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CONSTRUCTING SUBJECT MATTER IN HIGH SCHOOL PHYSICS: AN ETHNOGRAPHIC STUDY OF THREE EXPERIENCED PHYSICS TEACHERS

By

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ABSTRACT

CONSTRUCTING SUBJECT MATTER IN HIGH SCHOOL PHYSICS: AN ETHNOGRAPHIC STUDY OF THREE EXPERIENCED PHYSICS TEACHERS

By

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The purpose of this study was to examine the way in which experienced high school physics teachers construct subject matter in their daily interaction with students. The goal of the study was to derive detailed accounts of how teachers enact similar instructional units and topics as they strive to communicate the information content imbedded in them.

Data were gathered over a period of six consecutive months of a school year using ethnograhic techniques: participant observation, videotaping, document gathering and teacher interviews. The study of the coherence of the three teachers' discourses in an instructional unit on dynamics, showed that experienced, qualified physics teachers differentially construct subject matter by breaking the unit into topics that may or may not be logically connected. Also, analysis of the coherence of a common single topic, such as Newton's Second Law, revealed that the teachers enacted a series of logical successive steps that had different antecedents and eventual usages throughout the discourse.

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In addition to structural patterns in the way information content was temporally and logically organized, there were variations in the way teachers sequentially organized the physical materials used in teaching the content.

The study has implications for practice and research on preservice and inservice education and student learning. Its main contribution to the language of teaching and learning lies in the introduction of the notions of topic and coherence, two constructs borrowed from discourse analysis, as an alternative to interpreting subject matter enactment. A second contribution is an extensive corpus of datum in videotape formats that can eventually be used for further analysis and teacher practice. In this sense, inservice physics teachers can reflect upon their own discourse when organizing subject matter, and in doing so, make the changes they consider appropriate for students' understanding. Also, perspective physics teachers, and science teachers in general, can benefit from the strategies used by more experienced teachers to organize similar organic units and topics. The findings also direct attention to the issue that a large cohort of high school students are learning differently organized bodies of knowledge under a common rubric. This suggestion has some implications for those concerned with the assessment of the knowledge students are constructing out of schooling.

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This study is an ethnographic research to learn about how experienced teachers organize subject matter. To gather the data and make the proper references with respect to this question, the researcher established a close and personal relationship with teachers and students. Because of this, the necessary steps have been taken to protect anonymity of those involved. Pseudonyms have been used throughout this study, to protect the privacy of students and teachers.

Throughout the body of this dissertation, quotation marks (" ") have been used to indicate the exact words of the speaker. If the quotation was longer than five lines, it was typed in the block format. These quotations are generally followed by a notation indicating the source and the date; for example, fieldnotes, September 22, 1986 means the quotation was "pulled out" from the fieldnote set taken on September 22, 1986. In the case of long discourse segments from videotape transcripts, the source is generally identified at the beginning of the transcript, using the following items: teacher's name, topic, time frame and date. (Details of specific notations used in the transcripts are given in Appendix K.) There are a few places in study where it was necessary to paraphrase what the speaker was saying. In those cases, the single quotes (' ') was used instead.

CHAPTER ONE

INTRODUCTION

The purpose of this introductory chapter is to provide the reader with a general overview of the study. It provides a brief description of the nature of the problem, followed by a description of the questions addressed, and a summary of the research methodology. Also, the assumptions made in the study are given as well as a summary. The chapter ends with an overview of the dissertation itself.

The Problem

As the title of this study suggests, teachers in their daily interaction with students, books and other instructional materials, enact subject matter as they select the "academic work" (Doyle, 1983) students are expected to do. Through these instructional processes, students acquire information, and learn the skills necessary to assimilate such information.

The purpose of this study was to research the nature of teacher interaction in order to describe how school subject matter is enacted in real time. The study of the subject matter (i.e., what is taught and how it is taught) is a common concern among policy makers (Bybee, Carlson &

McCormick, 1984; National Research Council, 1985; Holmes Group, 1986), and educational researchers (Doyle, 1983; Erickson, 1982; Buchmann, 1983) for it has profound consequences on what students are learning: the fundamental reason for schooling. Buchmann (1983) highlighted the importance of subject matter when she pointed out that "content knowledge is a logical precondition for the activities of teaching; without it, teacher activities such as asking questions or planning lessons hang altogether in the air" (p. 23).

One aspect of concern with respect to school subject matter is how it is organized and accomplished in the classroom (Doyle, 1983). A second concern is learning how to construct and enact subject matter for meaning (Doyle, 1986). Researchers agree that these topics have been neglected in contemporary empirical studies on research on teaching and learning -- specifically, in research studies that focus on the nature of teacher interactions (Cazden, 1986; Erickson, 1986b). Teacher interaction can be seen as having two major functions (Lemke, 1982b; Erickson, 1982a). The first major function is to produce and maintain the social roles that are appropriate and expected from the participants in a classroom setting such as asking questions, lecturing, working in groups, etc. (Mehan, 1979; Florio, 1978). A second function is to construct the content of the subject by tying together different pieces of knowledge as organic units in the form of themes or topics (Lemke, 1981a; Stubbs, 1981). In a recent review on classroom discourse, Cazden (1986) indicated that studies pertaining to the nature of the relationship between classroom social structure and the school academic content are still rare. Generally, studies of classroom discourse have focused on the social structure of the class and have ignored the subject matter content being communicated in the discourse. Erickson (1982) acknowledged that subject matter has been neglected in his research when he pointed out that, in his observation of arithmetic classes,

> There were descriptions of social relations that were partly constituted by subject matter (by its logic of sequencing) and by the cues present that pointed to the sequential steps in task completion, yet my notes contained no mention of the actual subject matter content. What appeared in the notes were data about turn-taking patterns in conversations, the exercise of social control by the teacher, cultural patterns in the children's speech and nonverbal behavior. There was relatively little reference to what the teacher and the students were talking about and taking turns at or to the instructional aims toward which social control was being exercised. (p. 157)

Erickson's assertion has a parallel within research traditions that focus on the measurement of teachers' characteristics and instructional program effectiveness. As Doyle (1983) argued, school subject matter has been neglected in contemporary research at the expense of studies on topics such as amount of praise, the frequency and types of questions, time spent lecturing, ways of providing feedback and reinforcement, student perceptions and behaviors and cognitive operations.

A second set of concerns is how different teachers enacted and organized subject matter across different disciplines and within a single discipline. As early as 1973, Shulman and Tamir pointed out that sequencing of subject matter had been a "disappointing variable" in science education research due to the limited way in which that variable had been "experimentally manipulated." These authors hypothesized the existence of four different ways in which one could look at content organization and sequencing in a particular discipline: (a) the order in which the elements of instruction are presented within a single lesson; (b) the order in which lessons are sequenced within an instructional unit; (c) the order in which units are sequenced within an instructional term; and (d) the order in which instructional programs are sequenced and/or correlated across a multi-year curriculum. Shulman and Tamir (1973) pointed out that most empirical studies were of the first type, i.e., the study of single lessons, while the other three remained relatively "innocent of empirical trammeling" in spite of their importance for curriculum planning and development. More recently, in a review of research from the Institute for Research on Teaching, Porter and Brophy

(1987) reinforced a similar assertion when they pointed out that:

> Research tends to look at teaching in small segments, typically concentrating only on particular lessons taught within one subject matter area. More attention needs to be focused on larger units of instruction and on what is required to teach effectively all day, every day, year after year. (p. 23)

The study of subject matter knowledge through time and across different disciplines and teachers, as well as within specific disciplines, can provide us with multiple ways of teaching a topic or set of topics (Shulman, 1986).

This leads us to the third major concern: the teaching of school disciplines, such as physics, which have a "logical grammar" (in Hirst's sense) that need to be respected when the discipline is enacted. As Hirst (1974) stated, "this logical grammar involves an order of terms such that the meaning of certain terms presupposes the meaning of others" (p. 129). For example, the meanings of "acceleration" and "momentum" presuppose the meaning of "velocity." In this case, as Hirst (1974) argued, "the teaching of the subject must of course respect these elements of logical order" (p. 129). What the above discussion suggests is that teachers can approximately construct different logical sequences and strategies to teach subject matter as long as they adhere to the logical grammar imbedded in it.

The study of the enactment content organization and sequencing in school physics (the focus of this study) is a topic that has not been fully explored in contemporary research on teaching as inferred from recent reviews of literature in the natural sciences (White & Turner, 1986; Gallagher, 1987). Research on science teaching, instead, has focused on issues dealing with preinstructional strategies (e.g., use of advanced organizers), interaction and control in the classroom and the role of questions (e.g., questioning skills, wait time, etc.). The problem of what is actually taught in school physics becomes more critical in the content of high school physics[1] since it is here that most students encounter, for the first time in their lives, the "logical grammar" (Hirst, 1974) of physics knowledge. Thus, what they learn here and how they are taught may have profound consequences on their future academic life.

To sum up, there is a need to study classroom interactions in order to learn about how high school physics teachers enact subject matter; and communicate the information content imbedded in the instructional events.

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[1]High school physics is usually regarded as one of the most difficult subjects by students. According to Pallrand and Lindenfeld (1985), only 3 percent of the high school population (in U.S.A.) is exposed to this discipline.

The Research Questions

The research questions that guided this study revolved around one very broad question: How do experienced physics teachers organize subject matter? Out of this question, three sets of more specific questions emerged as the research study proceeded. According to Erickson (1986a), research questions can be "reconstructed in response to changes in the fieldworker's perceptions and understanding of events and their organization" (Erickson, 1986a:121) while in the process of conducting the research. In this sense, in trying to understand and interpret how subject matter was enacted by experienced teachers, several issues initially emerged.

The first one was the study of classroom interaction and discourse sequencing. As Stubbs (1981) indicated:

> By studying discourse sequencing, one can study in empirical detail how teachers select bits of knowledge to present to pupils; how to break up topics and order their presentation; how these discrete items of knowledge are linked; how distinct topics are introduced and terminated; how pupils' responses to questions are evaluated; how pupils are made to reformulate their contributions; how bits of knowledge are pieced and allowed to emerge when the teachers consider it appropriate. I cannot see how such topics could be studied, other than in an ad hoc way, by looking at isolated utterance by or features of language. But by studying the overall structure of the teacher-pupil interaction as a discourse system, these topics are inevitably studied. (p. 128)

Stubbs' insightful statements, undoubtedly brought up important methodological strategies concerning the method of studying structure of subject matter by researching teacher's discourse sequencing and, specifically, the nature of the discourse coherence within topics and across topics. The second issue that emerged, which also shaped the nature of the guiding questions, dealt with the proper "interpretive framework" (Erickson, 1986a) to explain the nature of the subject matter being enacted in those events. Erickson (1982) proposed a constructivist view of subject matter organization, according to which, there are four aspects that define the academic task structure in a lesson: (a) the logic of subject matter sequencing; (b) the information content of the various sequential steps; (c) the "meta-content" cues toward steps and strategies for completing the task; and (d) the physical materials through which tasks are manifested and accomplished.

Drawing from knowledge on discourse analysis (as suggested by Stubbs, 1981), from Erickson's constructivist view of subject matter, as well as from the researcher's understanding of the events under study (i.e., physics, classroom interactions), the set of research questions was eventually established as follows:

1. What is the nature of the coherence (global)[2] of the subject matter information content in the unit on dynamics as taught by three high school physics teachers?
2. What is the nature of the coherence (local)[3] of the information content delivered in a single topic (a part of the unit on dynamics) as taught by three high school students physics teachers?
3. What is the nature of the enacted task environment through which topics are delivered?

Research Design

The study of teacher interaction to make inferences about subject matter organization required the use of ethnographic techniques for data collection and analysis. For six consecutive months, the researcher attended three high school physics classrooms. Each classroom was visited daily. Several strategies were used to gather information on subject matter organization in high school physics. They included: participant observation, interviews with teachers, document gathering, and videotaping.

During six months of "participant observation" (Spradley, 1980), this researcher described, via fieldnotes, the nature of the classroom interactions in the three

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[2,3]The notions of global and local coherence have been adopted from Van Dijk (1985) and Agar and Hobbs (1985).

participating physics classrooms. During the initial phases of the research, emphasis was placed on the social structure of the class -- getting to know what role teachers and students played and how these roles were exercised. Also, emphasis was made on the description of the physical environment (classroom, physics equipment, textbooks, etc.) in which interactions took place. As the research progressed, the fieldnotes focused more on the subject matter content and specifically on how teachers planned for it, and eventually enacted the relationships between different topics. Special attention was paid to events such as: lecturing, laboratory activities, classroom demonstrations, homework and reading activities. Early analysis of these fieldnotes already indicated that there were variations in the way physics teachers structure similar topics.

Teachers were interviewed frequently -- formally and informally. Informal interviews yielded relevant information dealing with issues such as planning for the next day (i.e., what is tomorrow's topic and how will it be handled?), difficulties encountered by teachers in teaching a particular lesson or sequence of lessons and teachers' perceptions of students' understanding. These interviews, most of which took place during class breaks, proved to be very helpful in the comprehension of unclear statements made in the fieldnotes which needed further clarification. More formal interviews were conducted in order to gather information about the teachers' perceptions on planning for teaching and subject matter, as well as on the actual enactment of these plans. These formal interviews focused on the topic being selected for further analysis (i.e., dynamics). They took place several days after each individual teacher had formally concluded with the target unit of analysis.

Apart from the fieldnotes and interviews, the researcher also gathered information about subject matter sequencing through classroom documents. Most documents used by students were carefully filed and noted accordingly in fieldnotes. Documents included such items as quizzes, worksheets, laboratory reports, handouts, assignments and textbooks. These curriculum materials are important tools in science classes as they influence the nature of the scientific explanation during teacher-student verbal interaction (Roth, Anderson and Smith, 1986). Though not all of these documents were considered as part of the final analysis in this study, some of them proved to be key elements in the description of how physics teachers convey information to students. It was noticed that laboratory reports, handouts and worksheets contained important clues and strategies used by teachers in the process of structuring such information.

The fourth source of information on which these studies relied was videotapes. After properly "negotiating entry" (Erickson, 1986a) with teachers, it was possible to videotape most of the events that surrounded the teaching of an instructional unit on dynamics as taught by the three participating teachers. The transcripts from this videotaping gave detailed accounts as to what teachers (and students) said with respect to specific topics imbedded in the teaching of dynamics (see Chapter Three for more details).

The above-mentioned data gathering process yielded an enormous amount of information for analysis. A decision was made to analyze the physics unit on dynamics. The decision was based on the importance of such a theme in the high school curriculum[3] and the extent to which it is taught. The entire unit on dynamics was videotaped in each of the physics classrooms. The study of how teachers organized the theme on dynamics was carried out through a discourse analysis conducted at two levels: first, at a macro-level to see how different topics fit together; and second, at a micro-level to see how the elements of a single topic are coherently connected.

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[3]All high school physics books include this theme (see Pfeiffenberger & Wheeler, 1984).

Purpose of the Study

The main purpose of this study was to learn about how experienced physics teachers structure subject matter in their daily classroom interaction. To achieve this purpose, the following specific objectives were considered:

1. To describe, via "story-lines" (Erickson, 1982) how a selected group of experienced physics teachers link the different topics included in a unit of instruction.
2. To describe how teachers' discourses on a common topic compare in terms of the information content being delivered.
3. To describe the nature of the environment through which topics are actually delivered by teachers.
4. To interpret the findings of the study, including an assessment of the implications these findings have for further research and staff development.

Descriptions and interpretations of this nature are important when it comes to inform decision makers about teaching practices as they naturally occur in classrooms (Zumwalt, 1986). Zumwalt argued for the need to inform the deliberation of teachers, and to encourage similar inquiry from them. As has been suggested by several researchers (Erickson, 1986b; Shulman, 1986; Clark, 1987), ethnographic descriptions of classroom events can be appropriately used as a means for staff development and for the improvement of the teaching profession by having teachers reflect upon their own practices or their peers' practices.

The Importance of the Study

This study was conducted to generate knowledge which might prove useful to practicing teachers, prospective teachers, policy makers and educational researchers. The study describes a history of events (Erickson, 1982) on how three experienced teachers sequentially organized the subject matter imbedded in a unit of dynamics. Each account represents a separate case study that may be used independently by interested parties to study the strengths as well as the weaknesses of the subject matter organization as enacted by the participating teachers.

In addition, the study aims at contributing to the research literature of subject matter sequencing from the teachers' perspective. The study's main contribution to the literature lies especially in the development of a methodology to describe how practicing teachers actually construct subject matter in their day-to-day interaction with students and classroom materials such as books, lab equipment, etc.

Assumptions

Several major assumptions are made throughout this study. These assumptions reflect the nature of the interpretive framework of the study as well as the nature of the methodology being employed. The first major assumption is that the teachers investigated have some knowledge they share and that this knowledge has important consequences for how their actions are interpreted (Magoon, 1977). This knowledge (school knowledge) is "purposive" (Magoon, 1977) and as such it possesses some degree of organization and complexity. A second major assumption is that the knowledge enacted in classrooms is context specific. In this sense, "What people are doing and where and when they are doing it" (Erickson & Schultz, 1981) changes from moment to moment and from place to place. This leads us into the third assumption: the primary concern of interpretive-ethnographic research is particularizability rather than generalizability. "One discovers universals as manifested concretely and specifically, not in abstraction and generality" (Erickson, 1986a:180). In this sense, the study focuses on particular cases (e.g., three experienced teachers teaching a "unit on dynamics," or even more specifically "Newton's second law") so as to generate knowledge on the nature of the enactment of subject matter in high school physics.

Overview of the Dissertation

This dissertation contains six major sections. Chapter One provides an introduction of the basic study problem and the research questions. Chapter Two contains a review of literature related to the theme of the study. The first part of Chapter Two describes some of the most common sequencing strategies (macro-sequencing and micro-sequencing) derived from the work of contemporary educational psychologists such as Ausubel, Bruner and Gagne, etc. The second part of Chapter Two introduces a "constructivist" notion of sequencing derived from theoretical constructs in discourse analysis and ethnography of communication.

Chapter Three presents an account of how the study was accomplished. It includes a background of the study, the initial and final research questions and the research methodology including data collection techniques and analysis.

Chapter Four describes the nature of the context in which the present study was conducted. This chapter describes the classrooms where the actions of the case histories took place, the teachers, the textbooks being used, as well as a description of the teachers' conceptions of planning. This also includes a brief discussion of how the three participant teachers planned the unit on dynamics on which this study eventually focused its analysis.

The next section, Chapter Five, addresses the main questions of the study. The chapter is divided into two interrelated parts. The first part introduces a macro-analysis of each one of the teacher's discourses on dynamics. The data are presented in the form of "story-lines" which detail information on how teachers sequentially enacted the theme of dynamics through their interaction with the immediate environment. Both the nature of the information content as well as the environment are compared. A similar study is done through a micro-analysis of the teachers' discourse on Newton's second law.

In Chapter Six, the dissertation concludes with a discussion of implications of the study for further research and for practice.

CHAPTER TWO

INSTRUCTIONAL SEQUENCING OF SCHOOL SUBJECT MATTER

Introduction

The purpose of this chapter is two-fold: first, it offers a review of instructional sequencing from a psychological theory viewpoint; and, second, it presents an alternative view which asserts that instructional sequencing is socially constructed by teachers and students in their everyday classroom instruction.

Sequencing Instruction: An Educational Psychology View

How academic work is organized and accomplished in elementary and secondary classrooms has been an area of relatively new concern in educational research (Doyle, 1983), as it has a direct influence on what students are actually learning. The students' academic work is determined by the type of academic tools imbedded in the everyday classroom school context, the way information (facts, concepts and principles) is organized, and by the type of operations needed to achieve the goals demanded by the tasks (Doyle, 1983, 1986). This section focuses primarily on the second aspect (i.e., how information is organized by teachers for learning to take place). Specifically, it deals with the order in which content presentation is organized (sequenced), the kind of content relationships, and the way content relationships are taught.

The review follows the same line of reasoning as that developed by Van Patten et al. (1986) with respect to classroom content sequencing and synthesizing. In a recent review of literature, the authors focused on two fundamental questions: (a) how should the instructional events be sequenced over time, and (b) how should the interrelationships among different ideas and concepts be taught (synthesis). The bottom line of these two questions is that knowledge of instructional strategies for sequencing and synthesizing can help teachers to properly break the subject matter into small pieces, teach them accordingly and eventually pull them together according to the nature of their relationship (Van Patten et al., 1986).

Instructional strategies for sequencing (and synthesizing) deal with two questions: What is to be sequenced and how is it to be sequenced? (Van Patten et al., 1986). With respect to the first question, these authors pointed out the existence of two different views. One view argues in favor of factor sequencing the response and performance of the learner, and that relevant concepts, principles and procedures should be appropriately organized into the sequence in order to attend to students' responses.

The second view indicated that content should be sequenced and that learners' responses should be included in the sequence to assure a mastery of the content under study.

With respect to the second question: How are content or response to be sequenced?, there are different ways to organize the elements of an instructional sequence. Hirst (1974), for example, identified three principles: logical, psychological and historical. Tyler (1950) indicated the existence of four organizing rules, logical, psychological, chronological and part to whole. Thomas (1963) recognized five rules for organizing instructional sequences: known to unknown, simple to complex, concrete to abstract, observation to reasoning and whole to detailed.

