'. Munby and Spafford, on the other hand, added another level to what would be considered personal in research. The personal dimensions in the researcher's own perspective on his research should be made clear in research. The researcher's experiential history, his knowledge and beliefs would be all relevant to the outcome of his research.

In this research, much of what was discussed on the findings would relate to this amorphous conceptualization of what 'personal knowledge' would include. The teachers' various conceptions of science, of their students, of their lesson types, etc.; their ways of treating the subject matter; and the various metaphors and statements they used to describe other aspect of their work, may all be labelled as 'personal.' The teachers' knowledge that would, perhaps, be exempted from the general conceptualization is the four

clusters of knowledge described in chapter 4. These clusters of knowledge were conceptualized from a scientific philosophical perspective. Within this perspective science conceptions and meanings were assumed to be originally predefined by the scientific community. Teachers were assumed to preserve those conceptions and meanings. To the degree the teachers did that, their knowledge could be exempted from being "personal".

Let us look at the other level of "personal" that Munby and Spafford suggested to see how it appeared in this research. In chapter 1, I included some pertinent autobiographical information that explained the changes in my perspective that eventually shaped this research. I explained how some of my personal experiential history played a role in giving direction to this research, how my understanding of the word 'personal,' as had originally been explicated by Polanyi and later used by some researchers made me drop the word. At this moment I tend to agree with Marland that this recent conceptualization of 'personal' is ambiguous. Elucidation and definition of the term are needed before drawing any pertinent conclusions.

Expertise and Professionalism in Teachers' Knowledge

In their analyses of teaching as a cognitive activity, researchers working within the cognitive psychological perspective (Leinhardt and Smith, 1985; Leinhardt and Greeno, 1986) found that expertise involved in teaching

could be seen as emerging from two core areas of knowledge: lesson structure, and subject matter. Expert or skilled teachers had complex knowledge structures, composed of interrelated sets of organization called schemata, in both core areas of knowledge. An underlying assumption in their analyses was that knowledge of lesson structure was supported and partially controlled by the knowledge structure of the subject matter.

As was explained in this dissertation both teachers did have a complex knowledge base and structure within both the subject matter and lesson structure. In a sense both teachers could be seen as expert teachers. Complexity in knowledge structures, however, may have different levels. What was clear in this study was a tendency on the part of the teachers to move away from this complexity toward simpler forms. Both teachers, for example, explained how they moved away from inquiry techniques as suggested by the structure of the subject matter to more straightforward presentation of knowledge. The societal factors that could have influenced the teachers' decisions to do that were discussed. Such factors had no place in the research cited above.

Schön (1983) suggested that professional action flows from clusters of thoughts, even from images or pictures. Both teachers exhibited various clusters of knowledge that seemed to have influenced their actions. This could be best seen in the various metaphores and images that appeared in

the teachers' discourse, such as 'impedence match,' 'scattered on a shotgun,' and 'engineering success.' In addition to that much of their knowledge was very technical.

Describing teachers' knowledge as an expert and professional knowledge contradicts previous arguments by Jackson (1968) and Lortie (1975) that teachers lacked professional knowledge. It also goes one step beyond other descriptions of that knowledge which emphasized the practical dimension only, like Elbaz's (1983) study. If the idea of professionalism in teacher knowledge is accepted, then searching for those clusters of thought becomes very essential in educational research. Furthermore, such clusters of thought should be incorporated in some way in programs designed for the preparation of future teachers.

Teacher Actions, Teacher Intentions, and the Milieu of Teaching

The moral philosopher MacIntyre (1983), argued that we cannot characterize behavior independently of intentions; and that we cannot characterize intentions independently of the settings which make those intentions intelligible both to the agents themselves and to others. A good part of this study can be perceived within the framework and implications of this argument. Let us see how we can do that and then look at some of the implications of such a conceptualization.

Throughout this dissertation I attempted to describe and interpret the meanings of various teacher actions,

knowledge structures, and conceptions as they were held by the teachers themselves. I attempted as much as I could to refrain from any judgement or characterization of those meanings. There were, however, some instances where I stepped out of such a role and made some related comments. Those were mainly occasions when some aspects of physics or science knowledge were discussed. On these occasions I discussed the teacher's related knowledge structures and views in relation to what is authorized by the scientific community as physics knowledge. A good example on that was the discussion on how both teachers concretized and destructurized the content of what they taught.

As I answered many 'how' questions regarding the treatment of the subject matter, the 'why' questions surfaced as important. It became clear that in order to form an intelligible coherent picture of the teachers' actions, their unspoken motives, purposes, and intentions should be understood. Why did, for example, both teachers tend to literally follow their lesson plans even when some students appeared to experience serious learning problems? The answer to this and many other similar questions made intelligible connections between actions and intentions. We found out, for example, that both teachers were keen to have a wide content coverage and high enrollment. Probing further into the teachers' intentions, we found that both teachers appeared to have a life-long-term intention. Both teachers appeared to be concerned about their survival as

physics teachers; a finding that appeared in other similar studies (Stake and Easley, 1978; and Aikenhead, 1984).

Making sense out of a depiction of teachers' actions and intentions and from the teachers' perspective was not always direct or clear. Interestingly, the investigation of occasional paradoxes or implausibilities in the teachers' assertions often led to the discovery of more fundamental purposes or intentions, and sometimes tension, in the teachers' thinking. That was how the objectives of high enrollment and survival, and the conflict between the teachers' ideals and workplace realities, were arrived at.

To put actions and intentions in an intelligible picture for all people concerned, the setting was described. The experiential history of the teachers was extremely helpful in understanding the development or genesis of the teachers' intentions.

Other implications can be drawn out of the study from this holistic conceptualization. First, factors influencing the teachers' treatment of the subject matter seemed to have their roots outside the classroom and even the school organization. We saw, for example, how such treatment was tied up to the decline in student enrollment in science classes and with what Mr. Stewart described as the 'stresses and strains' of being a public high school teacher. There would be several unfavorable consequences for that not the least of which would be the tenuous connection rendered between teacher knowledge of the subject matter and his

treatment of its content. As was seen in this dissertation both teachers were very knowledgeable on the subject matter, yet they evaded many important aspects of the content. They both knew a lot about individual students; yet that knowledge was not employed by any significant manner for any serious educational diagnosis of individual students. The teachers seemed to 'cope' with those 'stresses' and strains by lowering the cognitive demands of their work and thus making the acquisition of some form of content knowledge easier (Gallagher, 1986; Tobin and Gallagher, 1987; Sedlack et al., 1986).

Second, contradictions between the teachers' workplace realities and their professional or personal beliefs is a pervasive theme in the research literature on teaching (Dreeben, 1973; Berlak and Berlak, 1981; Feimen-Nemser, 1984; Woods, 1984). When faced with these contradictions, teachers seem to redefine their situation in a way that would eventually sacrifice or compromise the treatment of the academic knowledge (Spencer-Hall, 1982, cited in Lanier 1984; Feimen-Nemser, 1984). The actions of the two teachers seemed to confirm these findings. These implications would have serious repercussions not only on student learning but equally well on teacher intellectual and professional development.

But what were these workplace realities that had forced the teachers to compromise some of their ideals? Both teachers gave fragments of the answer for this question.

They talked about work constraints at various levels: the classroom, the school, the school district, and society. They talked of low student standards, lack of equipment, little encouragement from both the school administration and school district. They also talked about a decline in the social status of teachers of their low salaries, and concerns about job security. They talked of politics going on, of "emotional bashing" they were subjected to through various media. Practically all of what they talked about has been described in recent literature on the work environment of teachers (Lortie, 1975; Sarason, 1982; Goodlad, 1984; Duke, 1984; Sykes et al., 1985; Sedlak et al., 1986). The nature of physics knowledge and the difficulties of its teaching and learning, together with the status of the physics course as elective, were extra 'bonuses' for the teachers of physics.

The implications of all that should be clear. Serious changes and improvements in the workplace of teachers, and in the teaching profession as a whole, are needed. Various suggestions for such changes have already been advanced (The National Commission on Excellence in Education, 1983; The National Science Board Commission, 1983; The Holmes Group, 1986). To what extent we shall see improvements in the educational system as a whole will be left to history, or, rather, to the men and women who make it. However, there is an implication here for those reform movements that emphasize the academics and pay less attention to other

workplace and societal factors that may influence the teachers' beliefs, conceptions, purposes, interests, and actions. Though it is self-evident to state that without knowledge of the subject matter we cannot expect any teaching of it to take place, the connection between teacher knowledge and his classroom actions should not at all be perceived as simple or direct. This study has shown us how such knowledge was sieved and filtered through a mesh of teachers' beliefs, purposes, and interests that evolved in the setting over a period of time, before some forms of that knowledge finally reached the students. At one point it was argued that the teachers deliberately relaxed the structure of that knowledge or even destructured it.

There is, I believe, at least one implication for policy makers at the local level of this study. The physics courses observed were elective ones. As was explained by the teachers there was a competition among electives to recruit students. Academic rigor, a traditional feature of physics teaching and learning, was not perceived to work in favor of these courses in such a competition. Quite the opposite seemed to be the case. Tougher science graduation requirements in the school district may change the teachers' as well as the students' conceptions of such courses, and consequently the level of sophistication at which physics topics are dealt with in classroom. It should be pointed out that the school district has just adopted a one-year science requirement for graduation. How much would the new

policy change the setting is left for further assessment.

Having said so, I believe that it is very important to examine teachers' beliefs and interests in order to decide what could be justifiable and what could not. This raises the question of criteria for such a justification. And this in turn goes down to the very foundations of the educational, political, and social systems within which we operate. Whatever the basis of such criteria may be, teachers have got to be perceived as responsible for their work. Furthermore, it should be clear that teachers can play the game of life just as intelligently and cunningly as anybody else. Any ambiguities or laxities in the system could very well be redefined by teachers, when they have to, in such a way that they would turn them to their personal interests. Sedlak et al. (1986) explained how in the midst of the prevailing work environment teachers take advantage of whatever autonomy exists to shape their conditions of work and to integrate their work to the rest of their lives. In this research Mr. Stewart asserted that a teacher, in his response to various elements in his work environment, should try to "glean something and turn that to his advantage."

One crucial implication out of this is that teachers need the type of education that would allow them to reflect upon their own beliefs, purposes and interests in order to see what among these goals and interests could be justified. This should be viewed as a call to promote the image of a teacher as a responsible intellectual rather than a

technician equipped with some skills.

Teacher Education

For teacher educationists, this study should have several implications. First, as should have been clear in this thesis much of what the physics teachers knew and talked about in classroom dealt with technical knowledge mediated through some form of pedagogical context. The education of such teachers, as I see it, should, therefore, be a shared responsibility between the college of education and the specific science department. Without such a shared responsibility and cooperation, high school physics teachers' knowledge and practices may be skewed one way or the other. Furthermore, such a cooperative policy would redress the imbalance not only in teachers' knowledge and actions, but equally so the imbalance in educational research in high school in general and its component dealing with the subject matter in particular. As was pointed out in chapter 2, research related to high school in general, and the subject matter in particular was very modest. Though there would be several explanations for that, a plausible one appears in the fact that researching the subject matter requires a knowledgeable researcher of both pedagogy and the technical knowledge of the specific subject matter. Very often this is not achieved in one person. Research teams that would include researchers with backgrounds in science and education may, thus, be more effective than individual researchers or monolithic teams in

dealing with high school research on the subject matter.

Second, in the case of these two physics teachers, it was clear that their formal college education sustained its influence on various levels of the teachers' knowledge and actions Their choices of topics for classroom discussions seemed to be heavily influenced by what they had learned in science departments. Their views and conceptions of the nature of physics knowledge seemed, also, to be very much influenced by their formal learning. Their ways of treating the subject matter appeared, in some instances, to be connected with their college learning background; however, more plausible connections appeared with the teachers' past experiences and other contextual factors.

The lingering influence of college years on the teachers' knowledge and practices may also be seen as a sign of lack of influence of effective in-service professional training programs for such teachers and even their teaching experience or their knowledge base. If we add to this interpretation the hypothesis I advanced earlier about the polarization of teacher knowledge through the long years of experience and its possible implications on the teachers' practices, in-service training programs that require, among other things, serious studies in the subject matter become of primary significance in teacher professional development. Such studies, I hypothesize, would restructure the teachers' knowledge of the subject matter described as polarized. That could be assumed to happen through some reflection, on

the part of the teachers, on what they study in such programs, and what they teach at school. Such studies would also stimulate the teachers' imagination about the unknown and create some connections with the already known and mastered. A state of entanglement of the known and unknown in the teachers' state of knowledge would be regained. The new entropic state of knowledge the teachers would regain, would be more stimulating for the teachers' intellect.

Among the non-traditional components of what physics teachers may have to study for their career development is philosophy of science. The nature of our scientific knowledge, the historical contextual development of such knowledge, and the relationship between evidence, the scientific authority, and our scientific knowledge, are some examples of what physics teachers may need to study in order to boost their intellectual and professional development.

On several occasions in this thesis it was explained how physics teaching was characterized by modest interaction on the part of students in the classroom. As I stated before, the teachers seemed to see their responsibilities confined mostly to their presentation of the subject matter to the class. Student learning seemed to be virtually eschewed by the teachers as part of student responsibility. Perhaps high school teachers need to be reminded that "teach" is, in a sense, a doubly transitive verb, and that "teaching" is not only presentation or demonstration of knowledge, but equally well, an "enlearning" process, among

other things. Moreover, during their education, teachers need to be provided with the fundamental knowledge skills that will prepare them to "teach in the broader sense of the term.

Curriculum Construction

Curricularists would also find some important implications in this study. The teachers' enthusiasm for the HPP course was clear, especially in the case of Mr. Stewart. However, that enthusiasm did not prevent the teachers from transforming that curriculum into an enacted one that differed form the literal curriculum in many important ways. This process of transformation was mediated through the teachers' knowledge of the subject matter as well as their beliefs and interests. A lot of contents were deleted, others were dealt with in different ways from what had been suggested. The implications of that for curriculum designers should be clear. Teachers should not be expected to be mere instruments in the process of curriculum implementation. Their knowledge, beliefs, and interests should be considered, and very seriously in such a process (Olson, 1981; Munby 1982; Elbaz, 1983). This lends support to those curriculum innovators who view teachers as co-researchers in the curriculum development process (Connelly, 1972; Reid, 1979).

Their enthusiasm for the course, then, did not mean adherence to its contents or suggestions. Part of that

enthusiasm was attributed to their past experiences with other courses particularly the PSSC. But there was another factor that, I believe, influenced their enthusiasm. As was explained before, the school had been chosen as a testing site for that curriculum, and Mr. Stewart participated in the development of its materials. It seemed that this sense of contribution or belonging had influenced the teachers' views about the course. This in itself should be of another significant implication to curriculum designers. Participation of teachers in a curriculum innovation or development in ways that reflect their contributions and give them some credit for that, may give a much better chance of success for such a project. This confirms previous findings by Lantz (1987), and Cullan (1982, cited in Lantz 1987). Both researchers found that a sense of 'ownership' or 'personal contact' with the curriculum materials is a strong determinant of teacher acceptance of curriculum innovations.

Teacher Epistemology

The origins, nature, and methods of teachers' knowing are important issues to investigate. This study has offered some hints in that respect. As for the origins of their knowing, four important factors seemed to have shaped much of their knowledge: their formal education, curriculum materials, their experiential history, and the milieu. These origins, however, do not explain or predict teachers'

knowledge in a direct straightforward manner. Each teacher would interact, in his own way, with each of these origins and construct his own conceptions and knowledge.

The fact that individual teachers act on the origins and sources of their knowledge would influence the nature of such knowledge. We should not expect such knowledge to be in objective well reasoned forms. Very often, for example, Mr. Stewart referred to their personal 'biases' in interfering in what they deemed proper or right classroom practices. That is why we should always expect uncertainties, tensions, and contradictions in what the teacher assert and practice. Both teachers in this study showed that more than once. Often they were aware of it.

Another important element in the teachers' knowledge was tacitness. Much of what the teachers knew about their practice was kept in tacit forms. Occasionally, they described their work in terms of metaphores and expressions which carried images and meanings beyond what they could articulate or describe in words. They described their physics course as an 'impedence match' and their method of physics instruction as 'a distillation' of various methods. But when they attempted to explain what they meant by that only few explanatory examples and brief descriptions were given. The images implied in these expressions, however, were powerful and convincing for them. The teachers, therefore, appeared to know much more than they could articulate, another characteristic of professional thinking

(Schön, 1983).

As for the component of their knowledge that dealt with the subject matter, both teachers appeared to hold it in forms that would confirm is presentation and construction in specialized textbooks. There was no dispute or questioning over the authority of this component of their knowledge. Both teachers recognized that such authority is the final arbiter of any arguments or uncertainties in their knowledge of the subject matter.

Teachers did reflect continually on their work. They made decisions about their work based on these reflections. They talked about method they tried and then abandoned after they thought about their consequences. But very often teachers thought about what they were doing while they were doing it. Mr. Stewart often expressed that by asserting that he would 'keep a finger on the pulse of the class' in order to have a feel of how successful he was in his work, or how responsive the class was. He even talked about 'keeping a finger on the pulse of society' as a means of assessing his practice for any necessary future changes or modifications in his practice. The method of using these interactive forms of thinking (Clark and Peterson, 1984) has been called 'reflection-in-action' (Schon, 1983). This method of knowing appeared fundamental in teacher epistemology.

Though many of the ideas raised in this section were discussed, under different conceptualizations, in previous

research on teacher thinking, teacher epistemology as such seems to be a neglected topic or framework in educational research. I believe that a research project within this framework could be an important approach in our attempts to understand the genesis, development, nature, and practical consequences of teachers beliefs, purposes, and interests.

Limitations

There are two strong limitations that may be raised in the context of discussing this research work. The first limitation has to do with the teachers who participated in this study, while the second one is related to students' learning.

Very often the question of representation is raised in studies that involve a small number of research subjects in order to see how much generalizability the findings of the study may entail. As was pointed out in chapter 3, it was not within the intent of this research to arrive at such generalizations that would be claimed to apply to other situations. Instead, however, it was assumed that some of the findings and descriptions offered by the study could represent generalizations within the study, and these, in turn, may represent concrete instances or examples of some generic aspects operating across other teaching situations.

To elucidate this issue let me pick up an example from this study. It was explained how the two teachers, when faced with their classroom and school realities, compromised

some of their ideals about what and how to teach. This assertion is clearly stated in a general form. It was arrived at through specific instances within this particular setting. It should have, therefore, some general meaning within this setting only. The question is: can we generalize it to other settings?

As far as this study is concerned the answer should be: no definite answer is warranted. It is left for other similar settings. Only when such an assertion appears again in other similar studies can we talk about it, only with less uncertainty, as a generalization that may apply to physics teachers, or teachers in general. Of course the assumption on the part of educational researchers is that we should always expect such generic dimensions for, after all, we deal with teaching conditions that have much in common and with teachers who are all, and only, humans.

The second limitation has to do with student learning. This work has emphasized various aspects related to the teachers and his classroom actions. Student learning was not examined, though there were some related occasional remarks. For those seeking any characterization or evaluation of the final effects of these teachers' instructions, an assessment of students' learning seems pre-required. Furthermore, a comparison of such effects with others in other settings where teachers might be different, would also be informative.

Notes for Further Research

The study is, in a sense, a beginning which requires similar other studies before drawing comprehensive conclusions about pertinent issues. What I see unique and important in this study is the attempts it made to show, not only how the subject matter was presented in classroom, but also how that presentation, both in form and content, was tied to a variety of school and societal events, both past and present, through the teachers' beliefs, purposes and interests. We can extend this a bit further. It was argued before that the teachers' presentation and treatment of the subject matter would, in turn, influence what the teachers would eventually know or forget about. If this is granted, then those school and societal events and factors could be assumed to have influenced the very contents of the teachers' knowledge of physics. Similar research in different settings may be of significance in shedding more light on these issues.

More focused studies could also be contemplated. Instead of looking across various topics discussed, one topic may be selected for more detailed analyses.

The idea of tracing the influences of college, textbooks, experience, and the milieu on teacher knowledge of the subject matter, and the changes that occur to these influences over the years, would be a promising long-term research project. I suggest that such a research would be done on a number of teachers in a longitudinal manner, i.e.,

the same teachers studied at the end of every specific period of time, say five years, for example. This would allow us delineate the changes in teacher knowledge and practices as time and context change. That, in turn, would inform us much about a variety of issues related to knowledge and practice, not the least of which teacher epistemology.

More specific research questions may probe into the role of science textbooks in the teaching-learning process. A description of the teachers' and students' conceptions and usages of the textbook may inform us much about how to make it more effective in such a process.

A study of physics lab equipment and how it is used by science teachers may also be needed. It was pointed out in this study that high school physics teachers use a variety of pieces of lab equipment in their work. They have become the artifacts of the culture of high school physics teaching. A closer examination of these artifacts and their roles and importance in physics teaching is, I think, needed.

High school science teachers' knowledge of philosophy of science and its relation to their practices, is another potentially revealing research topic. This study has shown that there is a potential connection between the two teachers' conceptions of the nature of physics knowledge and their classroom presentation of that knowledge.

Appendix A

Planning for Conservation of Momentum and Two Other Lessons in the IPS Course

[This appendix includes the worksheets prepared by the teachers for the chapter on conservation of mass and momentum, and two lessons in the IPS course. The two lessons include experiments 3.10 and 4.3 in the IPS textbook. In reproducing the original dittos both form and contents were preserved. The original dittos for the conservation of momentum were handwritten while the other ones were typed. To preserve the writing from fading away with time, all of those duplicates were typed. At the top of each worksheet appears the date on which it was used in classroom.]

(Used on 11-24-86)

CHAPTER 9 OUTLINE

Name _____
Hour_____ Date_____ S.D.

SCHEDULE

Conservation Laws Problem Set #1	Study Questions from book	Momentum Lab Block	Thanks-giving break Whew!	Collisions & Conservation of Momentum Prob. Set #2	Maxi Demo's including the famous "Shoot the Kitty"	Odds & Ends Bonus	Chap 9 Quiz ---- Papers Due

OBJECTIVES

Terms to Know

Velocity
Speed
Momentum
Conserved
  Quantity
Closed System
Open System
Elastic Collision
Mathematical
  Notations including terms & definitions
Subscript and prime (') signs.

If Given Situations

$P = mv$

All quantities except one in a missing mass experiment

2 Body collisions in 1 dimension
  A) Elastic
  B) Inelastic

Be able to

1. Identify quantities that are conserved.
2. Solve Problems involving momentum.
3. Calculate the missing mass
4. Predict the outcome of the collision with a precise word description.
5. Write a proper equation for conservation of momentum.
6. Solve the equation for the unknown quantity, substitute and solve.
7. Match 'em up.

ASSIGNMENTS

1. Read all of Chapter 9.
2. Chap 9 Study Guide (Questions)
3. Conservation Laws
4. Problem Set #1
5. Momentum Lab Block
6. Conservation of Momentum
7. Prob Set #2
8. Maxi Demo's

THINKER

Can You Solve It?

Given Kinetic Energy (See Ch 10)
$E_K = \frac{1}{2} mv^2$

Two elastic spheres, one 3 times the mass of the other collide head-on while traveling equal (but opposite) speeds. The more massive ball stops dead in its tracks, while the lighter one rebounds with twice its original speed. Show that both P and E are conserved.

(Used on 11-24-86)

CONSERVATION LAW

Name_____
Hour___ Date___ S.D.

I. How do we define a conservation law?

II. Thinking about some systems that a change is taking place... Is there anything that doesn't change?

(A) Mass of ice & melted ice

(B) Mass of mixed solutions

(C) Mass of Cu & sulfur

Heat & Burn...Stink!

(D) Mass of Alka-Seltzer and water

What Did Change	What Didn't Change

III. Lavosier 1743-1794
The father of [ ]

*Statement of the Law.... In a [ ] system....

It has been checked to 1 part in a [ ]

Knowing this...Why is it that we use <u>mass</u> to measure the amount of matter & not volume?

When can we use volume to measure matter....

In the following list...Which are measured by "vol" & which by "mass"...

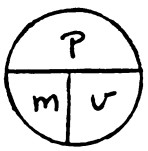
Mass	Vol	Other	
			1½lbs ground chuck
			1 med. size onion
			½ cup green pepper
			4 slices day-old bread
			1 teaspoon salt

Mass	Vol	Other	
			Pinch of pepper
			3 drops of worcestershire sauce
			Oregano to taste
			3 Tbls. oil
			1 1-pound can tomato sauce

(Used on 11-24-86)

ANOTHER CONSERVATION IDEA! Name_____
Hour___ Date___ S.D.

MOMENTUM | What is momentum? _____



Formula P = ☐ x ☐

What is the unit for momentum? ☐

Symbol	Name	Unit
P =		
mv =		
V =		

Try some simple problems...

1.) A car of mass 1100 kg moves at a velocity of 22 m/sec. What is the momentum?

2.) A snow-scooter has a mass of 250 kg and a velocity of 6 m/sec. What is the beginning momentum?

At the end of the run the velocity is 28 m/sec. What is the final momentum?

3.) A car has a momentum of 32,000 kg m/sec. Its velocity is 20 m/sec. What is the mass of the car?

4.) In question (2) what is the change in momentum?

5.) A rocket having a mass of 20000 kg has a momentum of 11,000,000 kg m/sec.

6.) A Newton is a kg m/sec^2. - What is the relationship between momentum as defined and a Newton-sec.

7.) How can an object have no momentum?

(Used on 11-24-86)

CONSERVATION OF MOMENTUM Name_____
LAB BLOCK Hour___ Date___ S.C.

1 Marble Billiards

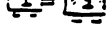
A) Roll one ball into the pack...How many come off this end? ___ How does speed compare?
B) Roll two balls into pack. How many come off?
C) Make a prediction for 3 balls. Try it.
D) Is momentum conserved in each case?
E) Is this an open or closed system?

2 Thought Problems. Read, Answer, Check.

A) Rubber Bullet

B) (unintelligible)

C) Scratch.

3 Mass Carts (unequal masses) 

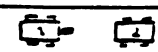
A) Send #1 into #2 (stationary).

Describe motion including direction
1. _____
2. _____

B) Send #2 into #1

Describe motion including direction
1. _____
2. _____

C) Is momentum conserved? _____

4 Mass Carts (equal masses) 

A) Send cart #1 into #2 (stationary) Direction _____

Motion of cart #1: speeds up / slows down / stops

Motion of cart #2: speeds up / slows down / same speed as #1 ____

B) Send cart #2 into #1.

Describe motion including direction
1. _____
2. _____

5 Air Track "Hit & Stick" Collisions

A) Heavy glider into light one

describe results include relative speeds and directions

B) Light glider into heavy

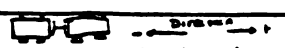
Is momentum conserved in inelastic collisions _____.

6 Film Loop

A) Describe briefly what is happening in the loop.

B) Describe an example in the film in which momentum is conserved.

7 Computer Read directions on the table. Answer questions here.

8 "Exploding" Carts 

A) Equal masses - fire mechanism to release the trigger.

Direction of cart #1 _____ #2 _____ compare speeds _____

B) Unequal masses - load a brick on cart #1
Direction of #1 _____ #2 _____ compare speeds _____

C) What is momentum of system before explosion? _____

After explosion? _____

Is momentum conserved? _____

(Used on 12-1-86)

$P_{total} = P'_{total}$ MOMENTUM Name_____ Date____ S/D

$P_A + P_B = P'_A + P'_B$

$m_A v_A + m_B v_B = m_A v'_A + m_B v'_B$

(1.) An empty 16,000 kg railway car coasts under a coal hopper at a velocity of 2 m/sec. 1000 kg of coal is suddenly dumped into the car. What is the velocity of the car immediately afterward?

(2.) A piece of sticky putty is put on the front of a laboratory car A so that when A hits Be they stick together and move off as a single unit. Assuming that the initial velocity of A is 0.10 m/sec. (and its mass is 1.0 kg) while B is a rest (B's mass is 3 kg), what is their final common velocity?

(3.) Lab car A of mass 1.0 kg has an initial velocity of 0.10 m/sec, strikes car B of mass 3.0 kg at rest. A rebounds with a final velocity of -0.05 m/sec. What is the velocity of B after the collision?

(4.) An oxygen molecule of mass 32 amu is moving at 400 m/sec. when it collides with a neon atom of mass 20 amu traveling in the opposite direction at -200 m/sec. After this collision the neon atom has reversed its direction with a velocity of 50 m/sec. What is the velocity of the oxygen molecule.

(5.) (From before) What would be the mountain lion's velocity if it was hit by just one bullet?

(Used on 12-1-86)

MOMENTUM PROBLEMS

Name_____

Hour_____ S or D (circle)

Remember

Momentum = mass x velocity ($\vec{P} = \vec{m}\vec{v}$)

Momentum is conserved ($\vec{P} = \vec{P}'$)

1 Find the momentum of a ford mustang (mass 900 kg) if the speed is 33 m/sec.

2 A bullet of mass .002 kg travels a distance of 1800 meters in 30 seconds. Find the momentum.

3 At what speed does a 1300 kg auto achieve the same momentum as a 1950 kg truck traveling at a speed of 20 m/sec.?

4 An "air car" of mass .23 kg is going .8 m/sec. when it hits a stationary car of equal mass. If the two cars stick together after collision, what is their final velocity?

5 Two astronauts are floating in space. The first has a mass of 75 kg, the second has 85 kg. At a certain instant they push apart, the first moving away at 5 m/sec. How fast and in what direction does the second move?

(Used on 12-2-86)

Name _____
Date _____
Hour _____ S/D

TWO CASES OF MOMENTUM CONSERVATION....



Case I A Hit & Stick Collision
The Bullet & the Kitty
Problem: Find the speed of a bullet

Proposed Solution: Use conservation of momentum. Collide a bullet into a "stationary" kitty. If the masses & the combined speed after collision are known - the speed of the bullet before collision can be calculated!

Items known..

Mass of Bullet m_B = [ ] kg. $V'_{B\&K} = \frac{d}{t} = \frac{.1\ m}{[\ ]\ sec.}$ = m/sec.

Mass of Kitty m_K = [ ] kg. V_K = [ ] m/sec.

Mass of Bullet & Kitty $M_{B\&K}$ = [ ] kg.

Unknown V_B = [?] m/sec.

Solution

$$P_T = P'_T$$

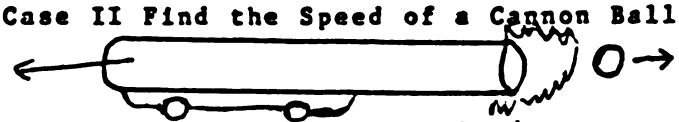
$$P_B + P_K = P'_{B\&K}$$

$$M_B V_B + M_K V_K = M_{B\&K} V'_{B\&K}$$

You! Substitute & Solve for V_B .....

$$V_B = \frac{M_{B\&K} V'_{B\&K}}{M_B}$$

Case II Find the Speed of a Cannon Ball



Your Job.....
Write the momentum equation; solve the equation for V'_B substitute & solve.

Data. M_B = kg V_C = 0 m/sec.

M_C = kg V_B = 0 m/sec.

means moving to the left

$V'_C = \frac{d}{t} = \frac{\quad m}{\quad sec.}$ = [V-] m/sec.

Unknown V'_B = ?

Start $P_T = P'_T$

Hint $0 = P'_T$

P_T = 0 kg m/sec. 0 = (·) + (·)

(Used on 12-3-86)

CONS - MOMENTUM Page 2 of 2

Name _____
HR._____ Date___ S/D

3 

Two astronauts float freely in space (weightless). The 1st has a mass of 25 kg. the 2nd a mass of 110 kg. They push apart. (momentum is conserved) The first astronaut moves away at a speed of -10 m/sec (to the left). How fast, and in what direction does the second astronaut move?

A) List all the known quantities in this problem with proper labels.

B) What is the total momentum of the system before the push?

C) What is the total momentum of the system after the push?

D) Simplify this equation, eliminating the zero terms.

$$M_1V_1 + M_2V_2 = M_1V_1' + M_2V_2'$$

E) Solve the simplified equation for the unknown. (in this case)

F) Substitute the values for the symbols and answer the question...