Posner and Strike (1976) proposed a scheme to specifically organize subject matter content. The scheme identified five types of principles that can be either empirically or logically based. These authors described the set of principles as follows:

1. World-related principles (based on space, time and physical attributes) that yield world-related sequences in which, "there is consistency among the ordering of content . . . and relationships between phenomena as they exist or occur in the world" (Posner & Strike, 1976).

2. Concept-related principles based on class relations, propositional relations, sophistication level and logical prerequisites. These principles determine concept related sequences that reflect the organization of the conceptual world. Examples of these instructional sequences are found in curricula that focus on "the structure and the discipline" such as PSSC physics, BSCS biology, etc. (Posner & Strike, 1976).
3. Inquiry-related principles that focus on how propositions and concepts come about. The instructional sequence derived from these principles are based on the "nature of the process of generating, discovering, or verifying knowledge" (Posner & Strike, 1976).
4. Learning-related principles are based on how students learn as a function of pre-requisites, familiarity, difficulty, interest, inter-realization, and development. These principles result in learning-related content sequences that draw primarily from knowledge about the psychology of learning. The work of Gagne (1977) and Ausubel (1964), as applied to curriculum development and planning, falls into this category.

5. Utilization-related principles that focus on how the learner utilizes the content once he has learned it. The instructional sequences that result from these principles generally deal with three possible contacts: social, personal and career. So, the content is organized according to the "personal needs" of the learner (Posner & Strike, 1976).

It is important to stress that Posner and Strike (1976) do not advocate the idea that only one type of principle is useful to create instructional sequences, rather, they indicate that highly sophisticated sequences can result when combining different sets of principles.

Micro-Sequencing Versus Macro-Sequencing

Two types of instructional strategies have been identified to guide teachers and curriculum designers in the sequencing of classroom content: micro-strategies and macro-strategies (Reigeluth & Merrill, 1979). Macro-strategies are used to organize skills and knowledge into lessons, and to structure content ideas. Micro-strategies, on the other hand, are used to teach individual ideas and to structure the teaching of individual facts, concepts, principles and procedures (Van Patten et al., 1986). Basically, micro-strategies differ from macro-strategies in the sense that the former deals with a wider range of concepts and ideas while micro-strategies are related to the teaching of one concept or idea at a time. In what follows, these two ideas are explained in more detail.

Micro-Sequencing

Merrill et al. (1979) pointed out that the "grist" of instruction is composed of two main elements: generalities and instances. A generality is a definition or rule whereas an instance is a particular example of that rule. These authors suggested that generality and instances can be presented to the students in two ways: expository (e.g., here is an example of . . .) or inquisitory (e.g., is this an example of . . .). The combination of these two forms of presentation gives rise to four different "primary presentation forms for microsequencing: (a) generality in an expository form, (b) generality in an inquisitory form, (c) instance in an expository form and (d) instance in a requisitory form" (Van Patten et al., 1986).

Merrill et al. (1979) also suggested a sequence of events to teach simple topics or general rules. First, present the generality or rule; second, introduce example; and third, give more practice (feedback). Van Patten et al. (1986) identified other principles commonly used for the selection and sequencing of instances in instruction. These authors argued that a micro-sequence can be organized as follows: (a) matching examples versus non-examples, (b) selecting successive divergent examples, and (c) selecting examples according to their degree of difficulty.

Macro-Sequencing

There is a variety of theoretical prescriptions for sequencing a set of concepts, generalities and rules. Some of these instructional strategies include: (a) the spiral curriculum (Bruner, (1960), (b) progressive differentiation and advance organizers (Ausubel, 1968), (c) hierarchical sequences (Gagne, 1977), (d) elaboration (Reigeluth & Stein, 1983), (d) backward chaining (Gilbert, 1962), (e) snowball (Landa, 1974), etc. The first three have been widely implemented by curriculum designers and will be briefly discussed below.

The Spiral Curricula

Bruner (1960) suggested that a specific concept can be taught to students in a gradual manner, according to their intellectual development. The fundamental ideas of a discipline, according to Bruner, can be structured and taught at each school grade level but with an increasing level of difficulty (in a spiral format) as the school grade goes up.

Progressive Differentiation

Ausubel's (1968) major assumption was that learners "subsume" detailed and specific information under more general and inclusive types of information. He suggested a general to detailed top-down sequence in which the more general and inclusive ideas (advanced organizers) are presented first to the learner, followed by more specific related ideas which are "anchored" to the advanced organizers and which they themselves act as organizers to the material to come.

Hierarchical Sequencing

Gagne's (1968) theories that content can be broken into components which then can be taught in a hierarchical manner following "part to whole" or "simple to complex" are organizing principles.

Synthesizing Strategies

Synthesis is considered to be a macro-sequencing instructional strategy rather than a micro-strategy. It indicates the way content relationship should be taught (Van Patten et al., 1986). The idea of synthesis, in this sense, is related to what is commonly referred to as the content or structure of the discipline. As Bruner stated, "grasping the structure of a subject is understanding it in a way that it presents many other things to be related to it meaningfully (Bruner, 1960, p. 7). The structure of a subject (or synthesis) indicates how concepts are logically related. It is considered to be an efficient tool for learning as well as an important aspect of the content of the discipline in its own right (Schwab, 1962). Several strategies have been proposed in the literature to synthesize the concepts, procedures, and principles of a discipline. Some of the most well-known strategies include: networking, mapping and concept mapping.

<u>Networking</u>

Networking has been suggested as an instructional strategy to effectively teach content relationships. Network models have been suggested by Rumelhart, Lindsay and Norman (1972), and Bobrow and Winograd (1977), among others. The basic idea is that a network can identify the most important ideas in a text and describe the interrelationships among ideas in the form of a diagram using nodes (for concepts) and links (for relationships) (Van Patten et al., 1986).

<u>Mapping</u>

The idea of mapping (a text) was suggested by Hanf (1971). This is a technique for organizing the structure of a text in which the main task consists of having the reader (teacher or student) first search for the main idea of the text, then locate the secondary ideas and connect them accordingly to the main idea.

<u>Concept Mapping</u>

The idea of concept mapping is widely used by current researchers in science education. This idea is theoretically based on Ausubel's notion of learning (Novak & Gowin, 1982; Moreira, 1979). A concept map can be defined as a two-dimensional diagram representing the conceptual structure of a unit (or topic) of subject matter. It shows a "top to bottom" fashion in different elements (concepts, principles and examples, etc.) of the synthesis. The different elements are logically linked by lines. This strategy is usually used to identify students' conception as well as students' learning of relationships among concepts.

Summary -- Sequencing Instruction

The preceding review describes some of the main ideas concerned with strategies for sequencing and synthesizing subject matter. Researchers seem to agree that the role of sequencing needs to be further explored and that new models need to be developed and tested (Van Patten et al., 1986). One of the major obstacles for effective research on sequencing is the lack of a precise and consistent terminology among researchers. Several models have been proposed by specialists in the field of educational psychology, but little empirical research has been carried out as to how curriculum designers and teachers actually sequence and synthesize a unit of instruction.

The previous account shows a normative approach towards research on sequencing and synthesizing. It indicates how instructional sequencing "should be" conducted and carried out, instead of how that strategy is actually enacted in real life. The purpose of the following discussion is to present a theoretical framework that will be used to conceptualize how an instructional sequence is constructed by the participants in a classroom setting.

Sequencing as a Teacher Construct

This section offers an alternative view towards conceptualizing instructional sequencing. This conceptualization draws on theoretical constructs from linguistics (discourse analysis), and ethnography of communication. The model derived from these disciplines and its analytical methods suggests that an instructional sequence is socially constructed as teachers and students interact and as they engage in daily classroom practices dealing with academic content. The model proposed follows a constructivist perspective as opposed to a psychological one. First, we will focus on a constructivist view of teaching; and second, we will discuss a constructivist view of instructional sequencing based on the work of Kelly (1955), Yorke (1987) and Erickson (1982).

Ethnography of Communication

Consistent with a constructivist view of the world are the methods and assumptions of ethnography of communication. This research tradition derives from work in sociolinguistic, verbal and nonverbal communication, anthropology and sociology (Erickson & Mohatt, 1982; Erickson & Wilson, 1982).

The use of ethnographic methods in the field of educational research has steadily been increasing as a major paradigm (Spindler, 1982). An ethnographer "strives to define objects according to the conceptual system of the people he studies" (Frake, 1961:192). An ethnographer discerns how people construct their world of experience from the way they talk about and interact with it. Ethnography is the work of describing a culture (Spradley, 1980). Its aim is to understand people's ways of life from their own point of view. As Malinowski (1961) said, "the goal of ethnography is to grasp the native's point of view, his relationship to life, to realize his vision of his world" (p. 25).

Ethnographers are mainly concerned with three fundamental aspects of human experience: what people do (cultural behavior), what people know (cultural knowledge), and the things people make and use (cultural artifacts) (Spradley, 1980).

Ethnography of communication specifically developed out of an interest in face-to-face interaction as to understand how these "micro" processes are related to broader cultural and social issues (Erickson & Mohatt, 1982; Jacob, 1987).

Jacob (1987) summarized the major assumption of ethnography of communication as follows:

1. Culture is central to understanding human behavior.
2. Context influences the patterns and rules of interpersonal interaction.
3. The social structure and outcomes of institutional process are derived, in part, from the process of face-to-face interaction.
4. Detailed study of interactional pattern says much about the culture of a group under study.

Focusing on "particular central scenes within key institutional settings" (Erickson & Mohatt, 1982:137), ethnographers of communication are fundamentally concerned about two issues: (a) understanding the rules of social interaction for various cultural groups, and (b) determining how "outcomes" are produced through social interaction.

In describing social interactions as well as outcomes, ethnographers fundamentally base their work on a phenomenological approach (Magoon, 1977; Yorke, 1987) as to construct knowledge-based human experience derived from the researcher's participation and observation in the social scene. In this sense, phenomenology is the basis of ethnographic research. As Bogdan and Taylor (1975) stated, "the phenomenologist view human behavior -- what people say and do -- as a product of how people interact with their world . . . the phenomenologist attempts to see things from the person's point of view" (p. 14). The person's point of view is a research construct within the phenomenological approach. Phenomenologists suggest that in order to obtain valid inferences from a phenomena, it is important to keep in mind the following considerations or rules (Ihde, 1979):

1. Attend to the phenomena of experience as they appear (p. 34).
2. Describe, don't explain the phenomena (p. 34). This rule prevents the researcher from judging the phenomena prematurely from his/her point of view.
3. Horizontalize or equalize all immediate phenomena (p. 36).
4. Seek out structural or invariant features of the phenomena (p. 39).

Repeated patterns (characteristic of empirical science) are significant and must be actively probed.

Phenomenologists also recommend that it is necessary to retain the informants' own words because they provide important insights into how they describe and define their world from their own perspective (Dodge & Bogdan, 1974).

Constructivist Perspective of Teaching

Constructivism in educational research is nothing new, and it has been brought to life with the upcoming of ethnographic research and the need to account for explanations of "thick descriptions" that result from this type of research perspective (Magoon, 1977). A constructivist perspective holds the chief assumptions that the "subjects" being studied must be considered knowing objects, and that the knowledge they possess has important consequences with regard to how actions and behaviors are interpreted (Magoon, 1977). A second major assumption is that the subjects must construct knowledge purposely (i.e., aimed at a specific end). In this sense, they have control over how they carry out this construction process. A third major assumption is that the human species has a highly developed capacity for organizing and constructing complex knowledge on its own (Magoon, 1977). The idea that individuals in their societies do precisely what individual scientists and scientific communities carry out too (i.e., invent, organize and produce knowledge) which deserves to be studied by social and behavioral scientists. Constructivist perspectives that focus on how individuals in their societies construct knowledge, come from different fields of inquiry such as anthropology (Geertz, 1973), psychology (Heider, 1958; Kelly, 1955), and sociology (Schultz, 1970). Recent ethnographics of classroom studies rely on these perspectives for interpretation (Green & Harker, 1982). They focus specifically on the acts of construction as they occur in schools.

In this sense, researchers may, for example, describe how a "problem student" becomes such a "problem" (Erickson et al., 1985); or how motivation is "negotiated" by the participants of a classroom setting (Sivan, 1986).

A constructivist view of teaching assumes that knowledge is the product of social interaction in which the knower (teacher or student) acts upon the subject (discipline) to organize the world and make sense of it (Kitchener, 1986). Drawing from Piaget's notion of constructivism, Kitchener (1986) derived three constructivist formulations as to how knowledge is acquired (e.g., teacher, student).

1. Constructivism is the view that reality itself is constructed by the epistemic subject (e.g., the teacher, the student).
2. Constructivism is the view that the subject constructs the epistemic object (e.g., discipline).
3. Constructivism is the view that the subject constructs the cognitive schema, categories, concepts and structures necessary for knowledge.

In this sense, teaching is an interactive process between the conception of the world (epistemic object), the conception of the person as knower (epistemic subject), and a conception of the act of knowing (epistemic relation).

Teachers, then, can act over the discipline and organize it accordingly so as to communicate the necessary information so that students also construct their view of the discipline. In doing so, teachers are selective of the type of information needed to construct the epistemic subject (or discipline). This perspective of teaching is consistent with Kelly's constructivist position that people usually construe their world by selecting the pertinent from the insignificant, by coding and selecting the proper information, and by anticipating events (Frake, 1962). In this construction process, people define alternative courses of action and make decisions among them (Frake, 1962).

A Constructivist Perspective of Instructional Sequencing

Constructivist perspectives are now common in educational research, particularly in studies that rely on ethnographic approaches (Magoon, 1977). Studies of classroom interaction or "micro-ethnography" (Erickson, 1986a) are consistent with constructivist assumptions. In a review of ethnographic research on classroom face-to-face interactions, Green and Harker (1982) pointed out the existence of a set of constructivist "premises" as follows:

1. Conversations are rule-governed, constructed entities.

2. Messages in conversation (verbal and nonverbal) can be transmitted in more than one channel of communication which can be operating at the same time. These messages may have different purposes.
3. The context in which conversations take place is not a given entity but it is constructed as part of the conversational process.
4. The context contributes to the interpretation of meaning in the classroom.
5. "Contextualizing cues" are the means by which a speaker (teacher) signals and the listener (student) interprets the semantic content. This content (or behavior) may be related to what precedes or follows.
6. The products of conversational processes are a series of meanings which are socially and semantically context dependent.
7. Lessons are not preset entities, but they are constructed by teachers and students to achieve instructional goals. In this sense, "classroom conversations" are not scripts to be followed rotely by teachers and students (Green & Harker, 1982). This situation allows for "breaches" in the cohesion of the lesson as conversation develops.

With these premises in mind, it should be noted that an instructional sequence is a teacher construct which is developed as teachers (the epistemic subject) interact with students and classroom materials as to enact the necessary actions (and events) that will result in the epistemic object (knowledge of subject matter) that students eventually will learn. They may choose lecturing, lab activities, seat work, etc. as some of the actions to be undertaken in the classroom. The analytical model that follows draws from two constructivist perspectives on teaching and learning which complement each other. In the first instance, Erickson (1982) arguing in favor of a (constructivist) natural history of learning, pointed out that in their daily interaction, teachers and students enact in academic task environments with a structure determined by four constitutive aspects:

1. The subject matter information content.
2. The logic of subject matter sequencing.
3. The meta-content cues toward task completion strategies and steps.
4. The physical materials through which tasks are manifested and completed.

Erickson (1982) pointed out that the first two aspects constitute the "underlying learning task structure" of the subject matter. The last two aspects represent the "enacted learning task environment" or "the physical stuff" through which academic tasks are accomplished.

The above four aspects are interrelated to the social task environment which is also characterized by four different aspects.

1. The social gatekeeping of access to people and other information sources during the lesson.
2. The allocation of communicative rights and obligations among the various interactional partners in the event.
3. The sequencing and timing of successive functional slots in the interaction.
4. The simultaneous real-time actions of all those engaged in the interaction (Erickson, 1982).

The present study will focus specifically on the first aspect, academic task structure, keeping the second aspect in the background (i.e., the social task structure). Researchers seem to agree that a substantial number of studies have been conducted on issues related to the social task structure at the expense of the academic task structure (Erickson, 1982; Cazden, 1986; Stubbs, 1981).

The second constructivist perspective is derived from Yorke's (1987) work on teacher thinking. Yorke, drawing from Kelly's (1955) personal constructivist theory, argued that classroom events can be constructed in retrospective if the researcher is to adopt an approach that is informed by phenomonology of the philosophy of history. In this sense, a teacher's construct system can be explored via three possible avenues:

1. The protagonist's verbalization concerning the event(s) of interest.
2. The protagonist's behaviors (actions) during that verbalization.
3. The researcher's direct observation of the event(s).

Yorke's approach towards curriculum construction (methodologically) supports (or complements) the study of "subject matter task structure." This suggests that the logic of subject matter, the information content, the meta cues used to accomplish tasks, as well as the usage of physical equipment, can be fully studied in retrospect by developing a "natural history" (Erickson, 1982) based on the participants' verbalization and actions as well as on the researcher's interpretations of these actions. As it is clear, a researcher needs to rely on a "metalanguage" to interpret those verbalizations and actions. The section that follows will focus on a discussion of discourse analysis as a means to develop the metalanguage needed to construct and interpret an instructional sequence.

Discourse Analysis

In order to properly describe and analyze participants' actions and verbalizations as to construct a history line of how events are constructed in real life, researchers frequently rely on constructs drawn from discourse analysis. The discussion that follows will focus on discourse analysis, with an emphasis on classroom discourse. The language of discourse is described as an analytical frame to interpret how a teacher's discourse leads to the construction of an instructional sequence.

A discourse can be defined as a socially constructed phenomena (Gardner, 1985) that occurs in the context of a "speech event" (Hymes, 1962). A discourse can have two major functions: transactional (i.e., to express content) and interactional (i.e., to express social relationships and personal attitudes) (Brown & Yule, 1983). In either case, it can be produced in both spoken and written format. Both types of discourses are structurally different in terms of cues, phrases, environment, connectors, etc.

As pointed out before, a discourse is a contextualized social phenomena that depends on the circumstance in which it happens to take place. Hymes (1962, 1964) specified several features of that context which may be relevant to the identification and characterization of a type of speech situation. He focused on the role of the addressee and the addressor, or the listener and the speaker. A third feature of that context is the topic, or what is being talked about; the setting, which indicates where the event takes place; the channel of communication between participants (signaling, writing, language); the code being used (e.g., English); the message form (e.g., debate, lecture, letter, etc.); and, finally, the event that is taking place. For example, in a physics classroom, the following features may be seen:

Addressor:	physics teacher
Addressee:	students
Topic:	"Newton's second law"
Channel:	speech
Code:	English
Message form:	conversation
Event:	physics demonstration

Lewis (1972) discussed a different list of features to define the discourse context, which somehow overlap with Hyme's categories. Lewis' features include, "possible world," time, place, speaker, audience, indicated object, previous discourse, and assignment.

<u>The Topic of Discourse</u>

Every discourse has a topic (Givon, 1983); and it is up to the discourse analyst to judge when the topic begins and when it ends. The notion of topic is fundamental in the representation of the content of a discourse. In this sense, a discourse can be fragmented using "topic boundaries" which show where a fragment begins and where it ends (Brown & Yule, 1983). The topic may just be a sentence or a sequence of sentences. Brown and Yule (1983) suggested the term "topic framework" as a more comprehensive term for "what is being talked about in a discourse." The topic framework consists of elements devisable from the physical context and from the discourse domain of any discourse fragment. This is similar to Venneman's notion of "presupposition pool" which contains information from general knowledge of the context as from the discourse itself (Venneman, 1977). This would include participants and verbal and nonverbal cues.

Related to the definition of topic is the notion of "speaking topically." This term refers to the situation when a discourse participant is making a contribution that fits into the most recent elements of the topic framework (Brown & Yule, 1983). In this case the speaker's discourse is said to be "relevant." The term relevance in the analysis of conversations is derived from the conversational maxims proposed by Grice (1975). According to Grice, when there is a general agreement of cooperation between conversation participants, then each speaker is supposed to comply (inexplicitly) with a series of conventions. These conventions are telling the truth (maxim of quality), telling the listener all he needs to know and no more (maxim of quantity), saying things that are relevant (maxim of relation), and using speech clearly and unambiguously (maxim of manner) (Kreckel, 1982).

Topic Boundaries

Important concepts in discourse content representation are the notions of topic shift and boundary markers. They are related to how the speaker structures what he is talking about (topic). Topic shift is the boundary between two different topics (Schank, 1977; Maynard, 1980). It can also represent the boundary between two paragraphs. The point to be made here is that a topic shift represents a way of "partitioning a discourse" (Grimes, 1975:109). This partition can be related to a change in time, theme or context (Brown & Yule, 1983). In the case of verbal discourses, linguists refer to boundaries called "paratones" which mark the boundaries between continuous paragraphs.

Generally speaking, topic shifts can be of two types: a termination or a break (Jefferson, 1972). In a termination, the topic is shifted from one area to another, and the first area is never picked up again in the development of the discourse subject matter. A break occurs when there is a topic shift and later another topic shift brings the discussion talk to the previous topic. If a topic is not talked about again, linguists refers to this phenomenon as "persistence decay" (Givon, 1983).

The Notions of Texture, Cohesion and Coherence

Three important concepts related to large chuncks of language are the notions of texture, cohesion and coherence. The three terms are commonly employed when referring to the "well-formedness" in a thematic development of a discourse, theme or topic. Here, the term thematic development indicates the process by which sentences, paragraphs, episodes, and discourse itself, are organized around the central topic or subject of discourse (Brown & Yule, 1983). The theme or central topic can be developed in an array of several constitutive topics (or subtopics). These topics may or may not be arranged sequentially in time (Brown & Yule, 1983).

In the process development of a theme, a text is being produced. Several authors are concerned with the principles that bind the constitutive elements of a discourse together to make it a text (Halliday & Hasan, 1976; de Beugrande, 1980; Givon, 1983). Halliday and Hasan, one of the most widely cited references in discourse cohesion, argue that it is the nature of the cohesive relationships within and between the sentences of the discourse that give "texture" to a particular text. The texture is provided by a set of relationships that can be categorized under the headings of reference, substitution, ellipses and lexical relationships.

The reference relationships, in particular, are of fundamental importance to the study of the coherence (logical connection) of a discourse or text. The reference relations "instead of being interpreted semantically in their own right . . . make reference to something else for their interpretation" (Halliday & Hasan, 1976). When their interpretation lies outside the text, in the context of situation, the relation is called "exophoric" (it does not play a part in textual elaboration). The expression "look at that" would be an example of that relation (Brown & Yule, 1983). When the interpretation of the relation lies within the discourse or text itself, then we talk about endophoric relation. Halliday and Hasan (1976) identify two types of endophoric relations: (a) anaphoric relations that look back in the discourse for their interpretation, and (b) cataphoric relations that look forward in the text for their interpretations.

Related to the concept of cohesion is the notion of coherence of a discourse (Givon, 1983; Hobbs, 1979; Brown & Yule, 1983). Coherence refers to the well-formedness of a discourse and how the elements of a discourse are connected together (Brown & Yule, 1983; Hobbs, 1979). It is related to how the different topics of a discourse or text are put together by the speaker(s). The coherence of a discourse is not located in the linguistic properties of the discourse sequence itself, as is the case of cohesion (Carrell, 1982), but it is located in the interpretation of the speaker's intended meaning in producing a discourse (Brown & Yule, 1983). This process of interpretation may involve three aspects: (a) the communicative function of the discourse; (b) the general social-cultural knowledge (of the discourse analyst and hearer); and (c) the inferences made out of the discourse (Brown & Yule, 1983). In relation to the first aspect above, it is argued that utterances in a discourse must be interpreted as actions of different types and that the coherence (or incoherence) of a discourse lies in the relationship between the actions performed with these utterances (Labov, 1972). Secondly, using knowledge about the world also contributes to the interpretation of a speaker's discourse in a way that it may seem coherent to the listener. This knowledge about the world can be looked upon as background material in the form of "scripts" (Schank & Anderson, 1977); scenarios (Sanford & Garrod, 1981); schemata (Anderson, 1977); mental models (Johnson-Laird, 1980), and frames (Minsky, 1975). The listener's world of knowledge is a substantial key element in the interpretation and understanding of a discourse and its coherence.

The third aspect mentioned above with respect to the process of interpreting a speaker's intended meaning is that of determining the inferences the reader needs to make to arrive at a coherent and logical interpretation of the discourse. In this sense, an inference can be defined as the connections people make when striving to read and interpret a discourse.

Characterization and Types of Discourse Coherence

Coherence in conversational discourse can be characterized by a set of relations that connect (logically) the different pieces (utterances, episodes, paragraphs, etc.) of a discourse together. Its interpretation lies in the context of the discourse and not necessarily in the linguistic format of the discourse itself. Hobbs (1983) summarizes the different views on coherence as follows:

1. A discourse is coherent if it exhibits a structural relationship between its various segments and topics of the segments.
2. A second view is that a discourse is coherent if the utterances it yields are seen as actions to achieve some goals. Coherence then can be inferred from the speaker's actions and its place in the overall discourse. This view is particularly shared by Labov and Fashell (1977).
3. A third view of coherence is the one suggested by Chafe (1979). According to Chafe, the coherence

of a discourse reflects the structure of content in memory.

In Hobb's view, for a discourse to be coherent, four requirements are needed: (a) the message must be conveyed; (b) the message must be related to the goal of the discourse; (c) what is new and unpredictable in the message must be related to what the listener already knows; and (d) the speaker must guide the listener inference processes towards the full intended meaning of the message (Hobbs, 1983). In order to fulfill these four requirements, there is a set of four corresponding coherent relations that the speaker needs to keep in mind.

1. Strong temporal relations. These refer to what happened first and what caused what in the discourse sequence.
2. Evaluation relations. These relations derive from the set of goals that speakers and hearers have. Hence, the need to evaluate and judge the discourse's effectiveness as it is enacted.
3. Linkage relations. The speaker needs to provide the proper linkage between what the actual message is about and what happened before. This linkage is achieved by making explicit background information and by explaining the new information.

4. Expansion relations. These types of relations refer to discourse statements that account for how the speaker moves between specific and general statements. This process can be achieved by contrasting, generalization, exemplification and parallel methods.

In the speaker's discourse, the coherence can be either local (one segment of the discourse) or global (the entire theme of the discourse) (Van Dijck, 1985; Agar & Hobbs, 1985). A speaker relies on local coherence strategies when he assumes that each new clause or sentence (or action) is being linked to the previous information. Apart from local coherence relations, the speaker also employs global coherence strategies to make the theme of the discourse understandable to the listener. In doing so, the speaker makes use of strategies to properly connect the different topics (or subtopics) that make up the entire discourse. Van Dijk (1985) referred to these "global theme" strategies as macro-rules or rules to sequence and construct semantic macro-structures. Examples of these macro-rules are: using implicit knowledge the hearer may have on the topic of the discourse; relying on information from previous texts; pointing at title and headings; using thematical sentences and key words (e.g., signalling what the passage is); referring the listener to the structure of the discourse passage; or telling him about the schematic structure of the discourse itself (Van Dijk, 1985).

Events in a Discourse

Both macro-sequence (several subtopics or social themes) and micro-sequence (one topic) are made up of events that may or may not be logically connected. Different parts of the discourse communicate different kinds of information. Depending on the nature of the information, the discourse analyst is looking for, the discourse can be "partitioned" (Grimes, 1975) in events which can have two dimensions, one is "tight versus loose" and the other is "temporal versus logical" (see Figure 2.1).

	Temporal	Logical
Tight	TT	LT
Loose	TL	LL

Figure 2.1. The two dimensions of events in a discourse.

The result of this 2x2 matrix is four different types of sequences in which discourse events can be classified: (a) "temporally tight sequence" in which the actions of the discourse overlap in time; (b) "temporally loose sequence" in which the next action begins sometime after the previous event ends; (c) "logically tight sequence" where the next action of events is a direct consequence of the event that happened before; and (d) "logically loose sequence" in which "earlier actions have effects which persist and are factors in what takes place later, but without direct connection" (Grimes, 1975:233-234).

In the study of text and narrative content, linguists focus on two important text relationships that describe how events become related. The first relationship (already mentioned) is given the name of linkage. This is an anaphoric relationship that is employed when language events are linked to preceding events by repeating them or making reference to them. The second relationship to connect discourse events is given the name of "chaining," cathaphoric relation (Grimes, 1975). This relation refers to the prediction of some of the content that the following event will contain. If the second event is to be about a different subject, then a "topic shift" has occurred (Brown & Yule, 1983). Otherwise, "topic decay" occurs (Tannen, 1984). Both chaining and linkage systems may coexist in a discourse in a situation in which an event in a sequence of events may be chained forward to the next event and at the same time may be linked backward to the preceding event (Grimes, 1975).

Classroom Discourse and Academic Content

Teachers and students devote a great deal of time in classroom communicating and talking. Teachers, in particular, have to lecture, inform, explain, define terms, post questions, correct students' answers, request, etc., while they engage in their daily work (Stubbs, 1983). Much of the talk is characterized by having one speaker, the teacher, in control of the topic or events in which classroom participants take part. Teachers decide on where to start a topic, where to stop, what should be in it, how it should be organized for a coherent discourse, and how topic related events need to be properly sequenced.

Traditional research on classroom discourse has not primarily focused on the cognitive aspect of the discourse itself but on the social structure imbedded in the classroom discourse (Cazden, 1986). In this sense, the way teachers enact subject matter through their daily interactions with students is a research topic largely ignored by discourse analysts. Cazden summarized the research on classroom social structure under the following headings:

1. Events and their participating structure.
2. Features of teacher-talk register.
3. Cultural differences and differential treatment.
4. Interaction among peers.
5. Talk on the unofficial peer culture.

6. Classroom discourse and learning.

Inspite of the wide variety of research on topics being studied, researchers acknowledge that the issue of academic content is often ignored in descriptive-ethnographic research (Erickson, 1982; Cazden, 1986; Stubbs, 1983). Erickson (1982) and Stubbs (1983) stressed the need to look at the organization of classroom content as a way to shed light on what and how knowledge is transmitted by teachers. Stubbs (1981) has stressed the need to empirically study clasroom discourse as a way to describe how different "bits" of knowledge are structured by teachers in their daily interaction with students.

The analysis of teacher-student interactions as a discourse system can yield important educational insights as to how educational knowledge is socially defined, selected and made available to students (Stubbs, 1981). A similar argument was raised by Doyle (1983:159) who called for explicit attention to "how academic work is organized and accomplished in classrooms. . ."

As far as discourse analysis of science classroom content is concerned, research is scarce. The research on how single topics are formulated in science classrooms (Heyman, 1986) and how the content of single science lessons is developed in its relation to the social structure of the classroom (Lemke, 1982a) are worth mentioning.

With the above discussion in mind, a discussion of the methodological issues involved in the study of classroom content will be presented in the next chapter. Specifically, Chapter Three describes an ethnographic study that focused on the nature of the construction of an instructional sequence as enacted by three high school physics teachers.

CHAPTER THREE

THE CONDUCT OF THE INQUIRY: A GUIDE TO STUDY SUBJECT MATTER (CONTENT-KNOWLEDGE) IN PHYSICS CLASSROOMS

Introduction

This chapter is organized into five sections. The first section gives the background of the study. Next, the research questions that guided the study are presented. Third, a description of the methodological approach is described. The method of analysis used to reach the findings is outlined. And finally, the main corpus of datum is briefly outlined.

Background of the Study

In the 1984-86 academic years, a research study of secondary school science was carried out at the Institute for Research on Teaching at Michigan State University. The study was ethnographic and its main purpose was to focus on the question: "What is the nature of the interaction among secondary school teachers, school administrators, and how do these interactions influence the character of the science program?" (Gallagher, 1985, 1986). In trying to answer this question as well as other questions generated by the nature of the research, the research team (of which the writer was a member), relied on ethnographic techniques such as participant observation, interviews and videotaping. Each member visited a school site once or twice a week during the data gathering phase of the project. Discussion among team members was held regularly to generate assertions and design strategies to confirm or disconfirm those assertions. Although the main purpose of the project was to study the nature of interaction among science teachers, very early on the project, the issue of what was taught in the science classrooms began to emerge as an important element in the teachers' daily discourse. Questions such as, What is the topic of the instructional sequence in Mr. X's class? How does Mr. X structure his class?, and the like were constantly asked. These questions were not really addressed fully as the project came to an end in June 1986. However, the project coordinator and this writer thought these questions were pertinent and should be pursued by a graduate student.

Research Questions

The nature of the content of instruction as enacted in physics classrooms was the topic of this study. In particular, the study initially focused on what was taught in physics classrooms and how it differed among different physics teachers. Since teachers usually act as gatekeepers of what is taught in their classrooms, it was assumed that there were variations on how to organize the subject matter of a lesson or unit and what to include in each one of these entities.

The original main questions addressed by the proposed study were stated as follows:

1. What is the content of instruction for a single curriculum unit as taught by physics teachers?
2. What is the logical development of the flow of information between teacher and student?
3. What is the "story line" or "sequence of connected actions" (Erickson, 1986b) as a unit of instruction is developed.
    a. How is this "story line" constructed by participants?
    b. What are the boundaries between phases of events (Erickson, 1986b) as the "story line" is developed? (In a physics class, examples of these events can be lectures, demonstrations, laboratories, films, etc.)
4. How do physics sequences vary among different teachers dealing with different textbooks and equipment?

After re-entry of the schools again (August, 1986), the author realized the questions were too broad and general to be studied. This situation led me to focus on a topic taught by the participant teachers. It was decided to particularize the research questions to look at what was taught in a unit on dynamics. Also, the nature of ethnographic research drove the researcher to redefine my questions as the research was carried out. According to Erickson (1986a), ethnographic research questions can go through a process of reconstruction in "response to changes in the field worker's perceptions and understanding of events and their organizations during the time spent in the field" (1986:121). In effect, "the understanding of events and their organizations" in physics classrooms in light of analytical constructivist framework and its method of inquiry, led the researcher to redefine the research questions in the following terms:

1. What is the nature of the coherence (global) of the subject matter information content in a unit on dynamics as taught by high school physics teachers?
   a. What topics are included in such an instructional unit?
   b. How are the different topics sequentially taught through time?
2. What is the nature of the coherence (local) of the information content delivered in a single topic

(on dynamics) as taught by high school physics teachers?

a. How is the topic connected to other topics within the unit?

b. How is the topic introduced and terminated?

c. What are the enacted logical steps as the topic is constructed?

3. What is the nature of the enacted task environment through which the topics are delivered?

With this set of questions in mind, the next step is to describe the research plan undertaken while the study was carried out.

Research Plan

The nature of the questions and the need to focus on specific understandings of content-knowledge construction required the use of an "interpretive research" (Erickson, 1986a) approach to gather data for the study. An interpretive research seeks to understand how "local meanings" and actions are constructed from the actor's points of view and how those meanings and actions compare (Erickson, 1986a). Answers to questions revolving around the foregoing issue are needed in educational research because of:

1. The need to make explicit the "invisibility of everyday life."

2. The need for specific understanding through documentation of concrete details of practice.
3. The need to consider "the local meanings" that events have for participants in them.
4. The need for comparative understanding of different social settings.
5. The need for comparative understanding beyond the immediate circumstances of the trial setting (Erickson, 1986a:111-121).

It is the purpose of this study to make explicit what is taught in physics classrooms in terms of content-knowledge as well as how that knowledge is organized and how such organization compares across three different teachers. To shed light on these questions, the researcher relied on extensive participant observation, videotapes, interviews and document gathering.

Participant Observation

Two months before the end of the 1985-86 school year, the researcher "negotiated entry" (Spradley, 1983) with three high school teachers to learn how they actually sequenced the content-knowledge in their daily interaction with students. Weekly visits were made to each teacher and field notes were carefully recorded. At the beginning of the 1986-87 school year, the researcher continued his observations from August 1986 through March 1987. During this time, the observations were done on a daily basis in two classrooms and on a weekly basis in the third one. There was a practical reason for this: the third teacher had begun his course with a unit on light and waves, and there was no plan to focus on such a unit. However, intensive observation of the third teacher began in January 1986 as he started a unit on kinematics. From mid-March until the close of the school year (mid-June), the researcher maintained contact with the three teachers by means of periodic visits. This was done to clarify unclear statements in the field notes, and also to sustain the friendship already established between the researcher and the teachers.

Overall, 200 classroom observations were made from August 1986 through June 1987. Observations focused primarily on the teacher's activities and its relation to the information being delivered to students. Students' activities and interactions were also recorded as they were relevant to the guiding questions of the study. During the observation phase, <u>fieldnotes</u> were carefully taken and relevant documents (worksheets, lab sheets, quizzes, etc.) were collected. These documents proved to be helpful tools during the process of re-writing and analyzing field notes. Over 2,000 hand-written pages were gathered during the participant observation phase of the study.

The nature of the research questions forced the researcher to focus on classroom events dealing with the organization and sequencing of content-knowledge, as opposed to issues dealing with the social structure of the classroom or students' learning which were kept in the background. This situation led the researcher to pay specific attention to the content of the teacher's discourse as well as the actions undertaken by participants as they were motivated by such discourse. In this sense, classroom events were described through the teachers' verbal statements and meta-cues that indicated the beginning and end of events. The descriptions were also constructed in terms of elapsed time between perceived events and changes in context (from lecture to lab, from lab to seat work, etc.).

Each observation was immediately followed by a write-up process in which field notes were carefully elaborated and substantiated with memos that helped to clarify and explain the field notes and the research guiding questions. Occasionally, field notes had to be rewritten as a consequence of new information gathered from teachers, students, or from more recent observations.

Videotaping of Classroom Events

With the purpose of focusing on specific details of classroom activities as related to content organization and sequencing, a whole unit of instruction was videotaped for each of the three teachers. Classroom videotaping is another important technique to gather ethnographic data. This technique was suggested by Erickson (1986a) as a way of reducing the bias of "premature typification" (jumping to early conclusions) and the bias "toward emphasis on analysis of recurrent events at the expense of analysis of rare events" (p. 144). This approach of relying on machine recording as a means of gathering data in interpretive research is often referred to as "microethnography" (Erickson, 1975), "constitutive ethnography" (Mehan, 1979) and "sociolinguistic microanalysis" (Gumperz, 1982; see Erickson, 1986a). Erickson (1986a) anticipated three advantages of tape recording over participant observation:

1. "Capacity for completeness of analysis" (p. 145). Tapes can be revisited and analyzed as many times as required by the researcher or analyst.
2. "Potential to reduce the dependence of the observer on primitive analytic typification" (p. 145). In this sense, a tape recording gives the researcher an opportunity for further deliberation, thus avoiding faulty inferences, particularly at the early stages of the inquiry process.
3. Tapes "reduce the dependence of the observer on frequently occurring events as the best sources of

data" (p. 145). In this sense, classroom videotapes provide the analyst with an opportunity to learn about "rare events" not accessible or visible through field notes.

However, Erickson (1986a) cautioned researchers about the limitations of this strategy:

1. When reviewing a tape, the researcher can only interact with it vicariously.
2. A tape itself lacks contextual information.

Both limitations can be ameliorated by the use of field notes.

The method of videotaping was particularly useful in the description of the events that took place as the three participant teachers dealt with a unit on dynamics. (In all, 25 hours of videotaping were conducted.) Soon after the proper negotiation with each individual teacher, the researcher brought a videotape camera into the classroom in order to familiarize the students with the camera. It was previously agreed that the focusing would primarily be on the teacher and not on individual students. The portable video camera used for the occasion was placed at the rear of the classroom, on a tripod, overlooking the teacher and the whole class. The camera was permanently held in the locked-on position (Erickson & Wilson, 1982) in order to record transitions between classroom events. Though the wide angle shot was generally used, on several occasions it was convenient to zoom in on specific details that were considered to be important in the process of inquiry. Specifically, close-up shots were appropriately directed toward the board whenever an equation or statement happened to be written there. Also, close-up shots were aimed at the teachers explaining a demonstration, giving lab instructions, or drawing diagrams on the board or any other place. In all, the researcher made 25 videotapes.

During the recording of the videotape, the researcher simultaneously took notes of the timing between events as well as other relevant information not captured by the videotape. These types of field notes were helpful in calibrating the tape transcripts (Lemke, 1982a). As these field notes were taken, the researcher focused primarily on off-camera events such as students working in the background, or the visual cues and dietic references (Lemke, 1982a) which were thought to be of relevance in the process of inquiry. Videotapes were transcribed and correlated with field notes gathered from the videotaped lessons.

Interviews with Teachers

Periodic informal interviews were held with teachers in order to gain insights into the hunches and inferences made by the researcher with respect to the organization of the content-knowledge being delivered on a daily basis. These conversations usually took place during class breaks, recesses, after school or during planning hours. The conversations served several purposes: (a) to clarify memos and questions left unanswered on previous field notes, (b) to find out about the next day's topic or activity (useful information during the videotaping phase), and (c) to keep record of the teacher's perception of "connectedness" across different topics. In addition to informal daily interviews, the three participant teachers were formally interviewed after they had completed the unit on dynamics. Two leading questions were formulated during this occasion: (a) Why did the sequence (on dynamics) come to be the way it did? and (b) How did you plan to teach such a unit? In addition to these two guiding questions, additional information was requested on the teacher's professional experience, overall content coverage (during the school year), perception of students, classroom environment, etc. These interviews were audiotaped and the transcripts included in the data corpus.

Analysis

The data that forms the central core of Chapter Five of this study was obtained through a method which required two levels of analysis. At this point, it is important to note that in the case of interpretive research, documentary materials such as field notes, videotape transcripts, documents, etc. are sources of information from which data can be constructed (Erickson, 1986a).