4 V_A = .1 m/sec. V_B = 0 m/sec.

M_A = 1.2 kg. M_B = 3.0 kg.

After collision the cars stick together what is their common velocity?

0 (A) 0 0 (B) 0

sticky putty

Known	Unknown	General Equation for cons. momentum	Solved in terms of unknown	Substitution of values	Answer

---

5 V_A = 1.2 m/sec. V_B = 0 m/sec. AFTER V_A' = .05 m/sec. V_B' = ? Find V_B' the velocity

1.2 kg. (A) Spring 3.0 kg. (B) COLLISION 1.2 kg. (A) 3.0 kg. (B) of RT-Hand cart after collision.....

Known	Unknown	General Equation	Solved in Terms of Unknown	Sub. of Values	Answer

---

6 An empty hopper-car coasts under a chute that fills it with rocks. This empty car has a mass of 10,000 kg., and a speed of 7.0 m/sec. Just before the dump, 4000 kg. of stone is added, so what is the speed of the car after loading?

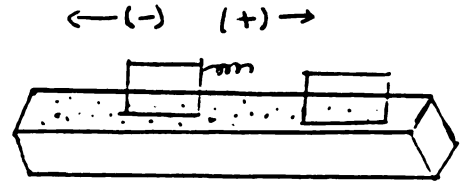
Known	Unknown	Gen. Equation	Solved	Subst.	Answer

(Used on 12-3-86)

CONSERVATION OF MOMENTUM Page 1 of 2 Name _____
Hour ___ Date___ S .D

BONUS 2 pts. if both sheets complete & correct

1



Cart A collides elastically with cart B. The two carts each have a mass of .25 kg, and before collision cart A is moving to the right with a velocity of 2.4 m/s. Bumping B which was stationary causes cart A to stop dead in its tracks while cart B moves at + 2.4 m/s.

A) From this problem, identify these quantities (include units)

V_A = ☐ M_A = ☐ V_A' = ☐

V_B = ☐ M_B = ☐ V_B' = ☐

B) Calculate these:

P_A = P_A' =

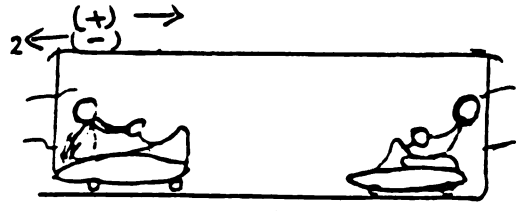
P_B = P_B' =

C) Simplify the general equation given below, and remove zero terms.

$M_A V_A + M_B V_B = M_A V_A' + M_B V_B'$

D) Substitute the values from the problem and show momentum is conserved.

2



Slam and his bumber car are moving at +2.4 m/s. The mass of Slam and car is 120 kg.. Bam and his cart have a mass of 105 kg. and move at a speed of -3.2 m/sec. After collision, Slam's speed is -1.0 m/s, and Bam's is +.8 m/s.

A) From the problem identify

V_S = ☐

V_B = ☐

M_S = ☐

M_B = ☐

V_S' = ☐

V_B' = ☐

B) Calculate:

P_S =

P_S =

P_S =

P_S =

C) What is the total momentum (P_S + P_B) before collision?

D) What is the total momentum (P_S' + P_B') after collision?

E) Is momentum conserved?

(Used on 12-4-86)

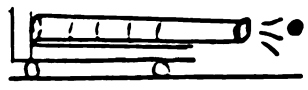
CHAPTER 9 QUIZ

Name _____
Hour ___ Date___ S .D

I. Matching

☐	1. Momentum	A) The father of chemistry--worked on conservation of mass.
☐	2. Inelastic	B) A "hit & bounce" collision
☐	3. Conservation Law	C) Principia
☐	4. Closed System	D) Amount before and after is the same.
☐	5. Inelastic	E) The vector product of mass & velocity.
☐	6. Open System	F) A "hit & stick" collision.
☐	7. Newton	G) Everything contained...no loss.
☐	8. Lavosier	H) Has a "leak"

II. Answer True (+) or False (0) Based on the Diagram.



M_C = 4.0 kg. V_B = 0 V_C' = -5 m/s.

M_B = .5 kg. V_C = 0 V_B' = ?

☐ 9. The momentum of the system is the same before & after explosion.

☐ 10. The momentum of the ball after explosion is zero.

☐ 11. The total momentum of the system before explosion is zero.

☐ 12. After explosion the cannon moves to the left with a momentum of +20 kg. m/sec.

☐ 13. $M_B V_B$ is an expression for the momentum of the ball before explosion.

☐ 14. If the cannon and ball were of equal mass, their velocities would be equal but opposite in direction.

☐ 15. After explosion the momentum of the ball is +20 kg. m/sec.

III.

Two air track carts collide. Before collision of cart A has a speed of 20 m/s, while cart B has a speed of 10 m/s. After collision cart A, whose mass is 4.0 kg. moves with a speed of 10 m/s, while cart B whose mass is also 4.0 kg. moves to the right with an unknown speed.

16. M_A = ☐

17. M_B = ☐

18. V_A = ☐

19. V_B = ☐

20. V_A' = ☐

21. V_B' = ☐

22. P_A' =

23 P_B =

24. Write the basic general equation for conservation of mass.

25. Solve the equation for the unknown.

26. What is V_B' ?

(Used on 11-4-86)

EXPERIMENT 3.10

Name _____
Hr ____ Date _____

1. What is the name of this experiment?

2. Why is it more difficult to measure the density of a gas?

3. How do we find the density of this gas?

4. Sketch the apparatus 5. procedure

CAUTION SAFETY GOGGLES MUST BE ON

Data:

1. Mass of beaker, test tube 1/3 full of water and 2 half tablets of Alka-Seltzer
2. Mass of the system above after mixing

_____ ___
3. Mass of the gas produced _____

4. Volume of water displaced by the gas _____

Calculation:
Calculate the density of the gas

Conclusion:
1. Why is it important to hold your hand across the mouth of the bottle while removing it from the bucket?

How do you find the volume of gas in the bottle?

2. How can you find the mass of the gas?

3. What is the density of the gas?

4. What assumptions have you made in using this method?

(Used on 11-17-86)

EXPERIMENT 4.3 Name _____
Hr ____ Date _____

1. What is the name of this experiment?

2. What are we trying to find?

3. Procedure (you must list the following steps.....)
   1.
   2.
   3.
   4.
   5.

Sketch and label the set-up

4. Observation from procedure #4
Compare your tube with others near you (remain in your seat). Does one sample of solid appear to be more soluble in water than the other?

5. To find the concentration of the saturated solution turn to page 72 in your text. Read the page and follow the directions carefully. You must wear GOGGLES and watch out for spattering.

What does your text say to do if you see spattering?

DATA TABLE

Mass of dry empty dish	_____g
Mass of dish and solution	_____g
Mass of dish and dry unknown salt	_____g
Mass of unknown salt	_____g
Mass of the water in the sat. sol.	_____g
Volume of water in the sat. solution	_____cm^3

6. Calculate the concentration of the saturated solution.

_____g/cm^3

Convert to _____$g/100cm^3$

7. The concentration of a saturated solution is called the _____.

8. Solubility is _____ of the _____ of the sample from which it is found.

9. It is a _____ _____ of the combination of the _____ and _____.

Appendix B
Examples of Lessons Whose Plans Appeared In Appendix A

This appendix includes transcripts of four lesson recordings. Plans of these lessons appeared in appendix A. At the beginning of each transcript appears some pertinent information about its date and the teacher who gave the lesson. Matching the dates on both appendices, B and A, shows the correspondence between the lessons and their plans.

(Date: 11-24-86) (Teacher: Mr. Stewart)

T: "Let me turn your attention to the sky, the motion of the stars, sun, and the planets, and so on. And after a lot of questions and difficulties in the results, Newton was the one who came along and says gravity is what holds the universe together. The planets are held into gravity about the sun. Otherwise inertia would carry the planets in a straight line; but they are in a curve because they are pulled by gravity into a curved path. And so Newton again comes to the scene with a set of physical laws that hold on the surface of the earth or anywhere else. Physics is a universal set of behaviors and we can discover by doing experiments here on the earth and extend this anywhere. Well, what we want to do in the next chapter is to extend the understanding of the way things move to see what sort of other understandings we can glean from that. We want to begin chapter nine today which is momentum, and we want to continue. You noticed the schedule says that we're going to get a well deserved long weekend if you...; and we all need that; and we'll continue our study of chapter nine next week; and do a test on Thursday. A week from this Thursday we'll have the exam. So what we have to do today is to get started in chapter nine.

Let me point out to you, what we're really looking for is a law that's so powerful, or a set of laws, or a different kind of law that's so powerful, that if it works, we can understand the entire economic system; the entire industry is all based on this one type of rule in science. It's not the kind of thing that was discovered by anybody. It's a sort of understanding that just evolves. What I am talking about is conservation laws. Conservation law doesn't mean saving the trees, or the whales and that sort of thing. What I am talking about is the conservation law: is a quantity, a conserved quantity that remains the same throughout an interaction. A quantity that remains the same through the interaction is a conserved quantity. Now let's see. Suppose, let me give you some examples of some situations of quantities that are conserved or not. Suppose that....I was telling the second hour a joke; it's always a danger; but I'll try it again, and maybe it will work this time. The story of the fellow who was sitting in the bar and watching a baseball game on television, but he had to go to the bathroom. So he had almost a full glass of beer. He got up, went to the bathroom when he got back, the glass of beer was almost all consumed; most of the beer was gone. Well, he ordered another one, and here again, he wanted to go to the bathroom again. So he said, well, I don't know who did this; who in the bar would drink my beer. He figured that he would solve the problem by writing a

little note. And he said in his his note "I spit in this." He put his note under the glass. He then went to the bathroom and came back and on the note there was an addition on the underside "I spit in it too." [Laughter] An example of conservation law! You would expect when you went to the bathroom and came back that the amount of beer you had was the same, conserved.

Let's see another example. Suppose that you have as your entire assets 37 cents; you have 37 cents in your pocket. You get home and you decide to transfer your assets from your pocket to your piggy bank. O.K., now; so you take the coins: a quarter, a dime, and two pennies, and put them in the piggy bank. Now the piggy bank has 37 cents in it. What does your pocket have in it?"

Ss: "Nothing!"

T: "O.K., and what is conserved in that situation and what is not? Is the amount of money in your pocket a conserved quantity?"

Ss: "Yeah!"

T: "No! Is the amount of money in your piggy bank a conserved quantity?"

Ss: "Yeah! No!"

T: "No. What is conserved in that?"

Ss: "37 cents!"

T: "Yeah, that represents the amount of money that you have. That is a conserved quantity. But in a system where you're adding or subtracting, then it's not conserved. O.K.; in a case of money it's important to have it been a conserved quantity. Is it nice to be able to say: I have a hundred dollars in my savings, and know that that 100 dollars is still there? That's comparable to know that it's a conserved quantity. Banks are based on the idea of conservation: conservation of money. Conservation laws are very important.

All of chemistry is based on conservation laws. So what we want to do is look for quantities that are conserved in physics, and we want to expand on that. Well. O.k., we define the conservation laws. Let's think of a system here. Here is an example that I may start out. Suppose that you have an ice cube in a glass, all ice, no water. You got to sit around for a while, the ice cube melts. What change is in that example? Let's see we might be able to get several different things that change. What was one of the things that might change?"

S(A): "The form!"

T: "The form: changed form from ice to water. What else changed?"

S(B): "Temperature!"

T: Temperature might have changed. What else could have changed?"

S(C): "Mass!"

S(D): "No!"
S(C): "Volume"
T: "Well, here mass, volume. Think of them and tell me, not guesses, which of those would've changed?"
S: "Volume"
T: "Does the weight of the ice differ from the weight of the water you get?"
Ss (3-4): "No!"
T: "That's something that stays the same; wouldn't it!"
Ss (2): "Volume!"
T: "If it were setting on a balance with just ice in it, after the ice melts we would expect it to be balanced. That's a quantity that doesn't change. Somebody mentioned volume. You either made a guess or else you're very astute, because the volume of ice is slightly larger than the volume of water, and so it floats. So you can see some things that changed, and some things that didn't change. Alright, suppose we have some two chemical solutions."
S: "What didn't change here?"
T: "Well, you can figure it out. In fact I told you some things...Part "B; the mass of mixed solutions. Suppose you have some two chemicals, note this, in a jar. An example of this it's one of the soda acid, fire extinguisher, that fire extinguisher is an example. Let's say that you tipped it over properly. What that has is two chemicals inside that are not mixed, and when you tip them over, the two chemicals mix together and the liquid out fights the fire. So there's an example of the mass of two solutions before you mix and after you mix them together. What would've changed?"
S: "Volume!"
T: "The volume would change! That's if I have half a cup of liquid here, and a cup of liquid here, and pour the two liquids together; I am going to get something other than a cup-and-a-half?" [Started to explain something but not audible on the tape]
T: "O.K.; in that case you might get volume change; or, are there other examples where you can get something to change volume? For example if it's alcohol and water: you have a cup of alcohol and a cup of water, you don't get two cups of mixture. It's something just a little less than that. That's the way water and alcohol mix together. You can say volume may change depending on your interpretation. What wouldn't have changed in that case?"
S: "Weight!"
T: "The weight! O.K., in that case weight may not change. But now you have to be careful about weight. Let me give you an example right here. Suppose you had a log, a wood log weighs five pounds. You take it and put it in the fireplace and set fire to it. And after it burns you wind up with just a little half a cup of ashes which does not weigh anything. What happened to

the five pounds of wood in the log?"
S (2-3): "It burned!"
T: "It burned! O.K., it's gone. It's not there. It's not conserved in that case isn't it! So sometimes when you have a chemical reaction, quantities such as mass are conserved, and sometimes they're not. Now the guy that really untangled that question was a Frenchman by the name of Lavosier. Lavosier said what you have to do; he said that mass is a quantity that's conserved in chemical reactions; and how he describes it is as this: you have to have a closed system. You can't let any of the parts get away. In the case of the burning log what gets away?"
S: "Gas, smoke!"
T: "Gas, smoke, heat, particles, right! Lavosier says if you have a box that you can put this in, a container, burn it inside a container the amount of what you have to begin with is what you have left over if the container is closed, you have a closed system. You can think about a closed system or an open system in terms of the money, the coins in your pocket. Well, alright, how about this one part C, what would Lavosier say about this one? You take some ground-up copper, some powder copper and some powder sulfer and mix it together. If you set fire to it it makes a very bright flame, a lot of smoke, and it stinks up the place. What would've changed in that reaction between copper and sulfer?"
S: "Mass, color, form!"
T: "Mass color, form, chemical composition! Is there anything that didn't change?"
S(A): "Volume!"
S(B): "No, weight!"
T" "Would the weight have changed if you had smoke getting away?"
Ss (2): "Yeah!"
T: "Some of the weight would've been carried away by the smoke unless you close the system. You can say, well, it didn't if the system is closed. But if you're burning it in an open jar like this, the weight would change. How about this one the mass of Alka-Seltzer in water: two tablets of Alka-Seltzer plop-plop fiz-fiz!"
S: "It's a relief!"
T: "Yeah, I didn't know that, but Mark says it's a relief. [Some inaudible comments]
What quantities would change? What things would change if you put Alka-Seltzer in water?"
S: "The weight!"
T: "The weight of what?"
S(A): "The weight...of water in Alka-Seltzer. The bubbles make..."
T: "Oh! But now the bubbles, now, wait a minute, now we got a problem. The bubbles are bubbles of gas that have weight..."

S(A): "Right!"
T: "And they go away, and so its mass's going to be conserved in that case?"
S(A): "I said the weight!"
T: "Well, alright, the weight. Is the weight going to change?"
S(A): "Yeah!"
T: "O.K., the weight is going to change because some of the gas escaped; the bubbles of gas escaped. Suppose you put...this is a close jar, with a cork on it, seal it up, then plop-plop, fiz-fiz you kept the gas inside..."
S(B): "No relief there..."
T: "No relief. You got more gas than before..."
Class: (Some laughter)
T: O.K., but wouldn't the weight be conserved then?
S: "Yeah, yeah...!"
T: "If you close the system, mass will be conserved, that's what Lavosier said. Part 3, 18th century, the father of chemistry (filling in blanks on worksheet). Statement of a law: in a closed system the mass of chemicals before reaction are equal to the mass of the chemicals afterwards. In closed systems.....[repeat of the same statement). This is being checked by more and more sensitive balances until we're convinced that this is true to at least 1 part in a billion; which means that if you wanted on percentage basis it's 0.000001% at least that accurate; one part of a billion. So that in a chemical reaction mass is a conserved quantity. It's a very powerful law, that's what chemistry is based upon. What you do in chemical reactions, is that you assume that masses before reaction are equal to masses after reaction. And all of chemistry is based on that.

O.K., knowing this why is it that we use mass to measure the amount of matter and not volume? Well, I would turn this around and say very often we use volume to measure quantities and not mass. Example: when you make a recipe, chocolate chip cookies or whatever; you measure the amount of sugar by mass or volume?"
Ss: "Volume!"
T: "Volume! It says a cup of sugar, right! Not a pound of sugar, or half a pound of sugar, but a cup of sugar. You're measuring by volume, aren't you?"
Ss: "Yeah!"
T: "In recipes, American style, recipes are given by volume measure to a large extent. European style recipes are given by mass measurements. They say so many grams of sugar, so many grams of water, so many grams of flour. Well, so why is it that we use the mass to measure and not the volume? Well, the volume can vary; it's not a conserved quantity in many cases; but mass is. That's why we measure mass in chemistry instead of volume. When can we use volume to measure

mass? Well, one example is when you're talking about liquids. Liquids don't compress, and so it's pretty safe to use volume for liquids. In fact there is an old wise saying that summarizes this. The saying is: "The pint's a pound the world around". A pint of liquid measure, that is two cups, is equal to a pound, and that's useful for you: cooks. So the future cooks, including bachelor cooks, to know that a pint's a pound the world around. Two cups is equal to a pound, a liquid measure. So that if you have two cups of water, equal to one pound of water. Two cups of strawberry, however, dry measure, it doesn't work. Here is a recipe for you. I don't know what it's a recipe for. But what are we using to measure? What are we measuring: is it mass, is it volume, or is it something else, when it says in this recipe to take one-and-a-half pounds of ground chuck?"

Ss (4): "Mass!"

T: "O.K., it's actually weight. Weight is proportional to mass, when we stay at the surface of the earth. There is a number of quantities in physics that is conserved. We look for these conserved quantities. A quantity that is conserved in addition to mass is called momentum. What is momentum? It's a vector. It's a vector product of mass and velocity. That's what momentum is. It's a vector that's the product of mass and velocity. We can write this in symbol. Momentum obviously can't be "m", so we have to choose a different letter. Instead, it's chosen the letter "P" to represent momentum. So "P" is equal to mass times velocity. That's the equation for momentum. Any questions? Momentum is a vector, it's a product, mass is not a vector, and so it doesn't have a little arrow there. "V", velocity is a vector ad so that's what the arrows stand for. Normally we'll see these vector sighs but that's what they mean. Alright, in my equation what does the "P" represent? [Teacher wrote on the board P = mv]

Ss (4): "Momentum!"

T: "What does the 'm' represent?"

Class: "Mass!"

T: "And the 'V'?"

Class: "Velocity!"

T: "Velocity, alright. What are the units involved here. What are the units for the mass?"

S(A): "Grams!"

S(B): "Grams!"

S(C): "Grams!"

T: "We're going to use, as before, units of mass: kgms; units of distance: meters; units of time: seconds. So we're going to use the "MKS" System; that makes the unit of mass in kgm, speed of meters per second. The MKS, meters for distance, second for time. This is

velocity (writing on board) and the units are meters/second. Alright!"

S: "What's momentum?"

T: "Good question. Now you see momentum is mass times velocity. So it's going to be the units of mass times the units of velocity. So what is the units of momentum going to be? Kilograms times meters divided by seconds. So the units of momentum kilograms times meters divided by seconds, kilograms meters per second."

S: "I have a question. When we do this thing is it like two meters times two grams and then divide by seconds?"

T: "Well, you have to know what the units are. For example, if you wanted to know the momentum of a 100 kgm object, travelling at 20 meters in 3 seconds, you take the mass times the distance divide by the time; kilograms times meters divided by seconds would give you the momentum. O.K., it may be handy that I keep this on your sheet: momentum is equal to mass times velocity. A sample of problems now. They're simple but remember identify the known quantities in the problem. The reason that I remind you to do this again is that when we get to conservation of momentum it's a book-keeping nightmare. Mathematically it's difficult to keep track of different speeds of two objects before and after. It's a book keeping thing. So, if you're not careful in mathematics, get used to it and do it carefully."

(Date: 11-26-86) (Teacher: Mr. Davis)

T: "These are observational type activities. The experiment is one thing that when you, at least in my mind, an experiment is something where you have a hypothesis, you have a definite overall purpose in mind, a procedure that you develop, you're collecting data, and form the data you're looking back and coming up with certain conclusions. Well, this type of experience here is, may be more in the order of an experience that deals with equipment, but it's not necessarily a formal experiment, like an activity-type experiment. The situation in the room then, at each table there is the same topic but a different view of the topic. And the topic is momentum, and it deals with conservation of momentum.

Let me review back or talk about momentum. From our work on Monday, and form your reading last night and yesterday in the classroom, we see momentum is a topic that is really the product of mass and velocity. Momentum is a sort of a contrive mathematical number that is arrived at by the product of mass and velocity. So let's kind of think about this a little bit, and as I am saying I want you to listen and in the mind picture (inaudible).....small car. O.K., picture a small car, four wheels. The car is moving at a fixed speed on the table, and has a momentum. When will the car not having momentum?"

S: "When it's not moving."

T: "O.K., the car is moving relative to the table, at least this now you can get the idea in mind. if that car, that has some momentum, let's see if you can compare the momentum of two different cars. Let's say a car having twice the mass but half the speed, how would the two momentum compare? [wait for 5 sec.; no response] How would the two momentums compare, if you had a second car which has twice the mass but only half the speed?"

S: "The same!"

T: "The two momentums will be the same. O.K., get that picture in mind. Imagine two cars that are not moving at all, they're at the center of the table; and a spring pushes at them. So that one car is thrown one way, the other car is thrown the other. In other words, like a metal spring pops up between them, make them fly apart. You can imagine that thing to happen. What if the momentum of the car moving to the right and the momentum of the car moving to the left are the same?"

[Students afterward started to do the activities while the teacher circulated around.]

(Date: 12-2-86) (Teacher: Mr. Stewart)

T: "One of the things we can do is measure the speed of a bullet. Now bullets travel rapidly. They can be so small, and so it's difficult to observe and measure. The conservation principles will allow us to calculate the speed of the bullet. What we're gonna do, this bullet by the way is powered by air, this is an air pistol and the bullet consists of a little lead pellet that we're going to shoot. Now I asked some of you yesterday, and this class really let me down on this, because I asked you to bring in some cats you didn't want anymore! Now every body that has cats, has cats that didn't want anymore. Usually I start with one cat, we wind up with seven before very long and then you get twelve and then you get up cats running up and down in threes. So, fortunately somebody in one of the other classes brought us a cat that we can use for this experiment. So, what we're gonna do is shoot the cat with the gun. We're then going to measure the speed with which the cat is moving after it's shot; and from applying the calculations involving conservation of momentum we can go back and determine how fast the bullet's travelling. Here is the cat; I got the cat in the sack; and I bet you think it's gonna be a whole real red stuff thing that I had before. I can tell that I skin some of the skin off it. Now here it is. Here is the cat I'm going to use. I use kind of in quotes cut. Here is the idea. This is air track pipe, and this is the kitty tail, there. And the kitty's tail is just at the right height. So, when this thing slides down the track of the air track, it will just go between the electric eye, between the light and the photocell there, that will cause the thing to operate. [Teacher started to prepare his set up.) O.K., here how it works. I'll show you the timer. Here is the timer and when this goes through the photogate it turns the timer on and keeps it on, or as long as its in the photogate. And when it goes through, the light comes out again, the time shuts off. And so we got a way of measuring the time that the cat will go through; and this part of the cat, the tail of the cat there is exactly a tenth of a meter long. So we'll be able to determine the speed of the cat from that. So, let's see, the idea is this: We fire the bullet at the kitty; the bullet sticks in the kitty; the bullet and the kitty move together; we measure that speed; apply conservation of momentum; determine how fast the bullet moves. That's how our problem works out. Well, let's do the mathematics of this. Now give me some values that we need. one value that we need is that the mass of the kitty is 0.255 kgms. Write that on the sheet as the mass of the kitty 0.255 kgms. The mass of the bullet is 0.001 kgms, just about 1 gm; so its mass is

.001 kgms. That means that when the bullet and the kitty are together they will have a combined mass of how much?"

S: "0.256!"

T: ".256 kilograms. O.K., you got that! Alright! Let's just thing some other things about our little experiment here we're gonna do. What is gonna be the mass of the kitty before...; excuse me, the momentum of the kitty before it got shot?"

Ss (2-3): "Zero!"

T: "It's gonna be sitting stationary and it gets hit and then carries that momentum through the electric eye. Let's take a second and work out the mathematics of this. We'll summarize everything. Here's the kitty, air track, bullet coming this way [making a drawing on the board], mass of the bullet 0.001 kgms., mass of the kitty 0/255 kgms., speed of the bullet well I don't know that. That's my unknown; that's the unknown. The speed of the kitty is how much?"

S: "Zero!"

T: "Zero, it's just gonna be sitting there until the bullet hits it. Then this is my unknown. After it hits the bullet and the kitty are gonna have the same speed. I am going to call that V prime. O.K., now, let's see: I know that V prime also, I know this is gonna be distance divided by time as it goes through the timer. And the distance is 0.01 meter divided by the time that I'm going to read that thing in seconds, and I'll be able to calculate this speed, and from that get back to the unknown. Here is my equation, mass bullet, speed bullet, mass kitty, speed kitty, mass bullet, speed bullet after, mass kitty, speed kitty after. Which terms're zero?"

Ss (2): "The speed of the kitty."

T: "It's right there, this is my unknown. So I write this equation in terms of the unknown, and what I get is the speed of the bullet is equal to the stuff: mass of the bullet plus the mass of the kitty times, remember this is just speed, divided by the mass of the bullet. Now there is something similar on your paper to this. O.K., So that's where we stand. We're ready to do the experiment. Let's try it and see what kind of numbers we get and we'll be able to calculate; you'll be able to calculate the speed of the bullet [started the air track and preparation of the piston]. Just about stationary there. [fired]. All right; and there is the time. Now let's go back and see what we have to do with this. Here is our time right here. It's 0.44 seconds. so, first of all, we're gonna have to calculate the value of "V": .1 divided by 0.44 meters/second. Then this speed goes there. Mass of the bullet plus mass of kitty; you know that was, mass of bullet is .001, plug it in and calculate the speed. O.K., on your sheet it's incorrect; it's a tenth of a

meter, this is 10 cm. long, it's a tenth of a meter not a hundredth of a meter. So your sheet is incorrect. If you're in trouble and you don't know what the answer is gonna turn out, it's sometimes useful to kind of keep in your mind some sort of accepted value that is reasonable. What's going to be the speed of that bullet? 1 meter per second? Is is faster or slower than this?"

Ss (2): "Faster!"

T: 1 meter per second is like this, to be travelling something like this. The bullet travels faster than this. An olympic runner can run 10 meters per second. And the bullet probably travels faster than that, faster than you could run, faster than you can sprint. A hundred meters per second, maybe not this fast, but somewhere in the vicinity: more than 10, in the vicinity maybe of a hundred meters per second. So, use your technique for working on. You set the equation, write in the values with the units, and you can calculate the speed of the bullet from conservation of momentum.

S: (inaudible question about the equation)
[The teacher gave an answer but not clear.]
[The students are trying to solve the question and the teacher is moving around for five minutes.]

T: "Here is what I call a cannon, I don't know if you call it a cannon or not. Maybe if you see it work you change your mind. You say yes it is or it isn't. But it's made quite simply of some steel, drink cans, not all of them are soft drink cans; I found in the junk yard, a beer can."

Class: [Some laughter]

T: "These are of all kinds, where cans are made of steel, hush please, where the cans are made of steel, and they have both ends removable, so that you can cut them and then you can fix them at the end, and thus make a smooth long tube, so that you can use this for a cannon. Now, for a number of reasons soft drink makers don't do this anymore. [There is a sentence here which I couldn't discern. However, I guessed the words to read: I don't do this cannon anymore.] For a number of reasons. One of the reasons, is doing this experiment in the past had caused people to be injured. Now they were not injured in the class. But when kids get these cannons and start aiming them at each other and having them propel off, when they are not expecting it, and not realizing that these cannons will recoil as you're going to see it recoil. Then, you know in the hands of some kids these things can be dangerous. So, I am not advocating that you learn how to do this, or that you make one of these things yourself. But I just want to show you with a little demonstration that we can measure, apply the conservation of momentum and measure the speed of the

cannonball. And whether the speed of this cannonball or the speed of any cannonball, the principle is the same. We're gonna have to have you have one share-- [he asked a student to hold a blanket or cloth and to stand at the back of the class to let the ball hit the cloth.]

S: [Asked about the liquid to be used.]

T: "I don't know. But I told you the concern the people have over the danger of these things. They approached the makers of hard rubber ball to be sure from now on that they don't make them so that the size of the ball just didn't fit. So, they just make them now so that they don't fit nicely into the can the way this does. So, if we get this one lost we can't find a replacement for it. So this is our cannon, this is our cannonball. We need some data on this. The mass of the ball is 0.077 kilograms. The mass of the cannon is 1.313 kilograms. Let me first of all demonstrate our cannon. And we'll try to get a reading on this; and we'll see if it works. And if we get a good reading then we'll go with that. If it doesn't get us a good reading then we'll try to repeat it.

O.K., what I am putting in here as a charge for the cannon is a volatile liquid that will mix with air and form an explosive mixture. Now you probably heard that gasoline and air form an explosive mixture, and natural gas from the pipes there forms an explosive mixture with air. And what I am doing is forming an explosive mixture in the can of this volatile magic fluid. And we're gonna wait for this evaporate and form a good vapor inside and mix with the air before we try to fire. I'd like to have you two guys, if you would, grab a hold of this blanket and hold the blanket straight from above back here. Hold the blanket on this side and let the bottom of the blanket rest on the floor. [Teacher gets ready to do the demonstration.] (Paul), I need a meter stick; would you get me a meter stick from under the board. What I am gonna do is when this goes; the cannon goes in one direction, the ball goes in the other, and what I am going to do is to measure the speed of the recoiling cannon. So I'm gonna have (David) do this, and when he pushes the start button on this it starts counting; and when he pushes the stop button it'll stop, and we can read the time that it takes the cannon to recoil from this line up to this line. (Two lines marked on the floor.)

(Date: 11-4-86) (Teacher: Mr. Davis)

[The main purpose of the lesson activity was to find out the density of gas produced from an Alka-Seltzer tablet that was mixed with water. During the preceding lesson, on Nov. 3, Mr. Davis demonstrated to his class how to do the activity. He measured all the masses needed, mixed the tablet with water, calculated the mass of gas produced, and described how to collect that liberated gas in order to find its volume and then its density. The students were given some time to draw the apparatus which he assembled (description of the activity and the apparatus appears on pages 60-62 of the IPS textbook).]