The first level of analysis was based on Yorke's methodology to reconstruct classroom events (Yorke, 1987). He proposes three possible avenues of exploration: the protagonist's verbalization concerning the event(s); his or her behavior during that verbalization; and the researcher's direct observation of the events (Yorke, 1987). For the purpose of this study, this categorical system was modified as follows:

1. Participant's verbalization.
   -- What was being said by whom during the event(s).
2. Participant actions.
   -- What participants (teacher and students) were doing while the event(s) were taking place: e.g., what was written on the board, how students were taking notes, etc.
3. Researcher's interpretation:
   -- What the researcher thought was taking place with respect to the development of the topic or theme. Specifically, the researcher's interpretation was based on the meta-cues being employed as the topic was constructed. These meta-cues were considered to be: topic

shift, linkaging, chaining, elaborating, restating, closing, opening, etc.

The above three categories, verbalizations, actions and interpretations, form the basis for a three-column coding system used to interpret the videotape transcripts described above.

The second level of analysis dealt with the structure of the text (transcript) to be analyzed. Since the purpose of the study was to learn about the nature of the coherence in the content-knowledge delivered by physics teachers, it was assumed beforehand that the teacher's discourse and activities revolved around a structured topic. To get a sense of how different pieces of the teacher's discourse baout a specific theme (dynamics) are bound together, a segmentation of the discourse was made. The major criteria followed in this process was that of identifying major topic shifts during the discourse. A similar approach was implemented by Agar and Hobbs (1985) and Lemke (1982a). Agar and Hobbs (1985) first macro-analyzed a whole text of an interview to put together a life history of a heroin addict who became a burglar. They then microanalyzed one segment of the history which dealt with the burglar's arrest.

A similar analysis was one employed by Lemke (1982a) in a study of the way teachers develop their science lessons.

Lemke (1982a) carried out a segmentation analysis based on major topic shifts during the teacher's discourse. This process consisted of reviewing a few lessons several times and noting topic shifts, verbal statements or other features that can be used as boundary markers within a lesson or unit.

A preliminary analysis of field notes and videotapes showed that in naturally occurring events, boundaries are fuzzy events difficult to trace within a lesson or set of related lessons. Videotape transcripts, however, are more precise for locating the moment in time when a teacher has shifted to a new topic or theme. These shiftings usually emerged in the form of statements like the following. "Let's get started with this (new) topic." "Yesterday, we talked about . . . today, we will refer to. . . ." "Today, we are ready to talk about a new subject." "Let me tell you about. . . . " On many occasions, topics were not announced at the beginning of a discourse stretch but at the close of it. This was the case in which topic-related demonstrations or tales were introduced before formally verbalizing what the conversation was about.

Discourse Analysis and Selection of Episodes

Preliminary analysis of field notes and videotape transcripts clearly indicated that definitions made in physics classes were highly content-dependent (Lemke, 1982a), i.e., the way meanings were constructed by different teachers varied across settings. Teachers use different sequencing strategies when they teach a topic or a series of related topics. The physics content talked about in similar units showed variations in terms of the topics, the order in which the topics were arranged and the strategies implemented to teach these topics.

Analysis of classroom discourse of more than 200 classroom observations and the videotapes would have been a very time consuming activity. Instead, a "funneling" approach was implemented to draw on a more narrow scope of information from a larger pool. In this sense, it was decided to focus on the theme "dynamics" (as traditionally defined by physicists). It is important to point out here that several themes were studied during the observation phase including areas such as kinematics, waves, momentum, energy, optics and the solar system. However, one of the reasons for selecting the unit on dynamics was the fact that it was possible to videotape most of the teaching episodes that evolved around that theme.

A careful analysis of the episodes led the researcher to learn how the different pieces of the discourse were put together, giving an understanding of the nature of the coherence of the whole unit. In addition to this macro-analysis of the whole unit, a micro-analysis of one segment (topic) was also conducted. In this case, a decision was made to micro-analyze how the three participant teachers dealt with Newton's Second Law of Thermodynamics (an episode) and how this topic is connected to the other topics considered in the unit as a whole.

The Corpus of Datum

The following is a list of the videotapes which formed the basis of the analysis of the present study. Although 25 videotapes of 50 minutes each were made, only 20 of them are mentioned below as they form the major data source from which conclusions and findings were derived. (The remaining five tapes correspond to Mr. Howard's teaching the last five lessons of a Kinematics unit.) The videotape topics and activities are described under the corresponding teacher's name (M. Simon, Mr. Ellis and Mr. Howard).[1]

Mr. Simon

1. Tape 1: The Principle of Inertia (demonstrations).
2. Tape 2: Newton's Laws.
3. Tape 3: Experiment on Newton's Second Law.

Mr. Ellis

1. Tape 1: Newton's First Law.
2. Tape 2: Newton's Second Law (friction).

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[1]Note: Each one of the participant teachers will be described in the next chapter.

3. Tape 3: Newton's Second Law (demonstrations).

4. Tape 4: Weight and Mass.

5. Tape 5: Weight, Free Fall, and Terminal Velocity.

6. Tape 6: Newton's Second Law Experiment.

7. Tape 7: Newton's Third Law.

Mr. Howard

1. Tape 1: Procedures on the Experiment: "What Forces Do To Motion" (Experiment 20).

2. Tape 2: Conducting Experiment 20 (PSSC).

3. Tape 3: a) Data Analysis on Experiment 20.
   b) Introducing Experiment 21: How Force and Mass Affect Acceleration.

4. Tape 4: Data Analysis of Experiment 21.

5. Tape 5: Conclusion of Experiment 21.

6. Tape 6: "Wrap Up" of Experiment 21.

7. Tape 7: Introducing Experiment 21: Inertial Versus Gravitational Mass.

8. Tape 8: Conducting Experiment 22.

9. Tape 9: a) Conclusion of Experiment 22.
   b) Solving "HDL's" (Home, Demonstration and Laboratory) Problems.

10. Tape 10: Solving "HDL's" Problems.

CHAPTER FOUR

CONTEXT FOR SUBJECT MATTER ORGANIZATION AND SEQUENCING

Introduction

The purpose of this section is to present a profile of the participant teachers in this study. First, the school and the classroom are described in detail. Second, an overview of each teacher is given. This is followed by a summary of the textbooks used by each teacher; and, fourth, a description of each teacher's plan for a single unit.

The Schools and the Classrooms

The schools used in this study are located in the mid-Michigan area close to the state capital. They house students from the 9th up to 12th grades. Each school is under the administration of different school districts with different policies.

School 1 (Room 200)

This school is located in an extremely mixed neighborhood shared by blacks, hispanics, orientals and caucasians. A large, well-known car manufacturer and middle-class houses are adjacent to the school. The school's population is about 1,400; and it has been steady for a few years. The building dates from 1928, with three floors and indoor and outdoor sport facilities.

Room 200 (fictional number), where the actions described in this study took place, was located on the second floor at the end of a large corridor with student lockers on both sides. During breaks, the corridor was usually an area of intense social activity. A small hallway, framed by bulletin boards, led to room 200. These bulletin boards were frequently used by the teacher to post science articles and posters that served to attract students to physics.

The classroom itself was semicircular (see Figure 4.1) with eight glass windows overlooking the school's main entrance and the students' main parking lot. The room was equipped for teaching high school physics to sophomores, juniors and seniors. There was space and facilities for at least 35 students. The room's seating structure was arranged in three large rows facing the teacher's desk. This structure was frequently changed to accommodate laboratory demonstrations or to prevent students from "cheating" during test periods.

The lab tables were mobile and were located in the curved section of the room, close to the windows. Behind each lab desk and attached to the walls were the gas, water and electricity outlets.

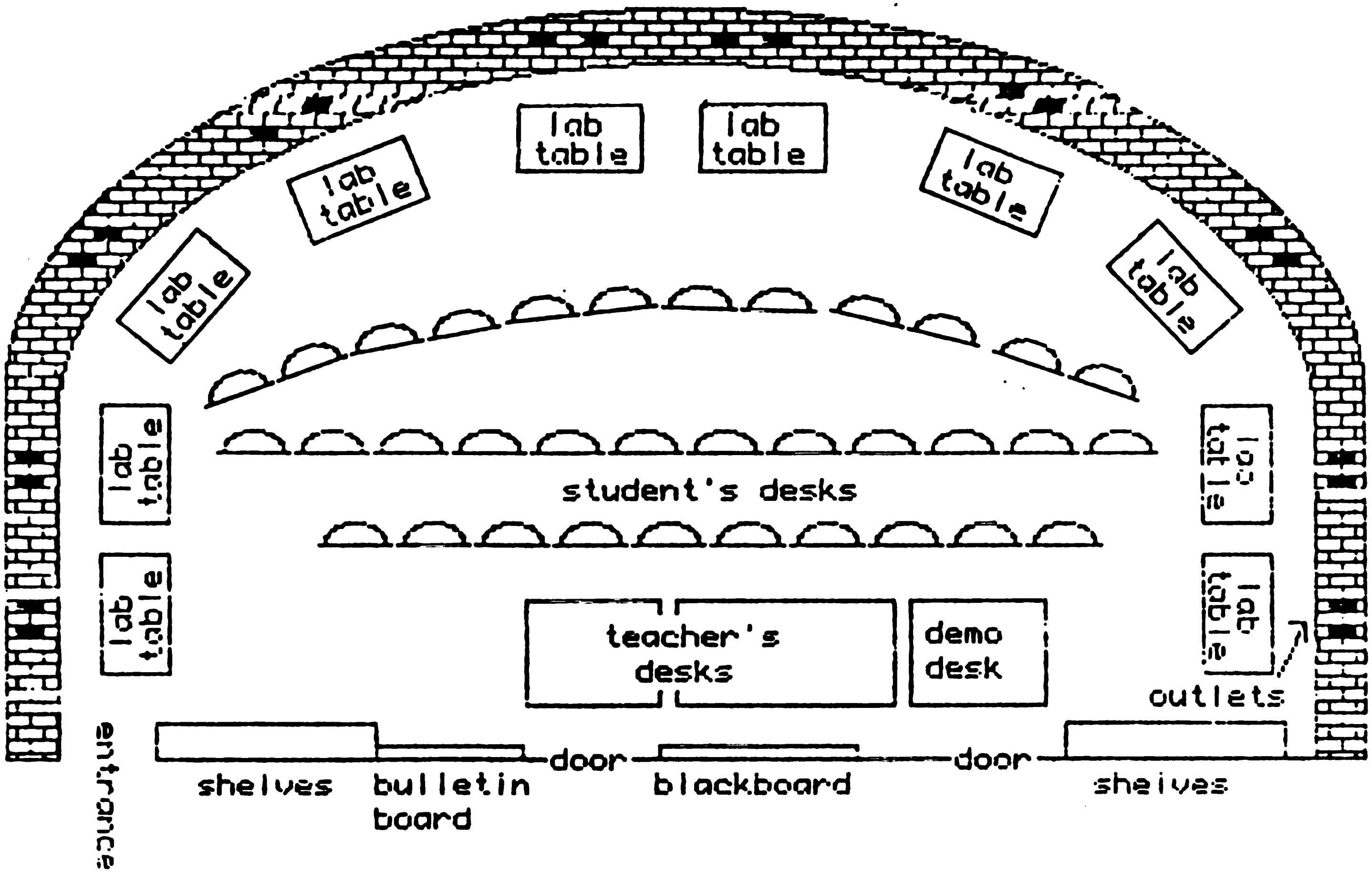

Figure 4.1: Floor map of classroom 200.

There were three blackboards located at different spots throughout the room. There were also two small bulletin boards on both sides of the blackboard close to the teacher's desk. These boards were frequently used for posting students' grades, cartoons and teacher's memos. In one of the classroom's corners there were two shelves used by the teacher to store handouts, worksheets and other classroom written materials. Close to the teacher's desk were the doors that led to the storage room and to a lecture room. The first room was used to store lab equipment and important documents such as quizzes, tests, etc. The lecture room was not part of the physics laboratory. Due to the lack of space, it was used to teach social science classes. Still, the physics teacher constantly needed to get through it because that room led to the physics library.

School 2 (Room 100)

The second school used in this study was located in a small community of about 40,000 people. It was close to a major state university and some local government offices. The school was attended mainly by caucasian students. The school was a one-level building erected in 1963 with a capacity for 1,300 students.

Room 100, where the observations took place, was the school physics laboratory with a seating capacity of 25 students (see Figure 4.2 for details). A large corridor with lockers on both sides led to room 100. The room had no windows. A fire exit led outside to the school playground. The room was rectangular in shape; and it was equipped with an overhead projector, bookshelves (displaying high school physics textbooks) and physics equipment stored on shelves located around the room. There were 12 fixed lab tables properly equipped with gas, electricity and water facilities. The ceiling of the room was fixed with metallic hooks used frequently by the teacher to carry out classroom demonstrations.

The blackboard covered a large portion of the front wall. Its frame was used to display the most common metric prefixes, and their numerical values, used in physics such as centi, nano, mili, micro, etc. Above the board was a permanent display which listed the more fundamental equations developed throughout the course. Alongside the board, there was a large bulletin board frequently used by the teacher to display cartoons, papers, posters, etc. allegoric to the physics unit being developed at that time. The teacher of room 100 always made sure the material displayed on the bulletin board was there before the referred unit got started.

The teacher's desk was located in front of the class. It was often used in conjunction with a large demonstration

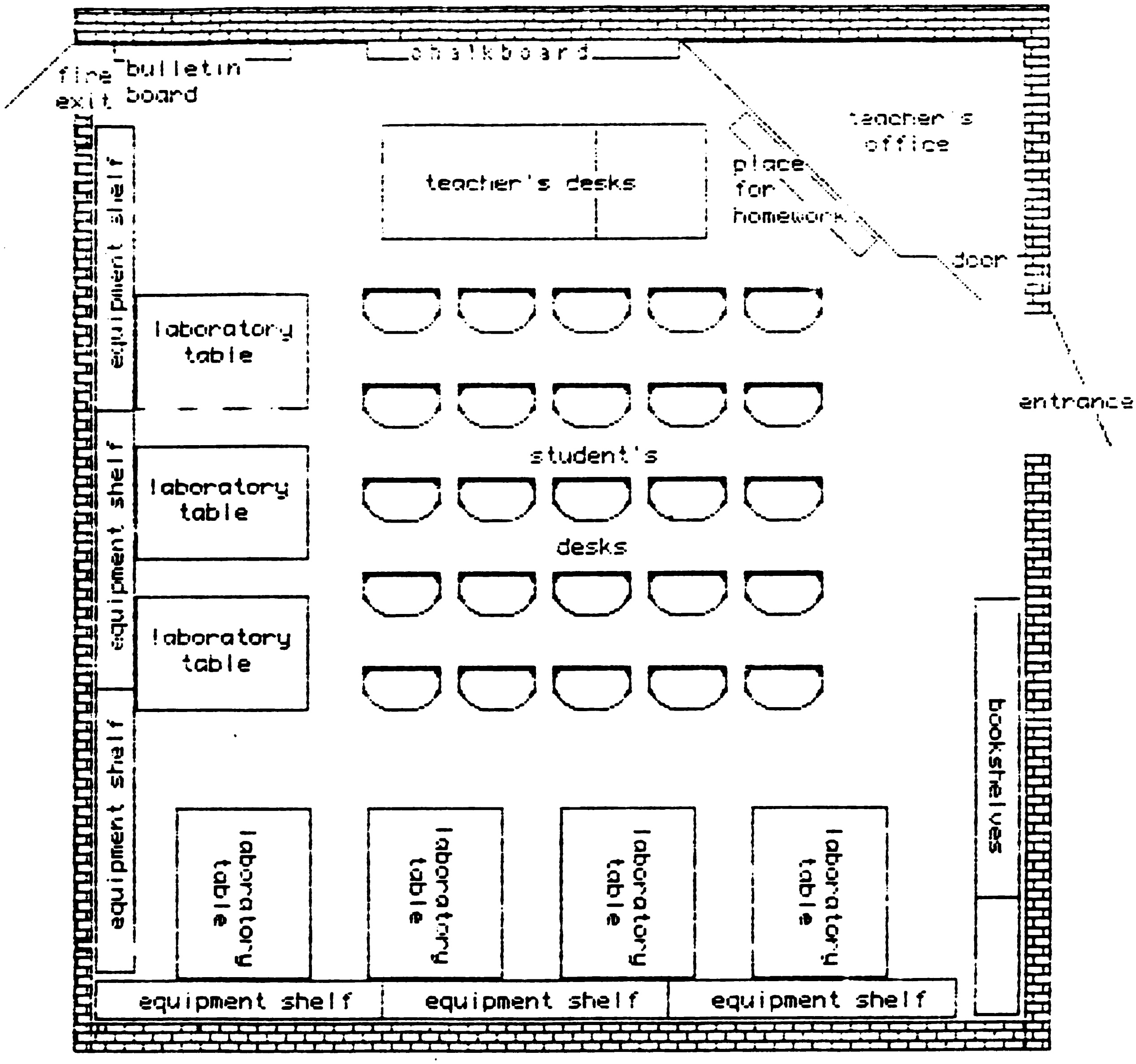

Figure 4.2: Floor map of classroom 100.

table to conduct class experiments. Before these demonstrations were actually carried out, the teacher made sure the equipment to be used was below the table. This way he did not waste time in between events, particularly on those occasions in which he wanted to sustain student interest in the concept being dealt with.

School 3 (Room 150)

The third school used in the study was located in a white rural middle class neighborhood, 15 miles away from a major state university. The high school was closely associated with frame houses and a middle school. The one-level school building was about 20 years old and was well-equipped with indoor and outdoor sport facilities. It accomidated from 700 to 800 high school students.

Room 150 (fictional number), where the observations were carried out, was located halfway down a corridor that led to other classrooms and school facilities. The room had a fire exit leading to the schoolgrounds outside; and there were no windows. The room was rectangular with a seating capacity of 30 students. Figure 4.3 shows the relative position of tables, teacher's desk, and lab facilities.

Room 150 was equipped with basic Physical Science Study Committee (PSSC) apparatus, which was stored in a contiguous room. This ajoining room was also used as the teacher's

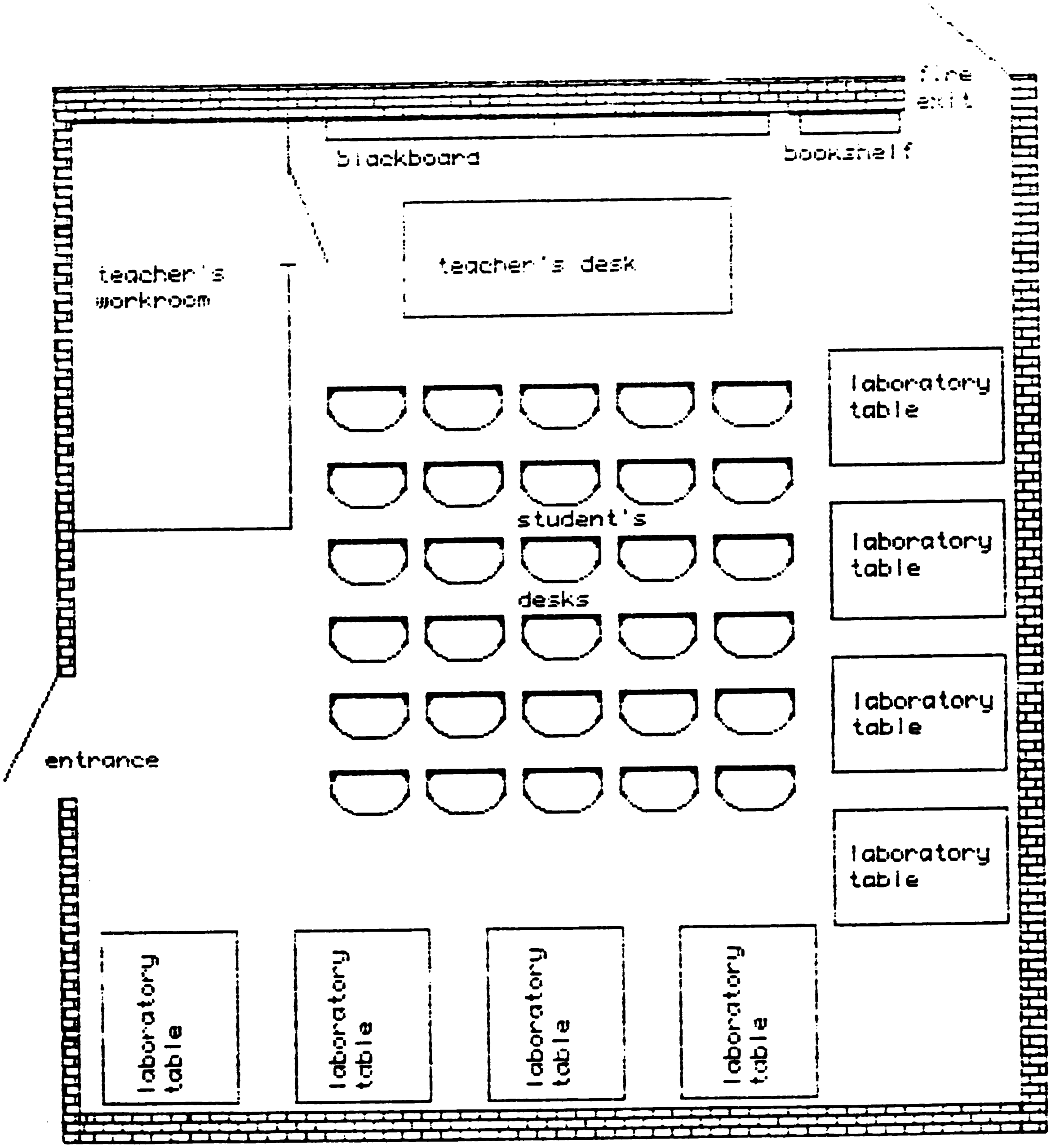

Figure 4.3: Floor map of classroom 150.

office, and it housed some bookshelves with a few, rarely used books. Some cabinets contained microscopes which were never used in physics lessons. The room was also used by the physics teacher to teach a course in zoology for freshmen students.