T: "The reason for the handout here is that this is a finished paper to be turned in. Yesterday you have a piece of lined paper that we started putting something on. The reason for that: is it possible to find water mass? You want to get the grid paper. So with the line paper the experiment is going to happen in this way. Anybody who is not facing his way turn this way. Please, (George), I need to see your face, not the back of your head. (Andy), (Chris), over here, head up. On the line paper or your master sheet, I want you to proceed with me. You know where we're going to go. Too many people did that over a period of time, few did know; many didn't know. So, listen, we have the set up here in this particular order; you have a test tube here with a third full of water, a stopper, a flask upside down, a pan. Let me do one here [started to assemble the equipment]. You fill the pan about half full water. There is a flask to be put upside down, if you have tiny hands, you can put your hands over the top; turn it over; put it in the water; and then take your hand away. If you got clumsy hands like me, then you may need piece of paper. You put on the top; turn it over as carefully as you can; put it under water; and then take your hand and the paper away, keep the flask upside down. This should create no problems. I watched the first hour, everybody did a very good job at it. (Teacher was always demonstrating how to do the assemblage.) Now this tubing, be carefully slipped so the tubing would go up underneath the chamber of water. So you end up with the tubing like that. Now how do we measure the mass of the gas? What do we have to do? Where would the gas come from? The gas comes form the Alka-Seltzer tablet; and when the Alka-Seltzer comes in contact with the water, so that the chemical reaction that goes on and the reaction then produces the gas. Now the mass of the gas is determined by measuring the mass of the system before we mix it and comparing it with the mass of the system after we mix it. In other words we're going to mass the system before the gas is released and then after the gas is released. The

difference between the two is the mass of the gas; O.K., so, let's get a look on what I mean by how do I measure the mass of the system before and how do I measure the mass of the system after. Everybody on the table should have a balance, and we'll take the test tube, put the test tube in a beaker like this, so you can use the beaker for support. You take your Alka-Seltzer tablet and you break in half, into two pieces, not necessarily halves. The reason I want it in half is that it will fit in the tube; the whole one could not go down the tube. O.K., put it on like that trying not to dribble any Alka-Seltzer pieces or chips. Then you measure the mass of the system before you mix it; put it then back into its holder; you collect gas in the bottle. That's basically our work. Now how do you measure the mass of the system afterward? Take this one. Where is the tablet now?"

S: "Dissolved!"

T: "Dissolved, its in there, right! Put it back in here; (putting the test tube in a balance) measure the mass of the system again. Do you have to include the beaker here? (A beaker that had the test tube in it) What is the purpose of having this beaker? This is for the test tube so as not to fall over.

Now, there are quick steps here. Copy them all. number one, set-up. Number two, mass the system before. Number three, add the tablets and collect the gas. Number four, wait, how many minutes? You want to wait ten minutes, or more, at the same time while waiting you may shake the test-tube to allow all gas trapped to go into the beaker. Number five, tricky; put your hand under the mouth of the collecting bottle, but we do that after removing the tube and the stopper. Remove the tube and the stopper from the pan, put your hand underneath the collecting pan. You can imagine what it's going to be like. If you have ugly hands like me put a paper down. Then lift the bottle up as carefully as I can with my hand over the top. And I turn the jar up here; I get my hand off the top, take it out, turn it over.

Now how do I measure the amount of gas that was in this container? How do I measure it? How do I measure the amount of gas in the container? O.K., what I do is: I add water to the system but I measure it every time I add; I measure it with my graduated cylinder, I add water from the sink by graduated cylinder measurement. How much would the graduated cylinder hold up to the top?

S: "A hundred!"

T: "A hundred! So in one-hundred-milliliter increment I start to fill it until it gets full. What if I end up with water that...., with 100 right to my finger here? What about the space here do I have to add that?"

S: "Yes!"

T: "Sure, I do! It's not going to be one hundred from where I was, right! It may be two-hundred-thirty-three or two-hundred-thirty-four. But you have to measure it in milliliter as carefully as you can. What do I have to do to find the density?"

S: "I don't know!"

T: "Mass divided by the volume. From yesterday the mass was about .6 grams, or there about. Check the mass. Don't let water from the test-tube come out. I think in such cases there is a violent Alka-Seltzer that is forcing the water out of the test tube into the collecting pail. That results in a great loss of mass. In some cases there was about twenty grams loss in mass. If you have big loss in mass, then it means it's wrong."

Appendix C
Some Examples of Lessons Types

This appendix includes transcripts of parts of some lessons as examples of the lesson types discussed in this dissertation. One of these transcripts, the lecture and demonstration type, includes the literal contents of practically everything the teacher said during that lesson. Whenever available, the worksheet prepared for that lesson was also included, preceding the transcript itself. Some introductory related information to each transcript was also added.

(HPP Worksheet: 11-17-86)

Name _____
HR ___ Date___ R/D

KEPLER'S LAWS

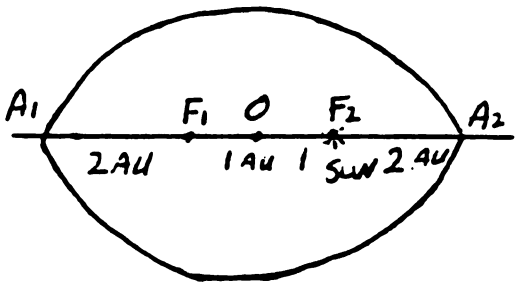
From his task, given him by Tycho, Kepler works out the orbit of Mars...This masterpiece of work based on emperical data along with inductive logic produced three empirical laws...

The 1st (2) published in _____ in his book. [ ]

I. Law of Elliptical Orbits
Stated This Way. _____

_____

_____



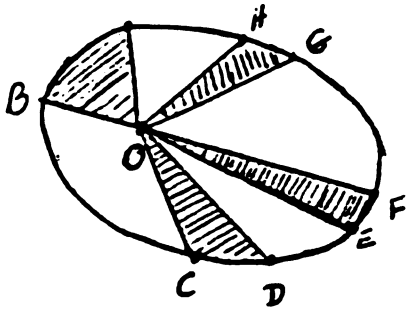
Identify the following
Major Axis _____
Center _____
Distance Between Foci _____
Perihelion Point _____
Perihelion Distance _____
Aphelion Point _____
Aphelion Distance _____

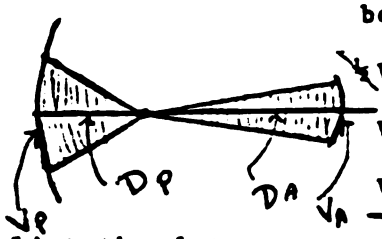
Eccentricity = $\frac{C}{A}$ = = [$\frac{1}{3}$]

II. Law of Areas _____

_____

_____





If time is equal for both areas...then

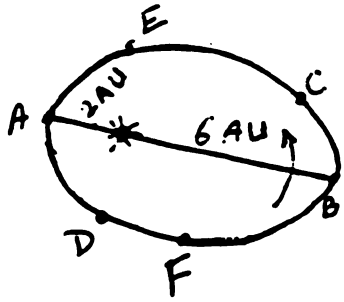
$\frac{1}{2} V_P t + D_P = \frac{1}{2} V_A t + D_A$

$V_P D_P = V_A P_A$ (or)

$\frac{V_P}{V_A} = \frac{D_A}{D_P}$

Note the ratio of distances equals the ratio of speeds...

List the letters in order of increasing speed (slow to fast).



_____ _____ _____ _____ _____ _____
slow ⟶ fast

If the speed at (B) is 10 km/sec what is the speed at (A) _____

If the speed at (A) is 5 km/sec. what is the speed at (B) _____

The following is an excerpt from a transcript of a lesson recording in which Mr. Stewart was attempting to review Kepler's first law in order to set the stage for the other two laws. In the two lessons prior to the one cited below, Mr. Stewart explained the geometrical properties of the ellipse including the definitions of key terms, like major axis, minor axis, and eccentricity. Students also did a related activity in which they constructed an ellipse with a loop of string using the important mathematical property of this shape. Kepler's first law was also introduced.

Mr. Stewart started the lesson by a brief description of the work schedule for the class during the week that had just started. He then indicated that he would be discussing Kepler's laws. His start for the discussion included a brief explanation of two kinds of laws: "empirical, and theoretical." His example on the empirical type was Kepler's laws.

(Lesson Type: Discussion-Recitation) (Teacher: Mr. Stewart)
(Course: HPP) (Date: 11-17-86)

T: "Our concern today is Kepler's three laws of planetary motion. We've already gone the first one with you, and we've already gone taking you through that to some extent. So we first start out as a kind of review. You remember that the first law said that the orbits of planets are not circles but they are ellipses with the sun at one focus. This was Kepler's first law of planetary motion. The orbits of the planets are ellipses, and the sun is at one focus. So on the sheet it says, by the way this is published in a book called "Astronomia Nova", you get that from your text. Identify the following: The major axis of an ellipse is the line that cuts across the ellipse and goes through the foci, it's the longest chord you can draw across the ellipse. What is the length of the major axis of the ellipse if the distance from one focus to one edge of the ellipse is 2AU, and the distance from that focal point to the center is one AU? What is the lengths of the major axis?"

S: "6 AU!"

T: "6 AU; and you have to follow reasoning, logic symmetry to say it's six. The whole distance across here is six and half of it is 3, the other half is 3, the total is six. The length of this major axis happens to be six. What is the distance between foci on this ellipse? The distance between the foci? [Wait for 3 seconds, a low voice said 2 AU.] 2 AU! That's the distance from this one to the center; and another one here to the other focus the total distance is 2 AU.You need to get out the sheet we did the other day on orbits and orbital mechanics and you need to review some of that, it appears not very clear to you. O.K., let's say then that here is the planet moving in the elliptical path about the sun. It gets far from the sun, and it's going slow, it gets close to the sun and it gets fast. And we call the closest approach to the sun perihelion. So where is the planet at perihelion? Where is the closest point of the planet to the sun? Right there. This is perihelion. This is the closest point, the closest approach to the sun. Now what is perihelion distance? What is the minimum distance? How close does the planet get to the sun?"

S: "2 AU!"

T: "2 AU, it's the same distance right here, 2 AU. What does AU represent?"

Ss (a group): "Astronomical---"

T: "Astronomical units; what it stands for? What distance are we talking about "AU"? Is it like a mile an inch or a centimeter?"

Ss: "Centimeter!"

[The teacher ignored this answer and called upon three students to answer the question in less than 3 sec. The last student gave the correct answer: the distance from the sun to the earth.]

T: "The distance from the sun to the earth. The astronomical unit the distance from the sun to the earth, is about 93,000 miles. The reason in astronomy that we use that is a, there is a couple of reasons. One reason is that it gives us a handy measuring stick, when we're talking about other planets how far away the other planets are. For example, the orbit of Saturn is 9 AU from the sun; this tells you Saturn is far away from the sun 9 times as far from the sun as the earth. It's a handy unit of measuring distance. Perihelion distance then is 2 AU. Aphelion point is the point at which the planet is furthest from the sun. Let's see, Ken, stop me when I get to aphelion. (Started to move on the orbit until he reaches point A1. the student says stop.) Right there, this is the furthest you get from the sun so this is aphelion. Aphelion means the farthest point from the sun. What is aphelion distances Chris?

Chris: "I don't know."

T: "O.K. You can figure out from this, nothing unique about that. How far is aphelion point from the sun?"

S: "4 AU!"

T: "4 AU. It's one to there, another two more, four total. When the planet is closest to the sun is when it goes the fastest. The farthest from the sun is when it goes the slowest. So here is the fastest speed, and here the planet is slowing down, getting farther away, slowing down, it's lowest speed and from here on it picks up speed, maximum speed, slows down, minimum speed, increases, maximum speed. [The teacher was pointing to various points at the ellipse between A1 and A2.] That's Kepler's first law of planetary motion is the orbits of the planets are elliptic with the sun at one focus.

What is the eccentricity of this ellipse?" [Wait 3 sec.]

S: "e = c/a!"

T: "e" is "c" over "a". What does "c" represent? [no response] C represents the distance between the two foci. What is that distance? Two AU, right! What is "a"? The length of the major axis. What is that in this case?"

Ss: "Six!"

T: "Six AU. So we have the eccentricity 2 AU over 6 AU, that's 1 over 3 or .3. Is there any units to the eccentricity?"

Ss: "No!"

T: "It's a ratio, a pure number, and it's always less than one. Good, O.K., well that's Kepler's 1st law. And that's kind of a review. The second law gets a little

one step more weird. Because Kepler says that not only the planets travel in elliptical path with the sun at one focus, but it goes in such a way that equal areas are swept out in equal times. Let me show you what that means. Suppose that the planet is right here at some time, we call it P. Suppose we take a month later say, where is the planet! And say right here at P2. That means a line drawn from the sun, from there to there sweeps out, let's say in one month time an area of that much. Now if we go anywhere in the orbit, anywhere and we take a one month period at P3, one month later where is the planet? It's down here at P4 so that a line drawn from the sun will have swept down an area that is equal to that one-month thing that it did when it was closer.

(HPP Worksheet: 9-16-86)

Name _____
HR ____ Date _____

Acceleration problems (a second try)

Some primitive societies were known to throw young maidens into "bottomless" pits.

1. A young maiden dropping into a bottomless pit had an initial velocity of 0.0 meters/sec. After 3.0 sec of fall her velocity is 30 meters/sec. What is her acceleration?
known unknown equation substitution answer

2. A rock dropped into this pit underwent an acceleration of 10 meter/sec/sec for an elapsed time of 6.0 sec. What is the change in speed of the stone?
Known unknown equation substitution answer

3. The initial speed of a moving object if 25 meters/sec and the final speed of this object if 42 meters/sec. What is the change in the speed of the object?

4. A falling object in the pit has an acceleration of 10.0 meters/sec/sec. The change in speed involved in the fall is 65 meters/sec. What is the elapsed time of fall?
known unknown equation substitution answer

5. A rock is dropped into the pit and strikes the bottom of the bottomless pit if 5.5 sec. The initial velocity of 0.0 meter/sec and the final velocity if 55 meters/sec. Find the distance travelled by the rock.
known unknown equation substitution answer

6. A more careful measure of the acceleration of a falling object in this pit is 9.8 meters/sec/sec. In one section of the pit it takes a stone exactly 6.0 seconds to hit bottom. What is the depth of the pit in this spot? (hint $d = 1/2at^2$)

(Lesson Type: Problem Solving) (Teacher: Mr. Davis)
(Course: HPP) (Date: 9-16-86)

T: "No, the two other forms of this basic equation turn out to be this: let's see, Δt over a, and we have another one. We have to divide, ΔV and $V_f - V_i$. So let's take a look on the questions that I got here on the papers and read along with me: Some primitive societies were known to through young maidens into a bottomless pit. O.K., (laughter) it was a sacrifice for one reason or another and young maidens were pitched over into these craters or whatever. Now looking at the first one, young maiden dropped into a bottomless pit have an initial velocity of 0.0 m/sec.. (Write on the board.) After 3 sec. of fall, her velocity is 30 m/sec and the question is what is acceleration? Would you look at that problem and put down the knowns for that particular problem. Now the question how it's written may be clarified a little. So looking at the problem here and as you're looking at it let me put down what I see altogether. And we'll compare. First of all we're told V_i as 0.0 m/sec.; we're told V_f is 30.0 m/sec.; and we're told that the time, the elapsed time of fall, is 3.0 sec., and the unknown of the problem is the acceleration. Now going directly then to the list of choice we go to the cafeteria cart or the smorgasboard of equations. Which we should order for this lunch, we got all of the choices here (looking at a list of equations written on the chalkboard). It looks like the top one is the reasonable choice for the equation to use. Why did I choose the top one? Because it's going to involve the ideas that we need to know, the change in velocity is $V_f - V_i$ so we know what ΔV is right there; and we know the time, and we're looking for a, so that tells us what to do. So we're going to use this equation ($a = \frac{\Delta V}{\Delta t}$ which is the same as saying $\frac{V_f - V_i}{\Delta t} = \frac{30 - 0 \text{ m/sec}}{30}$ = 10. What is the acceleration that the maiden is undergoing? We can say 10 m/sec^2. So the maiden as she is falling, first speed is increasing, and in this particular problem the speed increases ten meters per second every second of fall. So at the send of the first second the speed is what? [Wait for 3 sec.]"

S: "10!"

T: "Ten meters per second. At the moment the clock strikes two seconds what is the speed?"

Ss: "20!"

T: "At three?"

Ss: "40!"

T: What, what if we drop a football instead of maiden? What is the speed of football after 4 sec? [Wait for 3 sec., no responses.] Forty m/sec. Now that assumes that Galileo was right and that objects of different weights fall together, that the maiden and the football fall together. But in this case we are not going into that question, we're just saying that in this case acceleration of the fair maiden would be 10 m/sec^2."