As one entered the room, the first thing that attracted one's attention was a black and white poster of Albert Einstein stating something to the effect that, "It is not hair that counts, but the ideas." Alongside Einstein's poster, there was an old periodic table of the elements. On the front side of this wall, an old metric rule and a bulletin board were hooked to the wall.

The blackboard was multi-purpose in nature with facilities for film projection and other teaching applications. On one side of it, there was a pendulum (2 meters long) used for classroom demonstrations. On the opposite side, there was a metal hook used by the teacher to hang objects such as scales, springs, etc. Very close to this side of the board, hanging on the wall, there was a poster of Alice in Wonderland. This poster was used in the past to teach students about graphing complex relations between physical variables. Later, the teacher preferred to use the story of Gulliver's Travels.

The physics equipment was stored in the teacher's office, which was also used to keep the filing cabinets and some bookshelves. These shelves had several editions of the PSSC series as well as some zoology textbooks.

The Teachers

The purpose of this section is to introduce the reader to the main characters of the study. Up to this point, they have been described only as "he," or "the teacher." Mr, Simon (Room 200), Mr. Ellis (Room 100) and Mr. Howard (Room 150) (not their real names) were the three participant teachers in the study. They were experienced high school physics teachers[1] who expressed (at the researcher's request in late June 1985) their willingness to let the researcher learn about their teaching, and especially about the nature of the physics content being enacted through their teaching.

Mr. Simon (Room 200)

Mr. Simon was in his early 60s. He had been teaching at the same school for 29 years, and at the time of the study, he was acting as the science department chairman. He held a master's degree in physics and had been active in professional organizations in his own state (he is a past president of the State Association of Physics Teachers). He

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[1]In a 1983 survey, a typical high school science teacher in Michigan was a male, with about 16.5 years of experience, and holding a master's degree (see Hirsch, 1984). In this study, two of the participant teachers held master's degrees in physics and physics education, and the average years of experience was about 22.

was responsible for the teaching of seven physics courses offered at the school. This responsibility was shared by another physics teacher who was in charge of three of the courses.

Mr. Simon had been teaching the Harvard physics course since its creation in the early 1960s. His name appears in the "consulting committee" as one of the high school physics teachers who helped to put the course together. He had the philosophy that the course "Physics for Everybody," which was one of his major concerns, was a means of motivating students to take physics (35 percent of the graduating population at his school takes physics). In the early stages of implementation of the Harvard physics course, Mr. Simon was heavily engaged in the design and construction of the necessary equipment to run the course.

Mr. Simon was an eager reader of such professional journals as <u>The Physics Teachers</u>, <u>American Journal of Physics</u> and <u>Scientific American</u>. In addition to this, he was also knowledgeable about most high school physics textbooks available on the market. His experiences as a physics teacher were not only the result of teaching physics, per se, but also of his involvement in other related activities. During the data gathering phase of this study, he was acting as the school district coordinator of museum science activities. For this, he was later given a national award.

Apart from his interest in physics teaching (as shown in our daily informal conversation), Mr. Simon was a football fan. On this matter, he was a strong supporter of the school football team, so that during the football season, football was the subject of Mr. Simon's discourse at the end of class on Friday, and at the beginning of class on Monday. During this conversation, they talked about predicting scores, players, fan behavior, results, etc.

It should be noted that Mr. Simon was an excellent discussant on issues dealing with his personal views about his classes and the school as a whole. Through his actions, this researcher "became native" up to the point of assisting (on many occasions) his students on classroom physics tasks and participating openly in everyday social conversation inside and outside the classroom.

Mr. Ellis

Mr. Ellis was in his late 50s. He had been teaching physics at the school for 20 years since he graduated from college. He held a master's degree in science education from the university located in the vicinity. He was the coordinator of six physics courses offered at his school, where 20 percent of the graduating class took at least one course in physics. He was assisted by another physics teacher who was responsible for two of these courses. In addition to the four courses in introductory physics, Mr.

Ellis was also responsible for teaching an advanced physics course offered to seniors.

Mr. Ellis was an active member of the State Association of Physics Teachers and was a regular reader of such periodicals as The American Journal of Physics, Psychology Today and The Smithsonian. From these journals and other sources, he constantly extracted his papers, cartoons and posters which he eventually used to enrich the bulletin board with materials related to the topic of the physics unit being developed.

Mr. Ellis had been teaching physics with the Harvard physics course since 1967, when he became familiar with the course materials. The year before he had taught the PSSC course. Through the years, he prepared a "package" for each one of the Harvard physics courses. The package contained a number of items such as unit objectives, exemplary tests, lab instructions, problems sets (assignments) and readings.

During my role as a participant observer in Mr.Ellis' classroom, I learned that Mr. Ellis was a rather reserved person who rarely openly gave his opinion on something unless he was asked. However, it should be mentioned that as I was about to leave the school, our discussions of school physics and related issues were more open than at the initial stages of the study. He was very concerned with "what his students were getting" in his classroom which he claimed to be "one of the best physics classrooms around." In our after class conversations, he made reference to Piaget's psychology and the need to teach students to reason before they go to college.

Apart from his duties as a physics teacher, Mr. Ellis worked as a baseball coach for the school.

Mr. Howard (Room 150)

The third character of this study was Mr. Howard, an experienced teacher who was in his late 50s. Mr. Howard had been teaching physics at the school for 29 years. He graduated about 31 years ago as a geologist-engineer and eventually became involved in physics teaching after being offered the opportunity to participate in the initial trials of the PSSC implementation as a nationwide physics course. He was in charge of four physics courses for seniors and a zoology course for freshmen. About 15 percent of the graduating school population took physics at his school. He had also taught chemistry and mathematics, in addition to physics.

Mr. Howard had been teaching the PSSC course for 29 years. Apart from teaching physics and zoology, he was the coordinator of the school media center, and assisted students and teachers from the university located nearby. In addition to his role as a physics teacher, Mr. Howard was engaged in non-school related activities. He was one of the co-owners of a small oil-rig company that operates in the region. In this company, his main function was to work as a "dowser" as a means to search for oil and gas. In the late phases of this study, this researcher learned that Mr. Howard was a strong believer in transcendental meditation, and that during summer vacations, he offered courses on this subject to parents, teachers and other interested people.

Mr. Howard was very open in our conversations on high school physics and related topics. His main concern was to have students "learn the vocabulary to talk physics." He was also very open to having his classes videotaped or audiotaped, without objecting to the researcher's purposes and means.

The Textbooks

Textbooks play an essential role in the nature of the academic context enacted in schools. The purpose of this section is to give the reader a broad description of the textbooks being used in each one of the classrooms studied. Both, Mr. Simon and Mr. Ellis relied on The Harvard Project Physics[2] or just project physics as it was frequently called. Mr. Howard, on the other hand, advocated the use of

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[2]Published by Holt, Rinehart & Winston, New York, 1981, under the direction of F. Watson, G. Holton and F.J. Rutherford.

the Physical Science Study Committee[3] (PSSC). Both textbooks were widely used in high school physics courses across the U.S.A. (see Pallrand & Lindenfield, 1985).

The Harvard Project Physics

The Harvard Project Physics was one of the new science programs of the 60s. It was designed with three major goals: (a) to teach physics from a humanistic perspective, (b) to attract students to introductory physics and (c) to find out more about the factors that influence the learning of science (see The Harvard Project Physics, Preface). The project directors spelled out the project aims as follows:

1. To help students increase their knowledge of the physical world by concentrating on ideas that characterize physics as a science at its best, rather than concentrating on isolated bits of information.
2. To help students see physics as the wonderfully many-sided human activity that it really is. This meant presenting the subject in historical and cultural perspectives, and showing that the ideas of physics have a tradition as well as ways of evolutionary adaptation and change.

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[3]Published by D.C. Heath & Company, Lexington, Mass., 1976; and edited by V. Haben-Schain, J.B. Cross, J.H. Dodge and J.A. Walter.

3. To increase the opportunity for each student to have immediately rewarding experiences in science even while gaining the knowledge and skill that will be useful in the long run.
4. To make it possible for instructors to adapt the course to the wide range of interests and abilities of their students.
5. To take into account the importance of the instructor in the educational process, and the vast spectrum of teaching situations that prevail (The Harvard Project Physics, Preface, 1981).

To achieve the above goals and aims, the authors proposed a one-year course subdivided into six big units as follows:

1. Concepts of Motion[4]
2. Motion in the Heavens
3. The Triumph of Mechanics
4. Light and Electromagnetism
5. Models of the Atom
6. The Nucleus

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[4]This research study focused primarily on Chapter 3 of this unit, which is entitled "The Birth of Dynamics: Newton Explains Motion."

The Physical Science Study Committee (PSSC)

The PSSC physics course is one of the oldest "new" science programs of the 60s. It is a college-bound course whose aim is to present physics "not as a mere body of facts but basically as a continuing process by which men seek to understand the nature of the physical world" (Haber-Schain et al., 1976, Preface). The textbook is divided into 27 chapters which can be categorized under four main sections or themes:

1. Optics and Waves (7 chapters)
2. The Study of Motion (10 chapters)[5]
3. Electric and Magnetic Properties (6 chapters)
4. The Atom (4 chapters)

In contrasting the characteristics of the PSSC physics course with traditional physics courses, Marshall and Burkman (1966) stated that:

1. The course covers less topical material than is usually presented in high school physics while penetrating more deeply into selected areas which contribute most heavily to an understanding of the universe.
2. Physical models are developed and used as they are by scientists in attempting to explain phenomena.

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[5]The data reported here, as far as this textbook is concerned, focused on the third chapter entitled "Newton's Law of Motion."

3. Physics is treated as a unified, interconnected story, and as a human activity "set within our society and carried on as part of the historical development of mankind."
4. Less emphasis is placed on technological applications of physics and more on an understanding of fundamental principles.
5. The laboratory is integrated more closely with the rest of the course than is customary.
6. The materials provided for the students and the teachers make a more complete kit of materials for learning than have been available in any course previously (Marshall & Burkman, 1966:28).

Aims, goals, characteristics and content of the textbooks are key elements that determine how teachers enact the school academic content (Clark & Elmore, 1981).

Teacher's Planning

Teacher planning is a teacher's construct that has a powerful influence on how academic contact is organized and enacted in real life (Clark & Yinger, 1989b; Smith & Sandelsach, 1979; Clark & Petersen, 1986). Clark and Yinger (1979) identified at least eight different types of planning as carried out by teachers: weekly, daily, unit, long range, short range, yearly and term planning. Unit planning is reported to be the most common approach followed by teachers.

According to Clark and Yinger (1979), there are three clusters of reasons as to why they carry out planning:

1. Planning to meet immediate personnel needs (e.g., to reduce uncertainty and anxiety and to find a sense of direction, confidence and security).
2. Planning as a means to the end of instruction (e.g., to learn the material, to collect and organize materials, and to organize time and activity flow).
3. Planning to serve a direct function during instruction (e.g., to organize students, to get activity started, to aid memory and to provide a framework for instruction and evaluation). (Clark & Yinger, 1979, cited in Clark & Peterson, 1986: 261-262.)

Teachers' Conceptions of Planning

Analysis of field notes, interviews and documents from the three classrooms observed, clearly indicated that planning was an important element of how the academic content transpired in these settings. Basically, the type of planning was by unit of instruction or chapter of the book. This type of planning was conducted just before the chapter got underway. Daily planning was also visible during so called planning periods. During these sessions, teachers, for example, decided what to include in the lesson, what problems to solve, what demonstrations should be conducted and what equipment to use, etc.

Mr. Simon's Planning

Mr. Simon's conception of planning is portrayed in the following excerpts from an interview:

> Planning is done by chapters from the project physics textbook . . . and that usually takes a week and a half . . . so we are biting off a chunk of about that time size . . . and from there we go to the objectives . . . and maybe this is the key thing that we try to figure out. What is reasonable to teach the students about this? What skills we expect students to display?
>
> Our planning includes a time line for this material, and it also includes the objectives to clarify our thinking about what it is we are teaching.
>
> In planning, there are several parameters that we consider, variety of activities . . . and availability of equipment. Activities are varied as to motivate students. They include: reading, problems to solve, lecturing, experiments. The equipment determines the type and variety of demonstration and experiments that can be carried out in class, either in a group or by individual students.
>
> Daily planning is carefully done through worksheets which the activities . . . lectures . . . labs. They also indicate where they (the activities) start and what assumptions we would be making. (Interview, December 12, 1986)

Examples of a unit plan and a daily plan are given in Appendices A and B. The first one shows how the chapter on dynamics was planned for. It includes days, topics, objectives and assignments. Appendix B shows the worksheet that was distributed to students on the day Newton's laws were taught by Mr. Simon.

Mr. Ellis' Planning

Like Mr. Simon, Mr. Ellis also plans his teaching by textbook chapters which were blocked out in topics and activities. The following excerpts from an interview help to shed light on the above assertion. To the question of how planning was conducted, Mr. Ellis answered as follows:

> The basic part of planning comes from the textbook (project physics). You either follow it in that order, or try to amplify it by giving examples . . . which are not in the textbook.
>
> When planning for a unit (or chapter), I look at the materials . . . textbook . . . equipment. I block (the topics) out on the assignment sheet. Some (blocks) take two or three days to complete.
>
> When planning a chapter, I start out with an overall picture of what the chapter is about . . . how much time should we spend, and then I subdivide it. (Interview, December 12, 1986)

According to Mr. Ellis, the planning of a unit includes: (a) searching for the appropriate demonstrations to explain concepts, (b) arranging the bulletin board and (c) preparing readings from the textbook and the package. This process has become easier over the years as the information pool has increased as a result of Mr. Ellis' interest in searching for problems, questions, posters, etc. relative to the units he teaches in his physics course.

Appendix C shows unit planning carried out by Mr. Ellis as he was about to start teaching the unit on dynamics. Text refers to the project physics textbook (1976 edition) and HO stands for handout in the package. This package, as mentioned before, contained a series of handouts that indicated the objectives of the unit, problems to solve, experiments to be conducted and a sample test.

Mr. Howard's Planning

Contrary to Mr. Ellis and Mr. Simon, Mr. Howard did not rely much on written planning in order to guide the organization of the academic contact. However, daily observations of his classes clearly indicated the existence of an underlying operational planning that was made explicitly to students at the start of a textbook chapter. Subsequent activities were somehow rooted in that initial planning.

The following excerpts from an interview with Mr. Howard explain the above assertion. To the question, "What kind of planning do you do in your physics class?" Mr. Howard responded:

> Well, most of it is in my head. Okay, I got to know my kids pretty close . . . so my planning will attempt to set up the experiments so that my kids can do it . . . and if the data they are going to get will be viable. That's my initial step . . . get the graph done . . . interpret the graph . . . and find out what kind of conclusion we can draw.

> Planning derives from my experience with students over the years. I first try to find out what they know . . . and how badly those ideas are "entrenched" on them. (Interview, February 24, 1987)

In subsequent excerpts of the interview, Mr. Simon indicated that his 29 years of experience with the PSSC allowed him to conduct his teaching "relying on his head" and not on "written notes" though he usually "scribbles a few things . . . mostly on a weekly basis." This type of written plan "never works out."

Mr. Howard's conception of planning was very much consistent with what actually happens in his classroom during the teaching of a unit on the topic of that unit. For example, as he was about to start teaching the chapter on dynamics, and after he introduced the nature of what the chapter was about, Mr. Howard wrote out on the board the purpose and procedures of experiment 20 as follows:

<u>Experiment 20</u>

Purpose: to determine how a force affects the velocity of a body.

<u>Procedures</u>:

1. Practice giving a cart a run and then hook a timer and run a recording tape for a v-t graph.
2. One tock is four time intervals of ticks.
3. Make a record of a push and let the cart coast.
4. Run two trials:
   1. A cart and one brick.
   2. A cart and two bricks.

5. Plot v-t graph of each type on a sheet of graph paper.

(Field notes, February 4, 1987)

The above procedures somehow illustrate the subsequent activities in the three days that followed until the procedures for Experiment 21 were spelled out in a similar fashion. During these three days, Mr. Howard made sure that students get the graphs to him so that he could interpret them on the blackboard and find out what kind of conclusions can be drawn. Generally, once these conclusions were drawn, the next step was to apply them in the solution of numerical type of problems.

The teachers' conceptions of planning seem to fall into two categories. The first type of planning was exhibited by Mr. Ellis and Mr. Simon, who carried out a written unit plan that was carefully segmented in topics. The second category was represented by Mr. Howard, who, when teaching a unit of instruction, relied less on written plans and more on his experience and the knowledge of his students. Mr. Howard's planning, as compared with the other two teachers, was more lab-oriented. It was from the lab experiments that Mr. Howard drew the unit's major conclusions that were eventually applied in the solution of numeric problems.

Summary

Chapter Four contained four sections. First, a description of the schools and the classrooms were presented. Second, a description of the participant teachers was given. Third, an overview of the textbooks used by the teachers was considered. Finally, it presented a brief account of the teacher's theories on planning, as well as how this process was actually conducted for a unit on dynamics.

The inclusion of a large pool of background information in Chapters Three and Four was needed because of the important role that the information plays in relation to how a teacher constructs an instructional sequence, -- especially how the different topics of a physics unit are put together by the teacher. A knowledge of the teachers (planning, characteristics, etc.), classrooms and textbooks, as well as knowledge of how the researcher proceeded in the interpretation and construction of the findings will help the reader to understand how the three participant physics teachers enacted (in real time) an instructional sequence on dynamics.

CHAPTER FIVE

SEQUENCING SUBJECT MATTER IN HIGH SCHOOL PHYSICS

Introduction

This chapter returns to the major question of the study: How is content knowledge enacted by experienced teachers? The question specifically focuses on the nature of the relation between the different topics (coherence) as they are enacted in real time by physics teachers. In order to shed light on these questions, "story-lines" have been reconstructed from the teachers' discourses of a physics unit on dynamics.

Analysis of the teachers' discourses as well as the actions accompanying such discourses led the researcher to take into consideration the fact that content knowledge is enacted at two levels: macro-level and micro-level. A macro-analysis yields the nature of the global coherence of the unit of instruction (i.e., dynamics). It gives a sense of how different topics are put together to produce a coherent whole (Agar & Hobbs, 1985). On the other hand, a micro- analysis gives specific details of how a single topic is enacted in the context of a much larger unit. In this study "macro-sequence" will be referred to as the construct that results from a macro-analysis of a series of major topics during the development of a theme (e.g., dynamics). Similarly, "micro-sequence" will be referred to as the unit that results from a micro-analysis of a specific topic. Generally speaking, it could be said that the macro-sequence is an abbreviated version of subject-matter information content embedded in the story-line being enacted by the teacher. It focuses on specific details of content-knowledge organization and sequencing of a particular unit of instruction. By the same token, a micro-sequence would represent a map connecting the main statements presented in a discourse segment focusing on a single topic of that unit.

The chapter is organized in two different parts. Each part deals with a set of questions. The first part focuses on the nature of the instructional macro-sequence (on dynamics) as constructed by teachers. The second part deals with the nature of the instructional micro-sequence (on Newton's second law).

The results of this chapter will yield evidence for the assertion that: experienced physics teachers differentially construct subject matter at both macro and micro-levels. In this sense, the subject matter is enacted in organic units (topics) whose structure and elaboration vary from teacher to teacher. At the macro level, we find that the topics covered by the teacher are not necessarily the same as those covered by another teacher when dealing with a similar theme. In addition, similar topics are enacted through different sets of instructional events. At the micro-level, the content organization is enacted through logical relationships (among similar concepts) that are differentially structured by teachers.

PART 1

Constructing a Macro-Sequence on Dynamics

This section of the study compares the way three experienced physics teachers delivered a unit on introductory dynamics to high school students. The main purpose is to shed light on the following guiding question: What is the nature of the coherence (global) of a unit on introductory dynamics as it is enacted by the participant teachers? In particular, the study focuses on what topics are actually enacted and how the topics are sequentially and logically taught through time.

Story Lines on Dynamics

The nature of the coherence will be explained through story-lines that show how individual teachers put together different topics to eventually form a macro-sequence. Each story-line was developed from a data source composed of three entries: participants' verbalizations, participants' actions and researcher's interpretation. In constructing the story line, emphasis was made on the information content being dealt with as well as the "enacted environment" (Erickson, 1982) through which the information content was manifested and delivered. The following story-lines present three different accounts of individual teachers who strived to communicate the theme of dynamics. The vignettes describe a day-to-day account of the way in which teachers introduced new topics, the information content of each topic and how the topics were related to one another. In addition, the vignettes also describe how participants interacted with the immediate environment (books, worksheets and lab equipment) through which topics, and the information content embedded in them, were delivered.

Each story-line is first introduced, then followed by the researcher's interpretation in the context of the question being addressed. Mr. Simon's story-line is presented first, followed by Mr. Ellis' and, finally, Mr. Howard's.

Mr. Simon's Story-Line on Dynamics

The following vignettes attempt to describe an abbreviated story-line showing how Mr. Simon dealt with an introductory unit on high school physics. The theme of the unit is dynamics: i.e., the study of motion and its causes. The purpose of the story-line is to describe the nature of the global coherence across the different topics and relationships among concepts being dealt with in the unit.

The history begins after Mr. Simon had concluded a unit on Kinematics (i.e., the study of motion) and it concludes prior to a unit on circular motion. The vignettes were derived from a series of eight consecutive class observations, three of which were videotaped and transcribed. Figure 5.1 shows in sequential-temporal order, the different topics introduced by Mr. Simon during his teaching of an introductory unit on dynamics.

Day 1	Introduction to Chapter 3: "Differences Between Kinematics and Dynamics."
Day 2	The principle of inertia.
Day 3	Vectors.
Day 4	Exercise on vectors.
Day 5	Newton's Laws. - Newton's law of Inertia. - Newton's second law (a=F/m). - Newton's third law.
Day 6	Experiment on Newton's second law (a=F/m).
Day 7	Egg drop competition.
Day 8	Quiz -- paper due.

Figure 5.1. Chronology of major topics and activities in Mr. Simon's sequence on dynamics.

The story-line will tangentially touch on an activity that developed parallel to the teaching of the unit on dynamics. The activity was referred to by Mr. Simon as the "egg drop competition" and he explained in an interview: "Such an activity is to raise students' interest in physics . . . and it is not related to the concepts and ideas being taught in the unit." (Interview, September 22, 1986).

The story-line began after Mr. Simon had completed a unit on kinematics in which students learned about average velocity ($\Delta d/\Delta t$) and average acceleration ($\Delta v/\Delta t$). In doing so, they analyzed strobe records (ticker tape) of objects moving in a straight line.

The story-line that follows is intended to describe the nature of the coherence across the different topics talked about in the development of the unit on dynamics. The day-to-day account on dynamics is as follows:

Day 1 Introduction to Chapter 3

7:50 a.m.

After listening to the principal's announcements, Mr. Simon began today's discourse making reference to the 19th annual celebration of the egg-drop competition. He referred to previous experiences, rules and winners of a competition that takes place every year during physics classes.

8:07 a.m.

After indicating he would be providing the class with more information about the competition, Mr. Simon made his final opening statement on the next unit: "Well, today we need to get started on Chapter 3 and we have a demonstration for tomorrow . . . I'm going to do a demonstration on inertia . . . a very interesting one." After that, Mr. Simon distributed a worksheet and an outline for Chapter 3 (see Appendix A).

8:55 a.m.

During the 40 minutes from 8:07 until the end of the class period, students were left alone to work on the worksheet that contained a set of questions students had to answer by reading from the textbook. The questions focused on issues such as: the difference between kinematic and dynamic (this chapter), Newton's principles -- equilibrium, balanced, unbalanced and net forces. (Fieldnotes, September 22, 1986.)

Day 2 The Principle of Inertia

7:45 a.m.

At the outset of the class, Mr. Simon again referred to the egg-drop competition. He then distributed a handout on inertia.

8:05 a.m.

Mr. Simon:

Well, today . . . we look at one grand underlying principle of physics . . . very simple idea . . . but it prevails everywhere . . . it extends not

> only in the surface of the earth, but out in space. Inertia is the property of all matters to resist change in motion. Objects at rest remain at rest . . . . objects in motion remain in motion unless acted upon by an external force (principle of inertia). In other words, if we have something moving, it tries to keep whatever motion it has. Okay. Let's do a little test to see if that's true.

He then did six demonstrations having to do with inertia at the demonstration table. The first three focused on the need to eliminate friction to almost zero in order to make things move at a constant speed. For this occasion, Mr. Simon first slid a wooden block across the table, then a similar block on a track, and finally, the same block mounted on a dry-ice disk. They did this to observe how friction could be minimized, which allows objects to move at a constant speed.

He made reference to Galileo's work on constant speed and friction. The three other demonstrations that followed focused on exerting a sudden force (kick) upon over-hanging objects, and observing that the objects remained in place. An example of this was to hang a 1 kg. object from a metal rod with a thin string. A sudden force was applied to the object by pulling a piece of string hanging from the bottom of the object. In this case, only the lower string broke.

8:35 a.m.

After reinforcing the principle of inertia several times (once after each demonstration), Mr. Simon summarized the day's lesson: "Well, today we've shown you some ridiculous and some not ridiculous examples. We've seen inertia of massive objects . . . a block of steel (rolling down an inclined plane) and so on. Does air have inertia?"

A student's answer: "It should."

Mr. Simon went to get an air propeller and a candle and showed hoe the flame moved every time he spun the propeller with his finger.

8:40 a.m.

Next, students were given an optional puzzle to think about. Mr. Simon dropped a hollow and a solid metal disk, both of the same weight, onto an inclined plane at the same time. Observing that the solid disk slid to the bottom of the ramp first, he posed the question: "Why does the solid one get down first?"

8:45 a.m.

The above question (left unanswered) marked the end of Mr. Simon's lecture. On their own initiative, students began to fill out the worksheet Mr. Simon had distributed earlier.

8:48 a.m.

While students filled out the worksheet, Mr. Simon restated, the principle of inertia and announced tomorrow's topic. To this effect he added:

> What we are going to do next is look at another property of motion. And that is . . . you accelerate under the influence of a force . . . in order to take a close look at the fact that forces point in a certain direction . . . so we have to look at the properties of what we call vectors. Any question on what we've done? (no comment). Then you will stand at ease until tomorrow when we get involved with vectors and forces.

8:55 a.m.

As soon as Mr. Simon stopped addressing the class, students engaged in different activities. Some of them, for example, decided to complete the worksheet they had been using throughout the lesson. In doing so, they borrowed their peer's work. Others played around with the equipment displayed on the demonstration desks. By the time the bell rang, most students had already filled out the worksheet. (Videotape and fieldnotes, September 23, 1986.)

Day 3 Vectors

8:30 a.m.

On the third day of Chapter 3 (dynamics), Mr. Simon first distributed a set of three worksheets on vectors. He suggested students grab a ruler and a protractor from his desk, as they would be needed in the next two class periods. Mr. Simon then started talking about the definition of a vector, how to represent a vector (and an angle), and the difference between scalars (mass, time, etc.) and vectors (acceleration, velocity, field and force). Next, he talked about the representation of a vector using an appropriate scale. This short lecture was followed by the students working on a set of four vector-related problems. One example that is worth mentioning was one that required students to represent 12 Newtons. While working on this problem, Steve (one of my closest neighbors) asked, "Mr. Simon, what is a Newton?" The question was apparently ignored by the teacher, even though two other students raised the same concern later.

8:37 a.m.

At this point in time, most students had already solved the problems at hand. Mr. Simon explained the "tip to tail" method of adding vectors. The explanation was followed by another set of problems for students to work on with Mr. Simon's constant assistance.

8:53 a.m.

Mr. Simon: "Tomorrow, you will do an experiment involving vectors." (Most students had finished the previous task.) "Okay, get ready to apply what you have learned about addition, representation and so on of vectors." (Fieldnotes, September 24, 1986.)

Day 4 **Vectors**

8:00 a.m.

At the outset of the lesson (after taking care of daily administrative procedures), Mr. Simon summarized what they had covered on vectors the previous day. However, today's task was to get serious about page 3 (problem set on vector addition). He then suggested students spend the rest of the hour on that task.

8:55 a.m.

For 40 minutes, students worked in groups or alone on the task at hand. They were continuously assisted by Mr. Simon who answered students' individual questions as they worked on the problems set that he has given them. At the end of the class, Mr. Simon picked up the worksheets students had been working on. (Fieldnotes, September 25, 1986.)

Day 5 **Newton's Laws**

Day 5 began with Mr. Simon circulating a one-page worksheet entitled "Newton's Laws of Motion" (see Appendix B). After spending a few minutes talking about grades, he moved to the blackboard, ready to start his lecture.

7:45 a.m.

He began by introducing today's lecture as a "pretty powerful language . . . the greatest single achievement . .

. ever taken." He then said that physics "emerged from confusion and disagreement . . . because understanding the universe began with Newton's contribution and his principles."

7:55 a.m.

Mr. Simon stated,

> Well, let's look at his (Newton's) laws of motion. There are three of them. The first one you are familiar with (from the lecture on Tuesday), the so-called law of inertia. It says bodies at rest remain at rest. Bodies in motion remain in motion . . . straight line . . . constant speed . . . and that's the law of inertia.

(Students followed Mr. Simon with the worksheet that they needed to fill out accordingly.) Next, he talked about the conditions and results under which the first law holds:

1. No unbalanced forces act ($\Sigma F = 0$). (Mr. Simon elaborated on this idea by showing that the sum of all the forces (four) acting over a piece of wood resting on his desk was zero.
2. Velocity is constant.
3. Acceleration is zero.

8:05 a.m.

Having explained the conditions under which the first law holds, Mr. Simon pointed out students already had a pretty good idea of the first law. Seconds later, he shifted to another topic, Newton's second law.

> Let's go on to the second one . . . the biggy one . . . the second law. It says if you do have an unbalanced force, then you have acceleration . . . and these are Newton's words. An unbalanced force causes an acceleration, in the same direction and proportional to the net force. That means that acceleration is proportional to the force . . . but the net force.

At this point in time, the board read:

$$\Sigma F \neq 0$$

$$a \propto F_{net}$$

Next, he emphasized that a (acceleration) and "F" (force) were vectors. He continued as follows: "Now the second part of that (law) says that it (acceleration) is inversely proportional to mass. That is to say, acceleration is proportional to the inverse of the mass." The board showed:

$$a \propto \frac{1}{M}$$

8:07 a.m.

After giving a couple of examples to illustrate the relation $a \propto 1/m$, Mr. Simon's next activity was to describe the conditions under which the second law held. These conditions can be summarized as follows:

1. There is net force . . . and that's what causes a body to accelerate ($F \neq 0$).
2. As a result of this (force), the speed is not constant and the acceleration is not zero . . . and the object will:

a. accelerate

b. decelerate

c. change direction

With respect to the last statement, he added: "It is a curve ball which does not make sense at this point . . . but later."

8:10 a.m.

The immediate next step was to try to solicit from the class some examples in which both laws applied. The final result of this activity is indicated below:

Examples

Newton's first law:	air track - car at constant speed stopped car - ball on the shelf weight on table
Newton's second law:	speeding car burning rocket (accelerating) baseball as hit by a bat

Observe that some of these examples were discussed earlier.

8:15 a.m.

Another set of examples followed. This time students were given, in a worksheet, a series of v-t (velocity-time) graphs; and they were asked to identify which one of the two laws applied in each case. It was generally agreed that in cases where V (velocity) was constant or zero, Newton's first law applied. If acceleration was not zero, then Newton's second law applied.

8:17 a.m.

Mr. Simon: "Let's go back to look at the equation form of Newton's second law." He then referred to the two statements made above ($a \propto F_{net}$ and $a \propto 1/m$) and pointed out that Newton's second law could be expressed (mathematically) as: $a = F/m$ which could be read as: "Acceleration is proportional to 'F' (force) and inversely proportional to 'M' (mass)."

8:20 a.m.

From the equation of Newton's second law, Mr. Simon derived "Newtons" (Kg m/sec^2) as the units of force, and at the very end of this explanation he communicated: "So, that's where that Newton's business comes in . . . that we told you about before." (In previous classes he had used the word "Newton" without explicitly explaining what it was.)

8:22 a.m.

At this point in time, Mr. Simon began to distribute a handout with a set of problems that required the application of Newton's second law ($a = F/m$). Just before the students started this task, he added: "I want you to write something down you probably won't get out of your mind . . . silly ideas involving these two terms. I want you to write down the difference between what we refer to as mass and what we call weight." He then explained that "weight is a force caused by gravity. It varies because gravity varies from place to place." He expanded on this concept by giving several examples in which gravity varied. Seconds later he moved on to the concept of mass: "Mass is the same as inertia. In fact, mass is what we use to measure inertia, and it is not affected by position . . . as gravity is."

The board read:

Weight:

1. Force caused by gravity.
2. Weight varies from place to place.

Mass:

1. Is the same as inertia.
2. Constant . . . not affected by position.

8:25 a.m.

Once students had copied down the information from the blackboard, Mr. Simon proceeded:

> Well, let me just tie this (lecture) up with a little chat about Newton's third law. Newton's third law is not mathematical (as the second law). It is a sort of common sense law. In his principle, Newton says, 'To every reaction there is always an opposite and equal reaction,' or the mutual action of two bodies upon each other are always equal and directed to contrary parts.

He added that it was "easy to put it as for every reaction . . . there is an equal and opposite reaction. Forces always exist in pairs." The above statements were followed by a series of examples in which the third law applies:

1. The earth pulling on bodies (action) and bodies pulling on the earth (reaction).
2. The baseball bat hits the ball, the ball exerts a force on the bat.
3. A man pulls on a donkey, the donkey pulls on a man.

8:31 a.m.

Mr. Simon then demonstrated this law by blowing up a balloon and asking the students to explain its motion in terms of Newton's third law. Holding the full balloon, he waited for several seconds for an answer. As students kept silent, he explained that: "As the balloon goes up, it pushes the air down, or the air is pushed down. There is another force that pushes the balloon up causing it to accelerate in the other direction (up)." He then restated Newton's third law and suggested that students start working on the problem set he had distributed.

8:34 a.m.

Students began to work on the set of problems with Mr. Simon looking over their shoulders.

8:55 a.m.

Students worked on the set of problems until five minutes before the bell rang. As students waited to leave, Mr. Simon referred to "tonight's tough game" between the school football team and another local high school team. (Videotape and fieldnotes, September 26, 1986.)

Day 6 Newton's Second Law Experiment

7:55 a.m.

At the beginning of the class period, Mr. Simon reminded students about the egg-drop competition that would take place tomorrow (Tuesday) after class. He then spent a few minutes explaining the rules of the competition, as well as what students needed to do in order to participate in it.

8:00 a.m.

Mr. Simon:

> The experiment . . . we are going to do today is going to be a class experiment. We are going to have different people involved in analyzing the data. And the last few minutes we are going to assimilate our data . . . just a quick review of the way we are going to analyze our data.

He first explained that there would be two groups. One group of students (four) would keep the mass constant and vary the force. A second group would keep the force constant and vary the mass. These two groups would obtain the data (ticker tape) that would be analyzed by the rest of the class. Mr. Simon explained that the rest of the class would take the ticker tape to measure the velocity at the beginning and the end of the tape, or to calculate the acceleration of the body (cart).

8:05 a.m.

The first two groups were chosen arbitrarily and sent to the two lab stations. Each station was already equipped with: bricks, carts, ticker timers (one), ticker tape, pulleys and small weights (200 gr). Just before they started to work, they were given a lab worksheet (see Appendix K) to fill out.

8:10 a.m.

While the two groups worked at the lab tables, Mr. Simon divided the rest of the class into eight groups of three students each, who would analyze the ticker tapes obtained by the first two groups.

8:20 a.m.

Both groups worked at their lab tables. They were constantly assisted by Mr. Simon who checked to see if they were varying the mass (group 1) and the force (group 2) accordingly. Once students finished running the tapes, Mr. Simon assigned them to the rest of the class (one tape per group). Each tape had been marked as to whether the mass and the force were constant or variable. The board showed these labels:

Group 1

mass = 1, 2, 3, 4 (bricks)

force constant

Group 2

force = 1, 2, 3, 4 (weights)

mass constant

8:25 a.m.

While students worked on the data analysis, Mr. Simon circulated around assigning identification numbers to the students who were to participate in the egg-drop competition. He was constantly consulted about how to analyze the ticker tapes, particularly about how to calculate "V_1" (velocity at the beginning of the tape), "V_2" (velocity at the end of the tape), and "T" (time interval between those two instances).

8:40 a.m.

Mr. Simon: "Okay, Let's tie this up . . . if we can." He sketched a four column table on the board and asked each individual group for the acceleration value they had obtained. As he moved along filling out the table on the board, he stopped for a few seconds (staring at the board) and added: "There is something wrong in here . . . errors of 10000 percent." He completed the table as shown below:

Mass	Acceleration	Force	Acceleration
1	669	1	15.3
2	2285	2	75
3	120	3	1020.5
4	4.7	4	52.7

8:55 a.m.

As soon as Mr. Simon realized that the acceleration values were inconsistent with Newton's second law (the acceleration should decrease in the second column, and it should increase in the fourth column). He suddenly decided to stop referring to the experiment and to Newton's second law. Instead, he opted to ask for more volunteers to participate in tomorrow's competition. (Videotape and fieldnotes, September 29, 1986.)

Day 7 **Egg-Drop Competition**

On the seventh day students submitted the egg-drop boxes and then were allowed to complete their papers (see Appendix A) which were to be collected the following morning. (Fieldnotes, September 30, 1986.)

Day 8 Quiz -- Papers Due

Once the papers were collected, a test on Newton's laws was given. The test marked the end of the unit on dynamics. (Fieldnotes, September 31, 1986).

Interpretation of Mr. Simon's Story-Line

The above story-line shows how Mr. Simon and his students interacted among themselves and with the immediate environment (lab equipment, worksheets, books, etc.) to construct an instructional macro-sequence on dynamics. Figure 5.2 shows Mr. Simon's macrosequence on dynamics. The major focus was on Newton's three laws of motion. These were not presented in a lineal fashion. Instead, they were developed in conjunction with the egg-drop competition (unrelated to Newton's laws), and with two class periods on the topic of vectors. The unit on dynamics began by having students read about unbalanced and net forces and by providing them with an overview of what the unit was about. The end of the unit was clearly marked by a quiz, though content-wise one could affirm that the experiment on Newton's second law closed the theme on dynamics. From then on, Mr. Simon did not explicitly talk about the subject-matter content pertaining to this topic.

The major topics enacted were:

1. Vectors
2. Newton's first law or law of inertia

1.0. Principle of Inertia.
"Objects at rest remain at rest . . . objects in motion remain in motion, unless acted upon by an external force."

2.0. Vectors: addition, representation and subtraction.

3.0. Newton's Law.

3.1. Newton's First Law.
This law works under the following conditions:
a. there are no unbalanced forces ($\Sigma F=0$)
b. there is no acceleration
c. speed is constant

3.2. Newton's Second Law
Acceleration is proportional to the net (unbalanced) force ($a \propto F_{net}$)

Acceleration is proportional to the inverse of the mass ($a \propto 1/m$).

Newton's Second Law works under the following conditions:
a. there is an unbalanced force ($\Sigma F \neq 0$)
b. the acceleration is not zero
c. the velocity is not constant

Newton's Second Law is stated as $a = F/m$.

3.3. Mass and Weight
"Weight is a force caused by gravity and gravity varies from place to place . . . so weight changes from place to place."

"Mass is the same as inertia (resistance to change motion) . . . it is not affected by position . . . so it is constant."

4.0. Newton's Third Law.
"To every action there is always an equal and opposite reaction."

"Forces always exist in pairs."

Figure 5.2. Mr. Simon's macro-sequence on dynamics.

3. Newton's second law (a = F/m)

4. Newton's third law

In addition to the above topics, there were also subtopics. One of the most relevant subtopics was the difference between mass and weight that followed the discussion of Newton's second law.

A close look at the story-line above shows that Newton's first and second laws were anaphorically linked to the concept of net and unbalanced forces, and to the concepts of velocity and acceleration described in the unit on kinematics some days before. However, the three laws were introduced in a rather discrete manner with no explicit connection among themselves. The events dealing with these laws seemed to have an end in themselves, for example, during the topic shift that marked the introduction of the law of inertia (Newton's first law). There was no explicit anophoric reference to what students supposedly had read in the textbook the day before (day 1). In the process of elaborating on this law, through a series of classroom demonstrations, one topic that emerged was the idea of friction "which should be minimized as to try to keep a body moving at a constant velocity." This idea did not emerge again during day 5, when the conditions under which the first law held were explained. This is probably an example of topic decay (Tannen, 1984) in which friction was no longer a fundamental concept in the teacher's discourse. Another example would be the notion of a vector that was briefly mentioned in the events that led to the formulation of Newton's second law.

The idea of discreteness among topics and subtopics can be explained in the same vignettes in the story-line. In the first vignette, Mr. Simon introduced the mathematical equation of Newton's second law ($a = F/m$), and then explained the difference between mass and weight. He indicated that, "Weight is force caused by gravity. . . and it varies from place to place," while mass "is the same as inertia . . . and it is not affected by position." However, no reference was made to Newton's second law.[1]

The second vignette took place on day 6 when Mr. Simon conducted a class experiment on Newton's second law. Even though he indicated how students were going to proceed to study the relationship between acceleration, force and mass, Mr. Simon did not make explicit reference to how to measure the acceleration of the object being used, an instructional event that had taken place a week before. A careful look at the fieldnotes of that day showed that such an instructional event took place at the end of a class period and lasted only about two to three minutes.