S: "How did you get the meter per second square?"

T: "O.K., it's just a way of expressing the unit. Let me show you why I did get it that way. 10 m/sec./sec.. In other words the acceleration is the rate at which the speed changes. It's not the speed, it's the rate at which the speed changes. It tells us how much the speed changes every moment of time. That's what acceleration is telling us. Good question, but you're wondering why the unit can be written this way or that way, is that your basic question?"

S: "I know ten meters per second, but I don't know ten meters per second square."

T: "I said ten meters per second per second. Acceleration would be having the double seconds in it. There are two units of time. Because in the top one you're talking about speed and the change in speed is the distance divided by time; and you're dividing it by time again. Essentially, you see there is a double time in that thing, the speed is the change in distance divided by the change in time and the acceleration, then, is, shall we say, that it's the change in distance divided by the change in time divided by the change in time. [Students still look somewhat confused.] The reason that I expressed it that way is that the typewriter can't put an exponent. The typewriter can't write second square, it can put a slash, so I expressed it that way m/sec/sec.

Let's see Problem 2. Let's take a look at that problem and put down what we are given. You put the given, and I do the same and we'll compare it. We can write this (10 meter/sec/sec) on your paper as 10 m/sec^2 if you want to. What we are looking for is the change in speed. How do we find the change in speed, Ed? [Wait for 4 sec, no response for Ed was not paying attention.] Guilty! Guilty! What is the best equation to choose, knowing what we're looking for and looking at the cafeteria... Ken, is that good for you? O.K. $\Delta V = a \times \Delta t = 10 \frac{m}{sec^2} \times 6$ sec.

$= 60$ m/sec

Think of it like this 10 m/sec/sec.sec = 60 m/sec. How many saw that as an easy problem and got 66? [Around 2/3 of class raised their hands.] Not 100% but we're getting closer to it. Sixty meters/sec. though is the velocity of the rock as the elapsed time is six seconds; that's the change in speed sixty

meters/sec.. If the stone started at zero; if we just released it without giving it any kind of downward push, then that would be the speed at that moment, because the initial speed was zero. If we threw it downward so it left our hand with an initial speed of 10 m/sec what would the final speed be then? If it initially was going downward, threw it downward, what would be the final speed?"

S(A): "10!:

T: "What?"

S(A): "10!"

T: "What we just found was the change in speed. The change in speed is the difference between the final and the initial. So we all found that the final speed is the same as the change in speeds. If the initial speed is zero. It's hard to put them all together, I realize that. A lot of things being happening here, can you imagine the stone being released! And as time goes by the stone gains speed in a regular pattern 10 m/sec 1 sec.]

Let's go to question 3 "the initial speed of a moving object is 25 meters/sec, and the final speed of this object is 42 meters/sec. What is the change in the speed of the object? [Pause 1 minute.] What was the change in speed of our object?" [No response was given.]

(Lesson Type: Hands-On Activities) (Teacher: Mr. Davis)
(Course: IPS) (Date: 9-21-86)

T: "Here is a good stuff wrapped and put in here, there is a ruler, don't get hooked up on this one because it has inches on one side and centimeters on the other side of the ruler. You're gonna measure in centimeters; measure to the tenth of a centimeter, O.K.! Also in the package is a large rectangular object and two cubes, they're really cute. Look like little miniature dice. Now in this experiment the underlying purpose is to decide not by guessing but by calculation of density if these two cubes are made of the same material. Now if they have the same density one would probably conclude that they might be the same material, the main substance. So, decide whether the two cubes are made of the same material and you do that by measuring the density or by calculating the density. What things do you have to know to calculate density?" [Wait 4 sec.]

S: "Mass and volume!"

T: "Mass and volume, and by our work yesterday, on Friday, we see that density is mass divided by volume, so measure the mass. What unit does mass measure in?"

S: "Grams!"

T: "Grams, volume in?"

S: "Centimeter cube!"

T: "Cubic centimeters! And you divide the mass by the volume. Let me clarify that then, because still people get it confused, if you do it long division [teacher wrote on board] mass goes in the box volume outside and what you end up with your answer over here is the density. O.K., now after you got the decided factor of these two cubes the next question comes up: Is this made of the same material? Or is one of the cubes different? So what you want to do is identify the cubes. You can write on them as "A" and "B"; you can make a decision. The situation then with this experiment is basically done.

(HPP Worksheet: 9-29-86)

Newton's 2nd Law Experiment

Name _____
HR ___ Date ____ S/D

CLASS ANALYSIS.....

(1.) Identify your tape

Constant (Mass / Force) (circle) with a (Mass / Force) (circle) of 1, 2, 3, 4 (circle)

Tape Analysis... d_1 = _____

d_2 = _____

V_1 = _____

V_2 = _____

t_{total} = ( ) No. of intervals .0083 sec - _____ sec

$a = \frac{V_2 - V_1}{t_{total}}$ = _____ cm/sec^2

(2.) Class Analysis

Constant Force		Constant Mass	
Mass	Acceleration	Force	Acceleration
1		1	
2		2	
3		3	
4		4	

(a) With a constant force, how does mass change the acceleration?

(b) With a constant mass, how does force change the acceleration?

(c) Try combining the two ideas above into a word model, then a mathematical model.

(Lesson Type: Hands-On Activity) (Teacher: Mr. Stewart)
(Course: HPP) (Date: 9-29-86)

T: "What we want to do in our experiment is to hold the force constant and vary mass and see what happens to acceleration. We're going to hold the force constant and vary mass. What should we expect to see the acceleration do as we make the mass bigger and bigger? The acceleration will still be there because it's not going to be slowing down, but the acceleration is going to be less: A lesser acceleration. It's going to be picking up speed at a smaller rate. Later on if we hold the mass constant and change the force; what should we expect the acceleration to do in that case?

Class: (choral voice): "Speed up!"

T: "We should expect the acceleration to increase. O.K., now speed up is not really a precise enough way to say, because it's speeding up even when the mass is changing. So the way we're going to do the experiment: let me review this with you once again because last hour when people tried to do the calculation they were having a great deal of difficulty remembering how to do it. Let me go over this procedure with you again. (The teacher held a dotted paper tape in front of the class.) If we have a certain number of dots close together here, when the thing is not going very fast, we can make an interval say of one, two, three, four dots, four spaces, four time intervals; and measure this distance; and then as this proceeds down and makes dots down here and dots get farther and farther apart, we can take a four-dot section down here, four interval section, down here; and measure the distance call that "d_1" and "d_2". Now during this time interval the speed, the average speed was: we call this "V_i", distance over the time it took to go here. The time is four times it takes to go between the dots. One dot is a hundred and twentieth of a second. Four dots is going to be four a-hundred-and-twentieth of a second. So we're going to divide this distance that we'll measure by four one hundred and twentieth which is the same as multiplying that number by a hundred and twenty fourths. You invert when you divide by a fraction, you invert and multiply. We come down here and do the same thing (pointing to the drawing on the board and doing the writing). You get V_2 is equal to this distance divided by whatever, the four over a hundred and twentieth of a second. So you get the speed there. Now we're looking for acceleration. Acceleration, change in speed over time, (wrote $\frac{\Delta v}{\Delta t}$), the change in speed is by much this speed is different than that; so $V_2 - V_1$.

That's the change. What's the difference between the two values of the speed? And then the time. Here is the way you calculate the time. How long did it take to change from this speed to that speed, and that is making the assumption that if that speed at this point in time is the mid-point of time interval, and the speed at that point in time. What time has elapsed between these speeds? So you count the number of dots, every dot is a hundred and twentieth of a second, you count the number and this is what the time is there, t in the equation. It's whatever this number is, over a hundred and twentieth of a second. Then you have change in speed divided by time that gives you acceleration. Now what I'm gonna ask you to do here in the experiment; I'm gonna ask some of you to get us the data. We have the equipment set up on that table and this table. This table over here is going to hold the mass constant the mass in every case will be one brick on the cart. And we're going to vary the force between one, two, three, four of the weights we're having in here, and we're going to have doing this will be; Adam, Tom, Brian, and Ken. (Wrote the names on the board.) Down here, holding the force constant, we're gonna have one weight falling and we're going to change the mass putting different amount of bricks in here. We're going to have, Steve, John, Ron, Ralph. Those people who're going to start getting the equipment set up and the rest of you bring your sheet; and we'll lay assignment for you as they get the taps run up. We'll get the taps delivered and we'll make the assignment here, and you'll start doing this now. So if you're taking data, your going to be given one of those type and asked to measure these things and make the calculation."

(Lesson Type: Lecture-Demonstration) (Teacher: Mr. Stewart)
(Course: HPP) (Date: 9-29-86)

T: "We showed you water waves. Slinky waves were visible and useful because they were travelling slowly. Sound waves, among other reason, they're so familiar in so many aspects with daily existance. So our topic today is going to be sound waves. We'll show you some phenomena on sound. We say sound waves because I am going to be concerned with sound as a wave phenomenon than sound as such. So first of all in order to have sound we have three requirements. One is that you have to have some sort of a source of sound, some sort of vibrating body of some kind. This source, as far as I know, could be a solid, or a gas. To my knowledge I don't believe that I know of any liquids that vibrate and produce sound waves. But there may be some. I just don't know. The second thing you need for sound is some sort of a medium, a transmission medium. In the case of the sound you hear from my voice, it's transmitted by the air in the room. This medium can be a gas such as air in which case sound travels about 332 meters/sec. It varies a little bit depending upon the temperature. At high temperatures it travels at a slightly higher speed. Sound also can travel in a liquid. If you notice that while swimming under the water that sound can travel in a liquid. And it travels somewhat faster in the liquid than in the air above it. Sound can be transmitted by solids. For example, I can think of a couple of examples that sound can be transmitted by solids. One is the old Indian movies, where the indian's trying to listen to the arrival of the oncoming train. And so they press their ear to the railroad track. This is not a good device for detecting short range locomotives; but for a long range it works very well. You can hear a train several miles away that way that steel rails transmitting the sound and you can hear the vibrations of the train coming long before you see it, long before you can hear the sound through the air. Another one, I tried this when I was a kid, I suppose everyone tried this at one time. You can make a tin can telephone. Telephones out of tin cans. You see, when I see the commercial on television where the kid has this can, and the string just wind and lose, you know running off and yelling at this. The other kid holding the other can....What! What! It only worked if the string were tight. So if you have a solid connection between one and the other that it works. And finally you have to have some sort of a receiver. Now the most common receiver for sound you have is your ear. But it's not the only one. And certainly not the only one that's used. There are telephones, there're microphones, various kinds. I went to the hardware store the other day. They have a

light switch, that's sound activated. You clap your hands and you can let the light turn on. So this is a sound receiver as well. Let me just digress you a little bit and talk about your ear. It turns out that your ear is an amazing device that's capable of hearing very soft sounds, but also able of receiving very loud sounds without damage. At least under short terms range, you can hear very loud sounds and have no damage to your ears whatsoever. It's an amazing device that has both sensitivity and power to stand large amounts of noise at the same time. Well, let's concentrate on the ear for just a second. While the ear has a wide range of intensities that it may detect without damage, it also has quite a large range of frequencies that it can detect. And I would like to demonstrate that with you with this device. Here the speed is vibrating at about 300 cycles per second (started an audio oscillator). In fact this frequency range is the general vicinity of human voice: around 300 cycles per second. We hear a lot of sounds in this frequency range, although, surprisingly, this is not the range in which your hearing is most acute. In fact if we increase the frequency a little bit (increased the buzz); a 100 cycles per second. Here is the sound that you can't sing so high, musical notes don't. There are many musical instruments that don't play so high. But here is a region of sound where your hearing is very acute. It's easy to hear that sound against all kinds of background noise. In fact if you have, for example, if you have a warning device on a truck, then pedestrians over the noise of the truck can detect it. It's a sound that's easy to detect. If you have a sound where you try to hear a Morse code, you can hear a Morse code over the other kinds of noise because it's about 1000 cycles per second. Someone was on the street the other day, a motorcycle that had a turn signal that had a 5000 cycles per second peep for the turn signal, so that as the light flashed it gave a peep to remind the turn signal is going. Apparently motorcycles don't have a cancelling feature in terms of turning the signal off when you go around the corner. So it reminds the rider. Well, even though this is true, a thousand cycles per second is very easy to hear, it's not the region where the ear is most acute. The hearing is most acute at a higher frequency that this. I am going to higher tone there and listen to see whether or not your perception it sounds like getting louder [started to raise the pitch]. Is the sound getting higher? Notice at higher frequency it sounds lower. Notice that we reach this region where your ear becomes most acute. Above that the intensity appears to drop up a little bit. And if you go still higher than this: this is 5000 cycles/sec. Our range of maximum acuity of hearing is between 3 and 4000

cycles per second. We're beyond that to 6 and 7, 8 up to 10,000 cycles per second and your ear still picks up that. If you can hear this raise your hand, and for as long as you can hear it keep your hand up. Just look around the class and see how many differ from one person to another. Here is 10,000 cycles per second, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. [Still two hands are up.] You can hear it? It's turned off? Can you hear it? [One hand is still raised.] O.K. dogs and Sam can hear it. Well, your hearing, then; what is the range of your hearing? What is the highest frequency that you can hear at that intensity? What was it? 13? 14? 15,000 cycles? It depends upon a couple of things: male or female. Males can hear higher frequency. The second thing depends upon your age; because as you get older, your high frequency hearing acuity drops off. Your hearing might be gone by 12,000 cycles per second. I don't have to worry about buying expensive stereo pieces anymore because I can't hear that stuff anyway. But the third thing that it depends on is your history. You know, you've been told that listening to pop music over a long period of time damages your ears. And what part of your ear is damaged is the ability to hear high frequency sounds. So where that go-off takes place depends on sex, age, and history of sound. What about lower frequencies? What is the lowest frequency that you can hear. Well, I can't demonstrate that to you for a number of reasons. Number one is, as you go down in frequency...I started from 300 and went up. As you go from 300 down, you get down to the low notes and you should go very gradually from detecting those notes by your ear to detecting those notes by other parts of your body. Specifically your chest cabinet. Have you noticed that as you play music loud, listening to a rock concert. You can feel the low notes that beat the drums, the base notes. You can feel them in your chest, right! You can feel them in the vibrations of the floor; you feel them in your feet. In fact people who have no hearing at all can still learn to dance because they can do it by being sensitive to the vibrations of the body other than ears. So at low frequency it's hard to say where your ear drops off and where you're detecting by some other means. And to get low frequency sounds require much more power, electrical power, than is available here. So, I can't show that. Generally your hearing goes down about, maybe 50 cycles per second; there about what you can hear by your ear.

So sound waves require sources, medium, an elastic medium, and requires some sort of receiver. Let me go back and pick up on some of these individually. Let me talk about sources of sound. In order to have sound waves we have to have a vibrating body of some sort.

In a voice what is the vibrating body that represent the source of the sound? It's the vocal cords. Isn't it? The vocal cords are the things that are actually vibrating. And this is changed by the position of your tongue and lips and so on. But the vibrating body is the vocal cords. I got some unusual examples here of...What is the vibrating body in this case? Here is a plastic tube (started to rotate a plastic tube which gave some sound). What is the source there, the vibrating body?"

Ss: (2) "The hole!"

T: "The hole is there so it isn't the hole. It's the air in the tube. In fact it's the air hitting the edge of that tub that sets it in motion. Tubes, whistles, the various kinds of organ pipes depend on air hitting a sharp edge and setting the air in vibration. Here is an example of the air vibrating. Here is an aluminum rod similar to what you have with stands. [He hit the rod with a hammer at one end, it gave a sound.] It's vibrating back and forth this way. Here is another one, a tuning fork, there is (hit the fork) it's a vibrating body. You will not be able to hear it. So if I set it down here, (he put the fork on the table) you can hear it, because it's making...,this vibration of this is also making the middle part of this vibrating. We'll try it on David's head! Let's see some other examples, strings. Musical sounds are made by sustaining a string between two supports, pulling it and let the string vibrate to produce some sort of a vibration. Vibrating bodies, in a musical instrument, say a trombone: what's the vibrating body in a trombone?"

S: "Lips!"