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[1]Since gravity (g) had already been introduced, Mr. Simon could have indicated that since $F = ma$ and $a = g$, then F (weight) $= mg$.

Mr. Ellis' Story-Line on Dynamics

Mr. Ellis' story-line on dynamics differed in several respects from that of Mr. Simon, despite the fact that both teachers used the same textbook, Project Physics. The macro-sequence was developed over a period of nine consecutive class periods during eight school days (see Figure 5.3). All classes, except day 1 (Newton's first law), day 2 (test on vectors) and day 8 (test review) were properly videotaped and transcribed. Days 1, 2 and 8 were fieldnoted.

The following description represents a brief story-line of how Mr. Ellis dealt with major topics during the construction of his macro-sequence on dynamics. Its purpose is to show the nature of the coherence (macro) across topics and activities during the time the unit was being developed. The story-line focuses primarily on topic shifts and on the activities undertaken by participants during the development of these topics.

Here again, the story-line was derived from a data source that shows main entries: teacher's verbalization, participants' actions and researcher's interpretation of these actions.

As shown in Figure 5.3, Mr. Ellis focused on the following major topics: Newton's first law, Newton's second law, friction, difference between mass and weight, free fall and terminal velocity, and Newton's third law.

Day 1	Newton's first law.
Day 2	Test on vectors.
Day 3	Newton's first and second law, friction.
Day 4	Newton's second law (demonstration).
Day 5	Weight and mass.
Day 6	Weight, free fall and terminal velocity.
Day 7	Newton's second law experiment (first hour). Newton's third law (second hour)
Day 8	Test Review (Newton's Laws).

Figure 5.3. Chronology of major topics developed in Mr. Ellis' macro-sequence on dynamics.

The following story-line describes in more detail how major concepts were dealt with by participants.

Day 1 **Newton's First Law**

10:10 a.m.

Having spent the first ten minutes of the class period on a test review for the next day's test on vectors, Mr. Ellis announced a new topic: "In your own words, state Newton's first law of motion. When you get through, bring it back." While students read the textbook (yesterday, Mr. Ellis asked them to bring it to class), Mr. Ellis prepared a lab demonstration at his desk; he piled up a set of wooden blocks (5 x 5) on the top of the table. David was the first student to get up and show his work. He was given a candy for it. Other students immediately followed. As soon as most students had shown their work, Mr. Ellis began to hit pieces of wood out from under one another with a metric ruler. He then (without further explanation) looked for his "package" (set of readings and assignments).

10:18 a.m.

Mr. Ellis began to skim through his package and quickly assigned problem number three in handout 31. Students read the problem that dealt with a body travelling at a constant speed. Mr. Ellis commented that in this case the net force (from unit on vectors) acting on the body was zero, and that therefore, its acceleration was zero.

10:26 a.m.

At this time, Mr. Ellis moved to problem number four. He added, "Okay, state Newton's first law of motion . . . the law of maintaining the status quo." As students kept quiet, he added: "Objects at rest keep at rest, unless there is a force acting on them." David said the same law could be phrased as, "Objects keep moving forever . . . if there is no friction." Without further comment on David's statement, the teacher stated that Newton's first law is also called law of inertia, where inertia means, "resistance to start moving or to change motion." Mr. Ellis also elaborated on the idea that "inertia is a measure of mass."

10:39 a.m.

At this point in time, Mr. Ellis picked up the wooden blocks again and piled them up on his desk. After hitting them out from the bottom up, he commented that the top ones did not move because, "They don't have time to as the hit is applied very quickly." Following this demonstration, a bag of apples was hung from the ceiling with a thin string. Another piece of string was attached to the bottom of the bag. He then asked: "If I pull here (bottom), which string will break first?" The students' answers varied. Mr. Ellis then pulled very slowly observing that the top one broke first. He then pulled very quickly, breaking the bottom string. He explained that the top string had not time to move.

10:46 a.m.

Having finished the demonstration, the teacher referred to the application of Newton's Law to explain how difficult it is to walk on slippery roads during the wintertime due to the small frictional force between the road and the shoes. He then assigned problems "36-37 and 38 . . . for tomorrow." He reminded students that there would be no school on Wednesday because of parents' conference and Thursday because of the SAT test. (Videotape and fieldnotes, October 17, 1986.)

Day 2. **Test Day (Vectors)**

The main activity to date consisted of students taking a test on the previous unit on vectors which had been developed the previous week. The students learned about vector properties: addition, subtraction and representation of vectors. The notions of balanced forces and equilibrium were also discussed. Halfway through the class period, Mr. Ellis wrote down on the board: "Section 3.7" and later referred to individual students to read that section of the text as they left the room. That section of the textbook deals with Newton's second law. (Fieldnotes, October 20, 1986.)

Day 3 **Newton's Second Law**

On this day, the lesson dealt primarily with Newton's second law and the relationship between the net force applied to a body and the acceleration that the body acquires. Concepts such as net force, unbalanced force and force of friction were central topics in the discussion. This discussion was briefly summarized as follows:

10:03 a.m.

After checking attendance, Mr. Ellis made a brief comment on Newton's first law, focusing on some "wrong" statements made the previous Friday. He added, "What you said is not correct. You said, 'if friction does not exist, an object will coast forever.' Well, that is not the first law of motion. You don't have to talk about friction to define it." Mr. Ellis elaborated on the idea that the first law deals with inertia as the "capacity of a body to maintain its motion." "Inertia," he added, "is measured in kilograms, and it is an intrinsic property. . . that does not change with position." When elaborating on this idea, Mr. Ellis asked a girl to compare the inertia of two objects (light and heavy) by shaking them, observing that the heavy object was harder to shake than the light one.

10:25 a.m.

Mr. Ellis added that Newton's first law deals with equilibrium where,

> The net (unbalanced) force is zero. Under a net force of zero, a velocity of a body does not change. However, if an unbalanced force acts on a body, then it causes the body to accelerate and in this case we talk about Newton's second law.

Newton's second law "indicates that an unbalanced force . . . causes something to accelerate" (Mr. Ellis wrote down: $F_{net} = ma$). He added, "This is a cause-effect relationship."

10:30 a.m.

The mathematical formulation of Newton's second law was followed by an explanation of the units in which forces are usually expressed. Mr. Ellis substituted kg and slugs for "m" (mass), and m/sec^2 and ft/sec^2 for "a" (acceleration), and concluded that there were two force units: Newtons (kg m/sec^2) and pounds (slugs feet/sec^2)."

10:35 a.m.

At this point in time, Mr. Ellis looked for his package and asked students to open it to Handout 32 (see Appendix J). From then on the class worked on a set of five problems dealing with the application of Newton's first and second laws. The first three problems dealt with the idea of how friction affects the net force. During this discussion, Mr. Ellis actually measured the force of friction between the floor and a cart by pulling a girl across the room on the cart. The force of friction could be read on a scale the girl was holding while being pulled by the teacher. (This experiment would be conducted next week.) The force of friction obtained on the scale was eight Newtons. Following this demonstration, Mr. Ellis added that the force of friction was equivalent to the resultant force (from last week) and to the unbalanced or net force. The first three problems on friction and Newton's second law were followed by two different problems. The first one of these asked the students to calculate the acceleration of a body being pushed by a force of 1,000 Newtons up a 60° incline. Before going into the solution, Mr. Ellis remarked, "That's why we need to study vectors . . . as they are powerful to solve these kinds of problems." In this problem, Mr. Ellis split the 1,000 Newtons vector into two components, indicating that the net force would be the component in the direction of the motion. He then substituted the respective values (m and F_{net}) in the equation $F_{net} = ma$. The last problem proposed required the application of some kinematics equations (first unit developed two weeks earlier), as well as Newton's second law equation. It consisted of calculating the net force applied to an ice puck given its initial velocity, distance traveled and mass. Having solved this last problem, Mr. Ellis pointed out that a similar situation would be presented to students in the hallway next week.

10:40 a.m.

Mr. Ellis assigned problems to be solved for tomorrow. He pointed at the board and added: "Those are questions involving Newton's second law." During the remaining ten minutes, students worked quietly on the set of assigned problems. Mr. Ellis remained at his desk assisting a girl (Nana) who was concerned about her test on vectors. (Videotape and fieldnotes, October 22, 1986.)

Day 4 Newton's Second Law Demonstrations

In today's lesson, Mr. Ellis first showed qualitatively that in Newton's second law, the acceleration of a body (cart) was proportional to the net force applied to it, and secondly, that the acceleration was also proportional to the inverse of the mass of the body being moved. The following description indicates major events developed during the 50 minute class period.

10:02 a.m.

After briefing students on the previous evening's parent conference, Mr. Ellis pointed at the board where he had already written the equation for Newton's second law together with a set of Kinematic equations ($F_{net} = ma$, $Vf^2 = Vo^2 + 2ad$, and $V = Vo + at$). He rewrote Newton's second law in terms of acceleration ($a = F_{net}/M$) and began to elaborate on the idea of how the mass of a body affects its acceleration. Relying on two newspaper articles, Mr. Ellis emphasized that when the mass of a body is small, the acceleration is larger and vice versa. Such is the case of gymnasts who are given medication to retard their normal growth, and the case of old Mig airplanes that accelerated slowly due to their dependence on heavy metals.

10:05 a.m.

The teacher put the articles away and began to set up a demonstration with a wooden cart on a wooden platform being pulled by a rubber band. (He did not explain what he was going to do.) Mr. Ellis asked for Melissa's assistance to hold the cart on one side of the platform while he stretched the rubber band and waited for Melissa to set the cart free so that he could catch it on the other end. He then showed that as he increased number of the rubber bands from one to four, the speed of the cart increased at a rate difficult to be perceived by the eye. Once these four trials had been completed, Mr. Ellis moved back to the board and explained that Newton's second law gives a relation between three variables (F, a and M) and that to examine two of them, "we had to keep the third one constant." In this case, the constant variable was the mass of the cart (1/2 kg). He added:

> If we keep the mass constant, then we have a direct proportion . . . between acceleration and the net force (rubber bands). (The board showed: $a \propto F_{net}$.) What this means is that as we double . . . or triple the force, we double or triple the acceleration.

Mr. Ellis remarked that this statement could be expressed as:

$$\frac{a_1}{a_2} = \frac{F_1}{F_2}$$

Having established this relation, the teacher filled out a table (handout 32) in which individual students were required to apply the above equation to find the values for a, F and m accordingly.

10:22 a.m.

Once the class had completed the previous exercise, Mr. Ellis moved back to the demonstration table to vary the mass and keep the force constant (rubber band). Assisted by Melissa, Mr. Ellis added one, two and three bricks (1 1/2 kg each) on top of the cart and had students observe how the acceleration decreased as the number of bricks increased. Mr. Ellis then stated that, "It is difficult to learn about reciprocal relationships . . . such as the case of acceleration and mass. As one gets bigger (mass), the other gets smaller (acceleration)." He expressed this statement as follows:

$a \propto 1/m$

and concluded that the above equation could be written in the following way:

$$\frac{a_1}{a_2} = \frac{m_1}{m_2}$$

10:22 a.m.

Mr. Ellis: "Let's go to question 5." In the next eight minutes, students were individually asked to apply the above equation to solve for a, F and m in question 5.

10:30 a.m.

Before Mr. Ellis stopped to summarize what they had covered up to that time, he gave a third related exercise. Mr. Ellis found his unit schedule (pink sheet he had distributed earlier) and briefly referred to what he had covered since last Friday. He also made reference to the hallway experiment on Newton's second law next week. "This would be another day on Newton's second law," he said.

10:35 a.m.

Mr. Ellis assigned homework. He pointed at the set of problems already written on the board and shortly thereafter students began to work on them until the end of the hour. While students worked on these problems, Mr. Ellis circulated around the room showing each student the grade she/he had obtained on the previous test. (Videotape and fieldnotes, October 24, 1986.)

Day 5 **Weight and Mass**

The lesson centered on the distinction between weight and mass.

10:02 a.m.

At the outset of the lesson, after complaining about students' tardiness, Mr. Ellis opened the lesson as follows: "This is a concept which I am not naive enough . . . to know that it is confusing . . . and this is the difference between mass and weight. People use them interchangeably, which adds to the confusion." He indicated that usually chemistry teachers "across the hall" were primarily responsible for students' misunderstanding of the distinction between these two fundamental concepts in physics. This discussion was followed by Mr. Ellis' elaborating on the following statements related to the concepts of mass.

- mass measures inertia (in kilograms)
- mass is an intrinsic property built into the object
- mass is measured using a balance (not a scale)
- mass does not change with position

10:16 a.m.

Having established the definition of mass, Mr. Ellis first explained the difference between a balance (to measure mass) and a scale (to measure weight), before going into the concept of weight. The following interaction showed how this concept was introduced.

Mr. Ellis: Now, weight . . . I weight unfortunately about 200 pounds. What does it mean when I say I weight 200 pounds . . . see . . . that (students keep quiet) (5 sec.) . . . that's not an intrinsic property. That's not something that belongs to me. What does it mean . . . when I say I weight 200 pounds?"

Student: You are pulling down on the earth with 200 pounds.

Mr. Ellis: But why am I pulling down?

Student: Gravity . . . force of gravity.

Mr. Ellis: But what causes gravity? The bottom line here is . . . I weight 200 pounds because the earth loves me. It attracts me. It pulls down on me with 200 pounds. It likes me more than it likes you. (laugh)

From here on Mr. Ellis explained that because gravity changes, weight also changes as opposed to mass which is always the same. He explained that weight is a force that depends on the interaction of bodies with their surroundings. Using a small scale, Mr. Ellis showed that a 1 kg object weighs 10 Newtons at "this position of the earth" (lab). He indicated that the net force acting on net mass (1 kg) was zero because there was an equal force acting in the opposite direction. As soon as the object was released it would be in a free fall situation in which the only force acting on it would be the force of gravity. Following the previous discussion, Mr. Ellis substituted the values of m (= 1 kg) and a (= 10 m/sec^2) into Newton's second law (F = ma) and concluded that, "Indeed, the force acting on a 1 kg object in free fall was 10 Newtons." The argument led Mr. Ellis to affirm that mass and weight are related by Newton's second law (F = ma) for the special case in which "a" (acceleration) is equal to "g" (acceleration of gravity). In this case, weight then could be determined using the equation: F = mg.

10:21 a.m.

Having established the difference between weight and mass and the equation that related both terms, Mr. Ellis solved a set of three problems (from the package) that required the application of the weight equation.

10:35 a.m.

At this point in time, Mr. Ellis found his pink sheet (unit schedule) and indicated: "This is block 5 . . . and there are five questions assigned for today. They deal with the difference between weight and mass." He insisted that students turn in their work on time, and, "At the beginning of the class period. Otherwise, it won't count."

10:50 a.m.

Once the problem had been assigned, students worked quietly on it until the class period was over. Few of them requested any help from Mr. Ellis.

Day 6 Weight, Free Fall and Terminal Velocity

The main issue of this day's lesson centered on the concept of free fall and its relation to weight, mass and acceleration of gravity. A second major topic dealt with was the concept of terminal velocity that was characterized as the velocity reached by a body where the net force is equal to the air resistance.

10:01 a.m.

At the outset on the lesson, once students had handed in their assignments, Mr. Ellis referred to the 1 kg object (it was there yesterday) hanging from a hook above Mr. Ellis' desk. He mentioned that the reading on the scale was a measure of weight and not mass as some students had written on some of their assignments.

10:02 a.m.

Mr. Ellis picked up a couple of toy gun and jumped over his desk. From there, he described that one gun was loaded with a single dart, while the second was loaded with a dart with a ballbearing attached to it. He then asked (hands touching the ceiling), "If I stand up here and drop both of these darts, which one will strike the floor first?" Most students answered that both would drop at the same time because of the acceleration due to gravity. Mr. Ellis then asked a second question: "Is there any difference between dropping them and firing them? If I fire them, which one will strike first?" (with the gun loaded). The answers went two ways: "same time," and the "ball bearings." Mr. Ellis explained that since both guns were exactly the same, both darts would receive the same force but that one (ball bearing) was heavier (had more inertia) and, therefore, it would be harder to move initially. He then fired both guns, observing that the lighter dart struck the floor first. He repeated the demonstration firing both guns in the horizontal direction. This time the heavy dart fell behind the light dart.

10:10 a.m.

As soon as Mr. Ellis jumped off his desk, he looked for his package and added: "Handout 33 . . . (5 sec) . . . you can have some ideas about mass and weight and Newton's second law, but this question will puzzled students . . . and this is question 4 . . . 4a. Tell me, what is meant by 'free fall?'" As the students kept silent, Mr. Ellis stated that "free fall means that we neglect any resistance and that the only force acting is the weight of the body." He then posed a second question: "Why then don't heavy objects fall faster than lighter objects? Why doesn't the heavy dart fall faster than the light dart?" After a lengthy discussion on how objects are attracted by the earth, Mr. Ellis said that "motion depends on two things . . . from Newton's second law . . . those two things are force and mass." Mr. Ellis commented that students were looking at only one thing, which was acceleration (or gravity). He moved to the board and wrote down:

$$F_g = mg$$

$$g = F_g/m$$

He explained that acceleration (g) depends on the weight and the mass of the body, and that as the mass increased, so does the weight. He finally added, "Though it is true that heavy objects have a bigger force acting on them, they have more inertia, the acceleration is the same as indicated by the relation F_g/m."

10:25 a.m.

Having explained that heavy objects fall in free fall at the same rate as light objects. Mr. Ellis described how air resistance can exert a force in the opposite direction to the weight (force). He explained that as the air resistance gradually increased, the net force (weight-air resistance) decreased. "When these two forces become equal, then the body is not in free fall any more and the body is moving with what is called terminal velocity." He added:

"In this case, the net force would be zero and the air resistance would balance the weight of the body."

10:10 a.m.

Mr. Ellis talked about some examples in everyday life where air resistance could balance weight (e.g., skydiving). He then selected two problems from the package (Handout 34) that required the application of Newton's Second Law, the concepts of weight and vectors. The first problem used the "Atwood Machine." (There were two demonstration set ups of this machine in the room.) He showed how the acceleration of two bodies with different masses could be calculated. They were attached with a common string that passed through a pulley system. The second problem dealt with a similar system, but this time one of the masses was allowed to slide on top of a table. In both cases, Mr. Ellis carried out demonstrations before going over the solution to the problem on the overhead projector.

10:41 a.m.

At this point in time, Mr. Ellis looked from his pink schedule sheet (this was a sign that the lecture was already over) and briefly described the material covered in block six. He then suggested that students read about block seven in their books: Newton's Third Law. He added: "For every reaction there is an equal and opposite reaction." The third law would be discussed in the second hour of the first double period on Thursday. The first hour would be devoted to Newton's Second Law Experiment (block 4). Students were advised to go over the sample test on Newton's laws for Friday.

10:55 a.m.

As soon as Mr. Ellis put away his pink sheet, students engaged in all sorts of conversation (there was no homework), and played around with some of the stuff left on the lab tables. (Videotape and fieldnotes, October 28, 1986.)

Day 7 **Newton's Second Law Experiment and Newton's Third Law**

This was the last lesson devoted to the unit on dynamics. This was a double-hour class period. In the first period Mr. Ellis conducted a class experiment to measure the mass of a student by pulling a cart along the hallway in front of the physics classroom. Pulling consisted of a constant force that was measured using a scale held by the student whose mass was to be measured. The second hour was devoted to the idea that "forces come in pairs" (Newton's Third Law). The following story-line describes how these two lessons were dealt with, beginning first with Newton's Second Law Experiment.

First Hour: Newton's Second Law Experiment

9:19 a.m.

At the outset of the lesson, Mr. Ellis circulated around handing back the test on vectors (taken last Friday). He reviewed some of the questions and complained about the poor grades obtained by some students in spite of the amount of time spent on the vectors unit.

9:20 a.m.

After collecting the test answers and putting them away, Mr. Ellis remarked:

> Again, take your package . . . turn to Newton's experiment . . . it would be in the end of Chapter 3 . . . after handout 39 . . . two experiments. Skip the one on adding forces . . . and the spring scale . . . that's another one on Newton's Second Law. Read the first two paragraphs please.

While students read, the teacher began to search for some lab equipment: a scale used to measure the force of friction the previous week, the cart used to carry a student while measuring such a forces, timers, and a plastic red hat.

9:23 a.m.

Having placed the equipment on his desk, Mr. Ellis circulated a handout entitled: "Newton's Second Law Experiment" (See Appendix D). Then, he asked for a rider for the cart. Jim stood up and Mr. Ellis put the red hat on his head before pulling him across the room at a constant speed.