T: "Lips, vibrate the lips, kind of a thing in the mouth piece and that's what generates the sound, which the trombone then takes from there. What is the vibrating body in a clarinet? It's a flexible thin, reed, as it's called. It could be a strip of plastic or something that you blow against and this is what vibrates. And you can look for any source of sound, you can see that any source of sound is some vibrating body be it a solid or a gas. Let me go back to this one. And I'll show you a little demonstration about the medium required for the transmission of sound. This is a little set-up that I have: on a door bell, [connected a door bell to the power source and it rang.] and a vacuum pump, and a bell jar. Of course if you hear that sound now, it's because the air's transmitting the sound from the bell to your ears. Even if I put the bell jar over it. You'll still be able to hear it, although perhaps not so loud. But when I start taking the air off, (operated the pump) then the amount of sound that gets to you is less and less. [No sound is heard.] [Then let the air in and

the sound is heard again.] So it does require a medium that without it sound will have hard time being transmitted from one to the other. Suppose that you're an astronaut on the moon. The moon doesn't have any air. How can you talk to other astronauts?"

S: "Walky Talky!"

T: "O.K., by radio signals. You have to have around you in space sort a little bubble of air to breath, in order to keep your blood from boiling and so on."

S: "Blood boiling!"

T: "Well, because the temperature at which something boils depends on pressure. And at zero pressure it boils easily at low temperature. So in the space in order to talk even to somebody right next to you, you have to have a microphone, radio waves, radio waves can travel through empty space, it doesn't require air, to his receiver. He receives it back to earphones for him. And that's how you can talk with somebody in empty space. You have to live inside a bubble of air. Your space suit is inflated with air. And so you can have speakers and microphones inside there that will work with sound. And you transmit that sound by radio the other people in vicinity. Let me tell you about a source of sound that is the basis of something that you'll recognize immediately. You recognize this from a TV commercial; well some of you do some of you don't. Many would recognize this from a biography. This whole story, in fact the commercial is based on the story that occurred, that appeared in a biography of Enricko Crusoe. In the early days of radio, Crusoe would sing on the radio, make records; and people loved to listen to him. He'd a very powerful operatic voice. The story goes in the biography of Enricko Crusoe, the biographer apparently wanted to sell books or something, said that Enricko Crusoe to entertain people at cocktail parties by taking a glass and tapping it to the frequency with which the glass naturally vibrates. And then having done that Crusoe, with a voice very powerful and perfect pitch so that the can match that frequency exactly, would hold the glass like this and sing that note.....BLAAAAA! And caused the glass to break, okay. That's the basis of the Memorex commercial. Now you can do this experiment if you have some pretty sophisticated scientific equipment because it takes something like a 130 decibles of sound to break the glass. No voice, Enricko Crusoe's or or anybody else's, had that kind of power. So what this was, was a myth started by the biographer. It was a terrific commercial but it isn't gonna happen. If you want to try with a glass of Coke and turn on somebody singing and cause the glass to break, it's not gonna happen. The amount of sound energy required is too great. A 135 decibles be something like you standing at the end of a runway with a 4 engine jet taking off

with full power at the same time you're operating a jack hammer. At the same time you get your walk band playing full blast. That's what 135 decibles. It's enough to shake your head in pieces. Now there is a..., related to this, that you can do. You have heard that it's possible to make a glass sing! You can do that! You have to have two things happen in order to do that. Number one, it has to be a stem glass. You'll see later on in the demonstration why this is true; it has to have a stem. A straight side glass wouldn't work. It doesn't have to be expensive. It doesn't have to by crystal. This is K-Mart. The second thing you have to have is that you have to have your finger clean. If you are at a dinner party and you want to entertain somebody you have to borrow somebody's glass of water and wash your finger in order to make it work. You can do it. You have to clean your finger and then (started to rub the rim of the glass which started to give sound) rub the rim very lightly. You can make the glass sound. It has to be a stem glass. [Laughter and excitement.]

Other properties of sound which I would like to demonstrate to you. What is this? This is number 4, resonance. Resonance happens when you have two....well,...First of all before you can understand resonance, let me tell you about natural frequency. Natural frequency is the frequency that any elastic body would vibrate at. It's a unique frequency. It's a frequency....that which any elastic body will vibrate at. It turns out that any object will have a natural frequency. A tuning fork 320 cycles per second; this glass, that was the same one when you rubbed it. Every elastic body has a natural frequency. Even large things that you wouldn't think have natural frequencies, sometimes do. I had a 1960 Pontiac. I never bought a Pontiac since, and this is may be the reason why. The 1960 Pontiac at about 57 miles/hr you would have a huge roar inside the Pontiac. There was an enormous roar. I took it back to the dealer. I said: Good heavens! What's going on! He said you just got bad tires. I'm just gonna balance the tires and everything will be fine. Went back to get the car, drove away from the dealer, picked up speed, 55, 56, 57, HOOOOOOO inside the car. I took a turn around and drove back to the dealer and said did you check this? He said I didn't have to check it. It had bad tires and I balanced them. Gentlemen if you please! (Couple of students are hastling.) [Some argument between the teacher and one of them. The voice is not clear on tape.] So I asked the dealer take a road test. He said no I didn't have to do that. And I said come on. We went on 57 miles per hour and here is the roar again. He never was able to find why. He called the factory. The factory representative finally said;

well, we're working on it. He said we're not sure whether it's the floor panel of the car that's vibrating or the roof panel that's vibrating at that frequency. The natural frequency of this just matched 55 or 57 miles/hr and vibrating at that frequency.

Another example on resonance is that of a bridge. We had a bridge that it's natural frequency just matched what you get at winds in excess of 35 miles an hour. So they know at low speeds, at low wind velocity the bridge would vibrate. In fact above 20 miles per hour there was much..., and they calculate it and so as soon as the wind gets 35 miles per hour the ridge would collapse and come down. And sure enough, one day the high winds that blew at 35 miles an hour, they closed the bridge for traffic at both sides and they watched the thing vibrate higher and higher with a natural frequency and eventually exceeded the strength of the cables and the whole thing crashed. Nowadays when they build bridges they take care to prevent that. When they designed the big Mack bridge they did a couple of things to prevent that. Number one, they changed the resonance frequency so there wasn't going to be anything like when you get winds in the State of Michigan. At the center, two lanes of the bridge, it's open grading. It's not paved or cemented, but open grade. So that if the bridge does get vibrating from the wind, the wind can blow through that grading and doesn't hit a whole slab of cement. And that's one of design construction features that they made. The other thing hey did is that angled the bridge, they arched the bridge slightly into the wind which is very difficult to see. It looks like straight but it's curved slightly towards the west to prevent that. If you're in the military and you're marching along. If you march across a bridge your office will tell you to break step so that people are not marching with the same step across the bridge because it can happen that it could be the natural frequency. Resonance is when you match...is the match of two natural frequencies. Some examples of resonance where you're matching natural frequencies. The best example I can give you is the one you're most familiar with: tuning a radio. There's a radio station in the area that broadcasts at 106.1 million cycles per second, 106.1 megacycles per second, Mega Hertz. In order to listen to that signal you have a circuit in the radio whose frequency, natural frequency, you can adjust. So you got this frequency coming in you match the natural frequency of your radio to 106.1 and you get the station. If you want to change the frequency of your radio you can match it to frequencies of other radio stations and resonance then takes place and you're able to pick up that signal. And so that's an example of resonance of matching two natural frequencies. We'll give you an

example here with sound of matching two natural frequencies. Here is a natural frequency of any column of air and you can get it sound by blowing across it (doing the blowing). Here's another frequency that is different. This is 320 cycles per second [tuning fork]. I can't adjust that, but I can adjust the natural frequency of this, (column of water) by changing the length. Change the length by adding some water to it. (Started to add some water while bringing the fork close to the opening until it resonates.) Here I got the natural frequency of the column of air and the natural frequency of these are matched. And so I have a resonance. That's the basis of musical instruments. This musical instrument consists of a flat table of bars of varying lengths. Underneath are tubes of different lengths, long tubes for low notes."

S: "Xylophone, xylophone!"

T: "Xylophone, and a number of musical instruments based on this kind of principle where you have a resonance between a vibrating body and a column of air. Well, the last thing I want to tell you about is standing waves. It's a sound phenomenon, but it's also a wave phenomenon generally. The first example is not sound at all. But I'll give you some examples on standing waves in sound. Standing waves require identical waves travelling in opposite direction in the same medium. That's the condition for standing wave. The normal, the most often encountered standing waves you get is by reflection. Suppose that you have a string fastened at the ends; and if you put a pulse up here, this pulse can travel down and reflect up. If you continue to put pulses here; in other words, you put a periodic vibrator you can get waves travelling this direction, reflected off here and waves travelling this direction. They're identical waves because they're the same wave one is just reflected. So they're identical waves travelling in opposite direction. So you have the conditions for a standing wave. I have a demonstration here and I would like you to help me on this. What I need you to have you do is change the speed here...Here is my medium. We're gonna use a string here. [Teacher started the motor vibrator.] Now we got the conditions for standing waves here. O.K., here is the source of the waves down there coming down here reflected off this end back and so we got the condition for a standing wave: identical waves travelling in opposite direction. You have a node. That is the position of a minimum activity of the medium. (Pointing to points on the string where they look stationary.) You can see where the nodes are. These are called antinodes: regions of maximum activity. (Pointing to points of high amplitude.) And you can see that the wave consists of a series of antinodes and nodes. I'll play on here

to get a different number of nodes. It's kind of fun to see what happens. We got four loops on there. Standing waves: identical waves travelling in opposite directions in a medium. Let's see sound waves. Here's a section of pipe that we can fill with gas. Now the end of the tube is filled with a piece of rubber sheet, and I can vibrate...What I am going to do is put a wave in the tube and let the wave to stand. [He made a sound from the oscillater at the opening of the tube.] There're waves that're standing inside that tube. Now when waves stand like this there is a complete wave. Here your antinodes, here's your nodes. Notice that the distance between nodes is simply a fraction of a wavelength. What fraction of a wavelength is it? What fraction of a wavelength is represented by this space between the nodes?"

S: "Half!"

T: "It's half, isn't it! Here is a wavelength there, a whole wave, and the distance between the nodes is simply half of the wavelength. And so it's a very convenient way to measure a wavelength by letting the wave stand, and measure the distance between adjacent nodes, and you know that's a half wavelength. So in this experiment we can read the frequency on the dial; we can measure the distance between the nodes in the pipe and we can calculate the speed in which sound is travelling in this tube, or in the natural gas we are using in the tube. Well, resonance, standing waves is the basis of many musical instruments. The simplest of all musical instruments is simply a tube. This tube is going to be set into vibration by moving one end through here and making (inaudible) over there. The other end since it's open has to be an antinode as well. So the simplest configuration would be antinodes at the ends and a node at the center. But the only restriction you have on this is that you have antinodes at the ends and at least one node. It could be. [The teacher was turning the plastic tube again.]"

MICHIGAN STATE UNIVERSITY

UNIVERSITY COMMITTEE ON RESEARCH INVOLVING
HUMAN SUBJECTS (UCRIHS)
298 ADMINISTRATION BUILDING
(517) 355-2186

EAST LANSING • MICHIGAN • 48824-1046

September 9, 1986

Mr. Ribhi Abu Isneineh
Teacher Education
216 Erickson Hall

Dear Mr. Isneineh:

Subject: Proposal Entitled, "An Ethnographic Study of a High School Science Teacher's Personal Practical Knowledge of Subject Matter"

UCRIHS' review of the above referenced project has now been completed. I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and the Committee, therefore, approved this project at its meeting on September 8, 1986.

You are reminded that UCRIHS approval is valid for one calendar year. If you plan to continue this project beyond one year, please make provisions for obtaining appropriate UCRIHS approval prior to September 8, 1987.

Any changes in procedures involving human subjects must be reviewed by the UCRIHS prior to initiation of the change. UCRIHS must also be notified promptly of any problems (unexpected side effects, complaints, etc.) involving human subjects during the course of the work.

Thank you for bringing this project to our attention. If we can be of any future help, please do not hesitate to let us know.

Sincerely,

Henry E. Bredeck
Chairman, UCRIHS

HEB/jms

cc: Dr. J. J. Gallagher

MSU is an Affirmative Action/Equal Opportunity Institution

Date: July 28, 1986

MICHIGAN STATE UNIVERSITY
JUL 30 1986
OFFICE OF RESEARCH DEVELOPMENT

To: Dr. Henry Bredeck
Assistant Vice President
238 Administration Building

From: Ribhi Abu Isneineh (Graduate Student)
216 Erickson Hall, College of Education, MSU

Subject: Human Subject Clearance

Dear Dr. Bredeck,

Enclosed are documents related to my request to seek university clearance prior to conducting my research proposed to be done during the period of August 26, 1986 to February 1, 1987, and will involve one teacher. Documents enclosed include the following:

1. Six copies of a document containing information according to the Committee's guidelines.

2. A copy of my research proposal which has already been approved by my advisory committee members.

3. A signed statement from my major professor Dr. J. Gallagher.

The study described in these documents is a continuation, but in a new direction of the Institute for Research on Teaching (IRT) Secondary School Science Project coordinated by Dr. Gallagher. I have been working for this project since it began two years ago. Thank you for your consideration of this matter.

Sincerely,

Rihbi Abu Isneineh

R Abu Isneinel

CONSENT FORM

I, the undersigned, freely consent to continue participation in educational research conducted by Mr. Ribhi Abu Isneineh, Ph.D. candidate in the Department of Teacher Education. The study has been explained to me, and I understand the explanation that has been given as well as what my participation will involve.

I understand that the researcher, in conjunction with me and Dr. J. Gallagher will use the fieldnotes, discussions, and interviews for his research work. I also understand that some of the discussions or interviews may be taperecorded. I understand that every effort will be made to gurantee confidentiality and to protect anonimity in published reports which I will have opportunity to review whenever possible.

I understand that my participation in the study may result in benefits for myself as a science teacher as well as other science teachers, however, such beneficial results are not guaranteed.

I understand that I am free to discontinue participation in the study at any time without recrimination.

REFERENCES

Abu Isneineh, R. (1986a). High school science teachers' role conceptions as reflected in their classroom practices and discussions. Paper presented at the 59th Annual Conference of the National Association for Research in Science Teaching, San Francisco, California.

Abu Isneineh, R. (1986b). An ethnographic study of a high school science teachers' personal practical knowledge of the subject matter. (Research Proposal) 252 Erickson Hall, East Lansing, MI 48823.

Abu Isneineh, R., & Contreras, A. (1987). An ethnographic study of a high school physics laboratory: An experiment on acceleration. Paper presented at the 60th Annual Meeting of the National Association for Research in Science Teaching, Washington, D.C.

Aikenhead, G.S. (1984). Teacher decision making: The case of Parairie High. Journal of Research in Science Teaching, 21 (2), 167-186.

Anderson, C.W., & Smith, E.L. (1986). Teaching science. (Research Series No. 168). East Lansing, MI: Institute for Research on Teaching, Michigan State University.

Barnes, B. (1974). Scientific knowledge and sociological theory. London and Boston: Routledge & Kegan Paul.

Barr, R. (1980). School, class, group, and pace effects on learning. (Working Paper Series #2). Education Finance and Productivity Center: Department of Education, University of Chicago.

Barr, R., & Dreeben, R. (1980). A sociological formulation of the way first grade classroom and instructional group organizations affect learning to read. (Working Paper Series #3). Education Finance and Productivity Center: Department of Education, University of Chicago.

Barr, R., & Dreeben, R. (1983). How schools work. Chicago: The University of Chicago Press.

Becker, H.S., & Geer, B. (1957). Participant observation and interviewing: A comparison. Human Organization, 16 (3), 28-36.

Berlak, A., & Berlak, H. (1981). Dilemmas of schooling: Teaching and social change. New York: Methuen.

Berger, B.L., & Luckmann, T. (1967). The social construction of reality: A treatise in the sociology of knowledge. Garden City, New York: Doubleday & Company, Inc.

Blumer, H. (1969). Symbolic Interactions: Perspective and Method. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Buchmann, M. (1983). The priority of knowledge and understanding in teaching. (Occasional Paper No. 61). East Lansing, MI: Institute for Research on Teaching, Michigan State University.

Buchmann, M. (1986). Teaching knowledge: The lights that teachers live by. (Occasional Paper No. 106). East Lansing, MI: Institute for Research on Teaching, Michigan State University.

Chi, M.C.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Christenbury, L. (1983). The elective curriculum: Origin, development, and decline. English Education, 15, 73-91.

Clandinin, D.J., & Connelly, F.M. (1987). Teachers' personal practical knowledge: What counts as 'personal' in studies of the personal. Journal of Curriculum Studies, 19 (6), 487-500.

Clandinin, J. (1985). Personal practical knowledge: A study of teachers' classroom images. Curriculum Inquiry, 15 (4), 360-385.

Clark, C.M. (1980). Choice of a model for research on teacher thinking. Journal of Curriculum Studies, 12, 41-47.

Clark, C.M., & Peterson, P.L. (1984). Teachers' thought processes (Occasional Paper No. 72) East Lansing, Michigan State University, Institute for Research on Teaching.

Clark, C.M., & Yinger, R.J. (1979). Teachers' thinking. In P.L. Peterson & H.J. Walbert (Eds.), Research on teaching: Concepts, findings, and implications. Berkeley, CA: McCutchan Publishing Company.

Cohen, David K. (1984). The conditions of teachers' work. Harvard Educational Review, 15, 11-15.

Collett, A.T., & Chiappetta, E.L. (1984). Science instruction in the middle and secondary schools. Columbus: Charles E. Merrill Publishing Company.

Connelly, F.M. (1972). The functions of curriculum development. Interchange, 3, 161-177.

Connelly, F.M., & Clandinin, D.J. (1984). Teachers' personal practical knowledge. In R. Halkes & J. Olson, (Eds.), Teacher thinking: A new perspective on persistent problems in education. Heirwig, Holland, Swets Publishing Service.

Connelly, F.M., & Clandinin, D.J. (1985). Personal practical knowledge and the modes of knowing: Relevance for teaching and learning. In E. Eisner, (Ed.), Learning and teaching the ways of knowing. NSSE Yearbook (pp. 174-198). Chicago: University of Chicago Press.

Conners, R.D. (1978). An analysis of teacher thought processes, beliefs, and principles during instruction. Unpublished doctoral dissertation, the University of Alberta, Canada.

Crane, D. (1972). Invisible college: Diffusion of knowledge in scientific communities. Chicago: The University of Chicago Press.

Cusick, P.A. (1983). The egalitarian ideal and the American high school. New York: Longman.

Diorio, J.a. (1982). Knowledge, autonomy, and the practice of teaching. Curriculum Inquiry, 12 (3), 257-282.

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

Doyle, W. (1977). Learning the classroom environment: An ecological analysis. Journal of Teacher Education, 28, 51-55.

Doyle, W., & Ponder, G.A. (1977). The practicality ethic in teacher decision-making. Interchange, 8 (3), (1-12).

Dreeben, R. (1973). The school as a workplace. In R.M.W. Travers (Ed.), Second handbook of research on teaching. Chicago, IL: Scott Foresman.

Dretske, F. (1982). Knowledge and the flow of information: Cambridge. Massachusetts: The MIT Press.

Duke, D.L. (1984). Teaching: The imperiled profession. Albany: State University of New York Press.

Elbaz, F. (1987). Response to Clandinin and Connelly. Journal of Curriculum Studies, 19 (6), 501-502.

Elbaz, F. (1983). Teacher thinking, A study of practical knowledge. New York: Nichols.

Elliot, J. (1976). Developing hypothesis about classrooms from teachers' constructs: An account of the work of the Ford teaching project. Interchange, 7 (2), (2-22).

Erickson, F. (1985). Qualitative methods of research on teaching. (Occasional Paper No. 81). East Lansing: Michigan State University, Institute for Research on Teaching.

Erickson, F. (1982a). Classroom discourse as improvisation: Relationships between academic task structure and social participation structure in lessons. In L.C. Wilkinson (Ed.), Communication in the classroom. New York: Academic Press, pp. 153-181.

Erickson, F. (1982b). Taught cognitive learning in it immediate environments: A neglected topic in anthropology of education. Anthropology and Education Quarterly, 13 (2), 149-180.

Erickson, F., & Schultz, J. (1981). When is a context? Some issues and methods in the analysis of social competence. In J. Green and C. Walcott (Eds.), Ethnography and language in educational settings. Norwood, N.J., ABLEX Publishing Company, pp. 147-160.

Feimen-Nemser, S., & Floden, R.E. (1984). The cultures of teaching. (Occasional Paper No. 74). East Lansing: Michigan State University, Institute for Research on Teaching.

Fleck, L. (1979). Genesis and development of a scientific fact. Chicago: The University of Chicago Press.

Frake, O. (1980). Language and cultural description. Stanford, California: Stanford University Press.

Fuller, F.F. (1969). Concerns of teachers: A developmental characterization. American Educational Research Journal, 6, 207-226.

Gallagher, J.J. (1986). Secondary school science (Interim Report). East Lansing: Michigan State University, Institute for Research on Teaching.

Goodlad, J. I. (1984). A place called school: Prospects for the future. New York. McGraw-Hill Book Company.

Green, J.L. (1983). Research on teaching as a linguistic process: A state of the art. In Gordon, E.W. (Ed.), Review of research in education. Washington, D.C. 20036, 1230 Seventeenth Street, N.W.: American Educational Research Association.

Green, J.L., & Harker, J.O. (1982). Gaining access to learning: Conversational, social, and cognitive demands of group participation. In Wilkinson, L.C. (Ed.), Communicating in the classroom. New York: Academic Press.

Geertz, C. (1983). Local knowledge: Further essays in interpretive anthropology. New York: Basic Books, Inc. Publishers.

Glaser, B., & Strauss, A. (1973). The discovery of grounded theory: Strategies for qualitative research. Chicago: Aldine.

Glaser, R. (1983). Education and thinking: The role of knowledge. (Technical Report No. PDS-6). Learning Research and Development Center: University of Pittsburg.

Goetz, J.P., & LeCompte, D.L. (1984). Ethnography and qualitative design in educational research. New York: Academic Press.

Gordon, R.L. (1980). Interviewing: Strategy, techniques, and tactics. Homewook, Illinois: The Dorsey Press.

Halkes, R. (1986). Reports. Journal of Curriculum Studies, 18 (2), 211-214.

Hargreaves, A.C. (1984)· The significance of classroom coping strategies. In Hargreaves, A., & P. Woods (Eds.), Classrooms and staffrooms: The sociology of teachers and teaching. Milton Keynes: Open University Press.

Hargreaves, A., & Woods, P. (Eds.) (1984). Classrooms and staffrooms: The sociology of teachers and teaching. Milton Keynes: Open University Press.

Hashweh, M. (1985). An exploratory study of teacher knowledge and teaching: The effects of science teachers' knowledge of subject-matter and their conceptions of learning on their teaching. Unpublished doctoral dissertation, Stanford University, Stanford, California.

Hawkins, I. (1974). I, though, and it. In I. Hawkins, The informed vision: Essays on learning and human nature. N.Y.: Agathon Press.

Hempel, C.G. (1952). Fundamentals of concept formation in empirical science. Chicago: The University of Chicago Press.

Hempel, C.G. (1965). Aspects of scientific explanation and other essays in the philosophy of science. New York: The Free Press.

Holmes Group (1986). Tomorrow's teachers. 501 Erickson Hall, East Lansing, MI: The Holmes Group, Inc.

Jackson, P.W. (1968). Life in classrooms. New York: Holt, Rinehart & Winston.

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

Kennedy, M.M. (1983). Working Knowledge. Knowledge: Creation Diffusion, Utilization, 5 (2), 193-211.

Kitchener, R.F. (1986). Piaget's theory of knowledge: Genetic epistemology and scientific reason. Yale University Press: New Haven and London.

Kuhn, T. (1968). The structure of scientific revolutions. Princeton, N.J.: Princeton University Press.

Lacey, C. (1977). The socialization of teachers. London: Methuen.

Lakoff, G., & Johnson, M. (1980). Metaphores we live by. Chicago: University of Chicago PRess.

Lanier, J.E. (1984). Research on teacher education. (Occasional Paper No. 80). East Lansing, MI: Institute for Research on Teaching; Michigan State University.

Lantz, O., & Kass, H. (1987). Chemistry teachers' functional paradigms. Science Education, 71 (1), 117-133.

Leinhardt, G., & Greeno, J.G. (1986). The cognitive skill of teaching. Journal of Educational Psychology, 78 (2), 75-96.

Leinhardt, G., & Smith, D. (1985). Expertise in mathematics instruction: Subject matter knowledge. Journal of Educational Psychology, 77 241-271.

Lieberman, A., & Miller, L. (1984). Teachers, their world and their work: Implications for school improvement. 224 North Washington Street, Alexandria, Virginia: Association for Supervision and Curriculum Development.

Lortie, D.C. (1975). Schoolteacher: A sociological study. Chicago: University of Chicago Press.

MacIntyre, A. (1981). After virtue. A study of moral theory. London: Gerald Duckworth & Co. Ltd.

Marland, P. (1987). Response to Clandinin and Connelly. Journal of Curriculum Studies, 19 (6), 503-505.

Marland, P.W. (1977). A study of teachers' interactive thoughts. Unpublished doctoral dissertation, the University of Alberta, Canada.

Marton, F. (1986). Phenomenology: A research approach to investigating different understandings of reality. Journal of Thought, 21 (3), Fall 1986.

McCall, G.J., & Simmons, J.L. (1969). Issues in participant observation: A text and reader. Reading, Mass.: Addison-Wesley Publishing Company.

Mehan, H. (1979). Learning lessons: Social organization in the classroom. Cambridge, Massachusetts: Harvard University Press.

Mehan, H., & Wood, H. (1976). The reality of ethnomethodology. New York: John Wiley & Sons.

Miller, S.M. (1969). The participant observer and "over-rapport". In McCall, G.J., & J.L. Simmons (Eds.). Issues in participant observation: A text and reader. Reading, Mass: Addison-Wesley Publishing Company.

Mills, C.W. (1959). The sociological imagination. New York: Oxford University Press.

Mokrzycki, E. (1983). Philosophy of science and sociology: From the methodological doctrine to research practice. London: Routledge & Kegan Paul.

Munby, H., & Spafford, C. (1987). Response to Clandinin and Connelly. Journal of Curriculum Studies, 19 (6), 507-509.

Munby, H. (1982). The place of teachers' beliefs in research on teacher thinking and decision making, and an alternative methodology. Instructional Science, 11, 201-225.

Munby, H. (1984). A qualitative approach to the study of a teachers' beliefs. Journal of Research on Science Teaching, 21, 27-38.

Munby, H. (1986). Metaphor in the thinking of teachers. Journal of Curriculum Studies, 18, 197-209.

Munz, P. (1985). Our knowledge of the growth of knowledge: Papper or Wittgenstein. London: Routledge & Kegan Paul.

Nash, L.K. (1963). The nature of natural sciences. Boston: Little, Brown and Company.

Natanson, M. (Ed.). (1970). Phenomenology and social reality: Essays in memory of Alfred Schultz. The Hague: Martinus Nijhoff.

National Commission on Excellence in Education (1983). A nation at risk: The imperative for educational reform. Washington, D.C.: U.S. Dept. of Education.

National Science Board Commission on Precollege Education in Mathematics, Science, and Technology (1983). Educating Americans for 21st century. Washington, D.C.: National Science Foundation.

Olson, J.K. (1981). Teacher influence in the classroom. Instructional Science, 10, 259-275.

Ortony, A. (Ed.) (1980). Metaphor and thought. Cambridge University Press.

Philips, D. L. (1977). Wittgenstein and scientific knowledge: A sociological perspective. Rowman and Littlefield: Totowa, New Jersey.

Polanyi, M., & Prosch, H. (1975). Meaning. Chicago: The University of Chicago Press.

Polanyi, M. (1958). Personal Knowledge. Chicago, the University of Chicago Press.

Pollard, A. (1980). Teacher interests and changing situations of survival threats in primary school classrooms. In P. Woods (Ed.) Teacher strategies. London: Croom Helm.

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

Postman, N., & Weingartner, C. (1971). Teaching as a subversive activity. Harmondsworth: Penguin Education.

Putnam, R.T., & Leinhardt, G. (1986). Curriculum scripts and the adjustment of content in mathematics lesson. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, California.

Reid, W.A. (1979). Schools, teachers, and curriculum change. Educational Theory, 29, 325-336.

Roberts, D.A. (1980). Theory, curriculum development, and the unique events of practice, in H. Munby, G. Orpwood, and T. Russal (Eds.), Seeing curriculum in a new light. Toronto, Canada: OISE.

Roberts, D.A. (1982). The place of qualitative research in science education. Journal of Research in Science Teaching, 19 (4), 277-299.

Romberg, T.A., & Carpenter, T.P. (1986). Research on teaching and learning mathematics: Two disciplines of scientific inquiry. In Wittrock, M.C. (Ed.) Handbook of research on teaching. New York: MacMillan Publishing Company.

Sarason, S.B. (1982). The culture of the school and the problem of change (2nd ed.). Boston, MA: Allyn and Bacon.

Schatzman, L., & Strauss, A.L. (1973). Field research: Strategies for a natural sociology. Englewood Cliffs, NJ: Prentice Hall.

Scheffler, I. (1967). Science and subjectivity. New York & Kansas City: The Bobbs-Merrill Company, Inc.

Schon, D.A. (1983). The reflective practitioner: How professionals think in action. New York. Basic Books, Inc.

Schulman, L.S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15 (2), 4-14.

Schutz, A. (1973). Collected papers: The problem of social reality. The Hague: Martinus Nijhoff.

Schwab, J.J. (1964). Structure of the disciplines: Meanings and significance. In G.W. Ford and L. Pugno (Eds.), The structure of knowledge and the curriculum, (pp. 6-30). Chicago: Rand McNally.

Sedlak, M.W., Wheeler, C.W., Pullin, D.C., & Cusik, P.A. (1986). Selling students short. New York: Teachers College Press.

Shapiro, M.J. (1981). Language and political understanding: The politics of discursive practices. New Haven: Yale University Press.

Shavelson, R.J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgements, decisions, and behavior. Review of Educational Research, 51, 455-498.

Sikes, P.J., Measor, L., & Woods, P. (1985). Teacher careers: Crises and continuities. London: The Falmer Press.

Simon, D.P., & Simon, H.A. (1978). Individual differences in solving physics problems. In R.S. Siegler (Ed.), Children's thinking: What develops? (325-348). Hillsdale, NJ: Erlbaum.

Sizer, T.R. (1984). Horace's compromise: The dilemma of the American high school. Boston: Houghton Mifflin.

Spindler, G. (Ed.) (1982). Doing the ethnography of schooling: Educational anthropology in action. New York: Holt, Rinehart and Winston.

Spradley, J.P. (1980). Participant observation. New York: Holt, Rinehart and Winston.

Stake, R.E., and Easley, J.A. (1978). Case studies in science education. Center for Instructional Research and Curriculum Evaluation and Committee on Culture and Cognition, University of Illinois at Urbana - Champaign.

Terhart, E. (1985). The adventure of interpretation: Approaches to validity. Curriculum Inquiry, 15 (4), 451-464.

Tobin, K. (1987). Forces which shape the implemented curriculum in high school science and mathematics. Teaching and Teacher Education, 3 (4), 287-298.

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

Tobin, K., & Gallagher, J.J. (1987b). Target students in the science classroom. Journal of Research in Science Teaching, 24 (1), 61-67.

Watts, M., & Bentley, D. (1986). Methodological congruity in principle and in practice: A dilemma in science education. Journal of Curriculum Studies, 18 (2), 167-175.

Whitty, G., & Yound, M. (1976) (Eds.). Explorations in the politics of school knowledge. Nafferton: Nafferton Books.

Woods, P. (1984). Teaching for survival. In Hargreaves, A., and P. Woods (Eds.) Classrooms and staffrooms: The sociology of teachers and teaching, Milton-Keynes: Open University Press.

Young, M.F.D. (Ed.), (1971). Knowledge and control: New directions for the sociology of education. London: Collier-MacMillan Publishers.