The scale (held by Jim) read 7. While Mr. Ellis was pulling, the following interaction took place:

> Mr. Ellis: What am I measuring? (pulling the cart with Jim on it) This is coasting along. What is the net force?
>
> Student: Zero.
>
> Mr. Ellis: Zero . . . no force. How hard am I pulling?
>
> Student: Seven.
>
> Mr. Ellis: Seven. So, that must be the force of friction. So, what we are doing here is determining the force of friction. How hard must I pull to keep it rolling at a constant speed? It is not accelerating, there is no net force . . . so in the first line (of the handout), write seven.

9:25 a.m.

After determining the force of friction (between the floor and the cart wheels), Mr. Ellis asked for a puller. John volunteered, and Mr. Ellis asked him to pull Jim (on the cart) with a force (on the scale) of 40 Newtons. They practiced pulling at least three times in front of the class. Mr. Ellis insisted John keep the scale reading at 40

Newtons. The next thing Mr. Ellis did was to ask a third student, Chris, to go out to the hallway to use tape to mark the starting and the stopping lines, separated by a distance of approximately 10 meters. Before giving the order "Let's go out," two girls were assigned to control the time.

9:30 a.m.

In the hallway, John pulled Jim (on the cart) at least eight times. They carried out three trials before taking any measure. Mr. Ellis was in charge of giving the order "ready, set, go." Each time he insisted John keep the reading at 40. At the end of each run, he asked the time keepers to read the time it took John and Jim to cross the finish line.

9:40 a.m.

Back in the room, Mr. Ellis first asked for the times, and then copied them on the board: "6.0, 7.03, 6.6, 8.90, 6.82, 7.23, 7.26."

He then crossed out the two extreme values (6.0 and 8.90) and computed the average of the remaining ones. He got 7.03. The next step was to calculate Jim's acceleration which could be "kinetically done using the equation $d = Vt + 1/2at^2$." (This equation had been on the left and right hand sides of the board since last week.) Since the initial velocity was zero, and the distance between the starting and stopping lines was 11.20, acceleration was given by:

$$d = Vot + 1/2at^2$$

$$a = \frac{2 \times 11.20}{7.03^2} = .40 \text{ m/sec}^2$$

10:43 a.m.

At this point in time, Mr. Ellis added, "The problem is not over . . . that's acceleration. Now, mass is . . . net force over acceleration. We look back to the first line (in the handout). What is the force of friction? (He had written on the board $m = F_{net}/a$.)

Student: Seven.

Mr. Ellis: Seven. How hard was John pulling?

Student: 40.

Mr. Ellis: 40. What was the net force?

Chris: 33 Newtons

Mr. Ellis: Even though John was pulling with 40, seven of them overcame friction . . . that's the net force John was pulling.

He then wrote the following on the board:

$m = F_{net}/a$ Friction = 7 Newtons F_{net} = 33 Newtons

The next step was the substitute the values for the a and F_{net} in the equation $m = F_{net}/a$ to get m. The value obtained was 81.68 kg. Jim (the rider) was surprised and complained that "he did not weigh that much." Mr. Ellis went into his office and came back with a bathroom scale and asked Jim to step on it. He added that "although this was a scale (not a balance), it could read kilograms and pounds." Jim stepped on it (wearing the red heat and holding the cart) and the reading was "80 kilos." Mr. Ellis subtracted 6.8 kg (weight of cart) from that figure and asked Jim, "Do you weigh about 72 kilos, Jim?" Jim nodded his head affirmatively. Finally, Mr. Ellis commented that "we were off by 2 percent . . . hope this (experiment) will make you true believers in Newton's Laws."

9:45 a.m.

From now until the end of the class period, students and teacher engaged in friendly conversation, occasionally making reference to the experiment they had just finished.

Second Hour: **Newton's Third Law**

10:01 a.m.

During the 10 minute break, Mr. Ellis cleared the board and put lab equipment away. He replaced the one kilogram object hanging from the ceiling above his desk with the 16 pound black bowling ball he used when describing the idea of inertia the previous week. At the beginning of the lesson, Mr. Ellis suggested that students prepare "the sample test for tomorrow . . . which would be the last class on Newton's laws.

10:02 a.m.

The teacher picked up a cloth ball from his desk and said: "Newton's Third Law . . . I have a Nerf ball here. I confiscated it from two students last year. They have not come to pick it up yet." He went on, "On Newton's Third Law, I am going to go over some demonstrations . . . that I think . . . its complexity gets harder and harder. So, if you would turn to your reference handout 35 . . . on Newton's Third Law . . . question 2." Seconds later Mr. Ellis kicked the cloth ball and asked if his foot exerted a force over the ball or vice versa. Some students immediately responded, "both," while the others said, "the foot on the ball."

In "view of this confusion," Mr. Ellis looked for a bat and hit the hanging bowling ball and asked: "Does the bat exert force on the ball, or does the bowling ball exert a force on the bat?" Again, the answers were split into two groups -- one group agreed that, "it is the ball that exerts a force on the bat," and the second group believed in the idea that "both" were exerting forces. Mr. Ellis then looked for the cloth ball, kicked it again and students reiterated that he was exerting a force on the cloth ball. Mr. Ellis pointed out, "There would seem to be some inconsistencies here as students were of the idea that when he hit the bowling ball with the bat, there was a force acting on the bat, but when he kicked the cloth ball, the force was acting on the cloth ball."

Having concluded with the previous two demonstrations, the teacher asked, "What's Newton's Third Law?" After waiting for a few seconds for an answer, he added,

> It comes down . . . usually . . . as for every action . . . there is an equal and opposite reaction. Actually, that is not the third law. It says for every force . . . there is an equal and opposite force. Forces do not come alone. They are always paired up, they are equal in size and they act on different bodies . . . or different objects.

He elaborated on the idea that every time he hit the cloth ball (or the bowling ball) there was a force of the same size acting in the opposite direction. He explained that one body might be slower than the other because of inertia (resistance to move) "that is, heavy masses move slower than lighter ones under the influence of the same force."

10:10 a.m.

At this point in time, Mr. Ellis asked students to identify the "action-reaction" forces as indicated in seven different everyday situations described in the package. In closing the previous discussion, he commented: "forces always come in pairs."

10:17 a.m.

As soon as the previous discussion was over, the teacher took two carts and placed them on the floor (in front of the class). He then announced "problem 8." While students read what this problem was about, he asked two volunteers to come up to the front and step on the carts. He gave them a yellow rope to hold and suggested they keep it seven meters apart. Mr. Ellis told one of the students: "Mike, you will pull, okay?" Looking at the second student he added: "Kathy, would you hold?" Next he posed the question: "Who's going to move?"

"Both." "Mike will move" were the answers that followed. Both students ended up in the front row after Mr. Ellis had asked Mike to pull the rope. Mr. Ellis elaborated that in fact both students were pulling with the same force and that Mike, who was heavy, had moved the shortest distance because of his greater mass, and therefore, more inertia. He insisted that the action and reaction forces were not Mike pulling Kathy or Kathy pulling Mike, but "Mike pulling on the rope, the rope pulling on Kathy and Kathy pulling on the rope and the rope pulling on Mike."

10:29 a.m.

After restating that the force of action and reactions were equal in size and opposite in direction, Mr. Ellis performed three more demonstrations that he explained in terms of Newton's Third Law.

10:45 a.m.

At this time, Mr. Ellis began to take away the equipment he had used in the demonstration, allowing students to circulate around and interact with the equipment if they wished to do so. There was no assignment. (Videotape and fieldnotes, October 30, 1986.)

Day 8 **Test Review (Newton's Law)**

Interpretation of Mr. Ellis' Story-Line

The above description indicates that Mr. Ellis focused on three major topics: (a) Newton's First Law, (b) Newton's Second Law and (c) Newton's Third Law. In addition, he focused on the subtopic of inertia. The subtopics friction, mass versus weight, and free-fall and terminal velocity were developed as an extension or application of Newton's Second Law. Figure 5.4 shows a summary of the information content being delivered by Mr. Ellis in the unit on dynamics.

In constructing the first law, Mr. Ellis drew from the concept of net force that he had explained in the previous unit on vectors. From the first law (objects at rest keep

1.0. Newton's First Law.
"An object at rest stays at rest unless there is a net (unbalanced) force acting on it."

2.0. Newton's Second Law.
"If there is a net (unbalanced) force acting on a body, it creates an acceleration" (F=ma).

2.1. "Friction is a net force that affects motion."

2.2. "Acceleration is proportional to the net force ($a \propto F_{net}$)."

2.3. "Acceleration is proportional to the inverse of mass ($a \propto 1/m$)."

2.4. Mass and weight.
"Mass is resistance to change a body motion . . . it is an intrinsic property . . . which does not change with position . . . it is measured in a balance."

"Weight is a special case of Newton's Second Law where the acceleration of the body is equal to the acceleration of gravity. It changes with position . . . and it is measured with a scale."

2.5. Free fall and terminal velocity.
"An object is in free fall when the net force acting on it is equal to its weight and the air resistance is zero."

"An object reaches its terminal velocity . . . when the net (driving) force is equal to the air (resistance)."

3.0. Newton's Third Law
"For every force there is an equal and opposite force. These forces are equal in size and opposite in direction."

Figure 5.4. Mr. Ellis' macro-sequence on Dynamics.

at rest unless there is a force acting on them), the idea that inertia is the capacity of a body to maintain its motion was established. After indicating that friction had nothing to do with the first law, he established Newton's Second Law, "If an unbalanced force acts on a body, then it causes the body to accelerate." This statement was followed by a series of events dealing with "friction as a net force" or resultant force, and with the application of Newton's First and Second Laws in the solution of numerical problems.

The development of Newton's Second Law (explained in detail in Part II of this chapter) was anaphorically (Halliday and Hasan, 1976) done by Mr. Ellis drawing on the concepts of acceleration and inertia. In this sense, he established that "acceleration is proportional to the net force" and "acceleration is proportional to the inverse of the mass" (or inertia). Newton's Second Law was used to explain the distinction between mass and weight and the ideas of free fall and terminal velocity.

Newton's Second Law was demonstrated again later (day 7) during a laboratory experiment. The content of the experiment was anaphorically linked to most of the topics already taught. A close look at the vignette on day 7 (first hour) shows the application of the following topics: friction, weight and mass, Newton's Second Law and acceleration. The experiment was also a link between the previous theme on kinematics (observe the application of kinematic equations) and the theme on dynamics.

Mr. Ellis' elaboration on Newton's Third Law was less explicitly linked to previous ideas and topics taught. Instead, he began the topic of Newton's Third Law by probing the students' knowledge of the topic. However, there was one instance in which he referred to the idea of inertia to explain the action of the pair of forces on different bodies. This instance is indicated on pages 149 and 150. There, two students were described: Mike (heavy one) and Kathy pulling on a rope. On that occasion, Mr. Ellis explained that Mike moved a shorter distance compared to Kathy, because he had more inertia and, therefore, was harder to move.

Mr. Howard's Story-Line on Dynamics

Mr. Howard's macro-sequence of the introductory unit on dynamics was constructed over a period of 11 consecutive days. The first ten classes were videotaped and eventually transcribed. During this time period, three experiments dealing with the relation between force and acceleration were performed. Each experiment was analyzed by the class (individually), and the analysis was subsequently used by Mr. Howard to derive the major conclusion of the theme being developed.

Figure 5.5 indicates the main topics that Mr. Howard discussed during 11 consecutive days he developed the theme of dynamics. Since Mr. Howard's class was "activity-oriented" and "lab-centered," emphasis was placed on the main activities that took place around the topics being discussed. A careful look at the videotape transcripts, for

Day 1	Galileo's constant motion and procedures for Experiment 20: What forces do to motion.
Day 2	Conducing Experiment 20.
Day 3	Data Analysis of Experiment 20. Galileo's constant motion and friction. Forces cause a constant change in velocity. Experiment 21: How force and mass affect acceleration.
Day 4	Data Analysis of Experiment 21.
Day 5	Conclusions of Experiment 21.
Day 6	Wrap-up of Experiment 21 (F = ma).
Day 7	Experiment 22: Inertial versus gravitational mass.
Day 8	Conclusions of Experiment 22.
Day 9	Conclusions of Experiment 22. Mass and weight -- solving problems.
Day 10	Solving HDL's. (home, demonstration and laboratory).
Day 11	Reviewing HDL's. Introduction to new unit on projectile motion.

Figure 5.5. Chronogram of major topics and activities in Mr. Howard's macro-sequence on dynamics.

indicated that topics were explained through statements, without giving them a specific name. For example, while the previous two teachers explicitly mentioned Newton's First Law and Newton's Second Law, Mr. Howard did not make reference to these labels, in spite of the fact that he explained what the topics were about.

The following is a day-to-day story-line describing how Mr. Howard constructed the unit on dynamics. Three major topics were covered:

1. Galileo's constant motion and friction.
2. The effect of force on the velocity of a body.
3. Inertial versus gravitational mass.

This summary indicates the temporal order in which topics were developed. The story-line that follows attempts to describe how these concepts were coherently connected across time, through the major events undertaken by Mr. Howard's class.

Day 1 Experiment 20: Galileo's Constant Motion

On day 1, Mr. Howard briefly referred to Galileo's constant motion. Then, he moved on to the purpose and procedure of the experiment that followed: how force affects motion.

9:10 a.m.

During the first 15 minutes of the class period, Mr. Howard discussed students' grades from the previous week's test on vectors. Having collected the tests, he found his textbook (PSSC) and said:

> Let's look at what Galileo says. . . . Now that we know all about motion, and how it is described, we begin to take a look at things that affect motion. So, the whole unit which consists of a fairly long chapter . . . lot of HDL's there . . . we don't get away from vectors . . . what we have to do is to take a look at ideas about force and motion . . . how force and motion relate.

Then, Mr. Howard discussed Galileo's idea of constant motion: "Objects move at constant speed . . . if there are no forces (friction) acting on it." Next, he briefly described the pendulum and inclined plane as two situations in which Galileo's ideas apply, then pointing out "the need to investigate the acting of forces over the velocity of a body, which is the purpose of Experiment 20." The purpose and procedures for Experiment 20 followed (on the blackboard):

Experiment 20: Force and motion

Purpose: to determine how a force affects the velocity of a body.

Procedure: force is a pull of one rubber band stretched 40 cm from the cart front.

1. Practice giving a cart a run and then hook a timer and run a recording tape for a v-t graph of this trip.
2. One tock is four time intervals of tick.
3. Make a record of a push and let the cart coast.
4. Two trials:
   a. a cart and one brick.
   b. a cart and two bricks.
5. Plot v-t graph of each type on a sheet of graph paper.

oc. [Observe that at this point students are familiar with v-t graph (velocity time graph); and with the analysis of the tapes. The only new concepts are: push (or force) and the bricks.]

10:00 a.m.

As Mr. Howard elaborated the procedures (occasionally skimming over the lab book), he showed the students how to hook the timer and stretch the rubber band to pull the cart along the lab table. Having finished with the procedures, he added: "Let's go to work." Students found their partners (same as last week) and moved to the tables in the back. Each table contained a cart, a timer, ticker tape and a meter stick. Students had to get the bricks from a shelf and the rubber band from Mr. Howard. Once they had gathered the equipment, they practiced pulling the cart with the rubber band stretched at 40 cm or pushing it along the table until the end of the hour. In both cases, they hooked the ticker tape to the timer to record the motion of the cart. (Videotape and fieldnotes, February 4, 1987.)

Day 2 Conducting Experiment 20

9:20 a.m.

At the outset of the lesson, Mr. Howard pointed out, "I want to get some consistent data today . . . don't know . . . try to pull back from 40 to 30." (The previous day students had a hard time trying to keep a constant stretch of 40 cm in the rubber band.) He then refreshed the students concerning the procedures -- suggesting they do a small push first and then a big push. (This was a new procedure.) As soon as students were given the order to go to work, Mr. Howard went back to the board and wrote down:

> Part 1. The coasting of a cart to see how small forces affect the velocity of graph.
>
> Part 2. The pulling force of one rubber band on two masses to see how it affects the velocity graph (force 30 cm).

Some students wrote the above information in their lab report (to be) before engaging in any work.

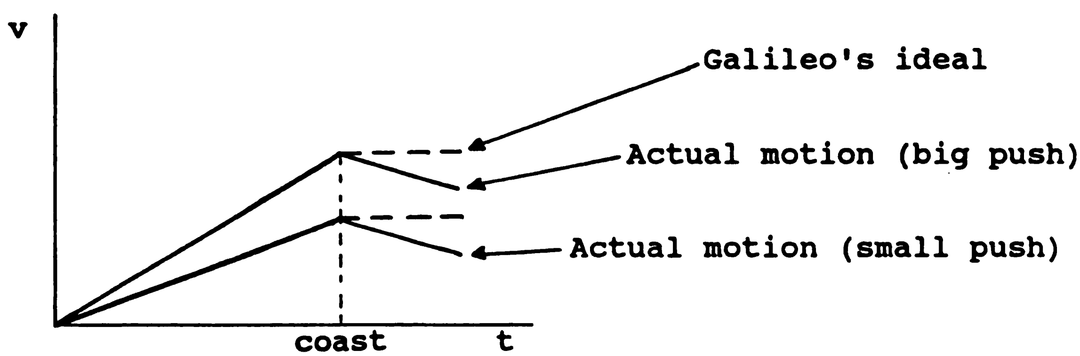
10:05 a.m.

Following the lab procedures, students obtained four ticker tapes (small push, big push, one rubber band and one brick, one rubber band and two bricks). They worked on running the experiment until the end of the class period when Mr. Howard suggested students "get their v-t graph" from the table as well as the acceleration (they had worked on these concepts in the previous chapter). Before students left he added: "Try to get a conclusion formulated on these two (parts) . . . for tomorrow, so that we can begin to take a look at what we are saying here. We'll run into further experiments." Some students had already started analyzing their tapes. (Videotape and fieldnotes, February 5, 1987.)

Day 3 Conclusion of Experiment 20

9:10 a.m.

Immediately after checking attendance, Mr. Howard stated: "Who's got a graph to take a look at? Let's take a look at coasting first." He looked around for two graphs (see Appendix E) and sketched them on the board as follows:

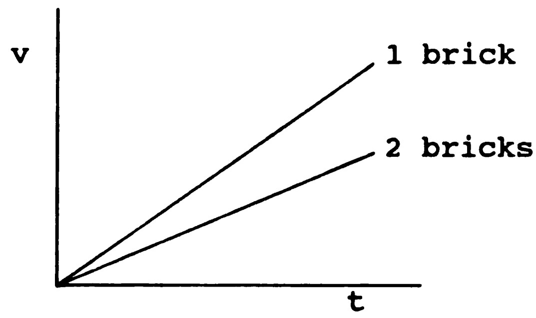


He explained, using the v-t graph, that the speed of the cart increased to a point at which the cart began to coast. However, he added: "The bodies ought to keep the same velocity. If there is not friction . . . or force acting on it" (referring to the dotted lines in the graph). The graph showed, according to Mr. Howard, that because of friction with the lab desk, the velocity was not constant during coasting as predicted by Galileo. According to Galileo, "when no force is acting (as in the dotted lines), a body will coast with a constant velocity if there is no friction." Having stated Galileo's idea of constant motion and friction, the teacher wrote down on the board the first two major conclusions:

1. Small forces cause a small constant decrease in velocity or deceleration.
2. Friction forces do not depend on speed.

9:30 a.m.

At this point in time, Mr. Howard borrowed another set of graphs (velocity-time) for the other two trials (part 2), and sketched them as follows: (see Appendix F.)



He explained that what these graphs indicated was that "forces cause a constant change on velocity, or a constant acceleration." He added that with respect to the effect of mass "one cannot say anything on its effect on the acceleration because they had used only two bricks" (so a conclusive statement could not be reached at this point). Instead, "further research is needed" and "this was the purpose of Experiment 21 in which the effect of mass and force on the acceleration would be investigated."

9:38 a.m.

Mr. Howard found his lab book and said, "Let's take a look at Experiment 21. Maybe we can resolve the problem." Shortly thereafter, he began to elaborate on the purpose and procedures of Experiment 21.

Experiment 21: Force, acceleration and mass.

Purpose:

1. To find out how forces affect the acceleration value.

2. To find out how masses affect the acceleration.

Procedures:

1. Stretch one rubber band to 30 cm and keep mass constant.
2. Use 1, 2, 3 and 4 rubber bands as forces.
3. Sample change in velocity to estimate acceleration.
4. Plot acceleration versus force.

He added that these procedures corresponded to Purpose 1 above.

9:40 a.m.

Having elaborated on the procedures one at a time, Mr. Howard gave the order: "All right, let's try that . . . get these four acceleration and those four forces that go with them. Let's go to work." Students worked at the lab tables that already had the equipment to be used on them: bricks, ticker timer, tape, meter stick, etc. Under Mr. Howard's supervision, students (in groups of two) worked at the lab tables until the end of the class period. They simply hooked the cart to a ticker tape to record the motion, and pulled it four times with one, two, three and four rubber bands stretched at 30 cm (as indicated by the meter stick). Some students did not get beyond the second rubber band though. As students left the room, Mr. Howard remarked: "Remember now . . . a force causes a constant change in velocity . . . or a constant acceleration." (Videotape and fieldnotes, February 6, 1987).

Day 4 Data Analyzing Experiment 21

9:15 a.m.

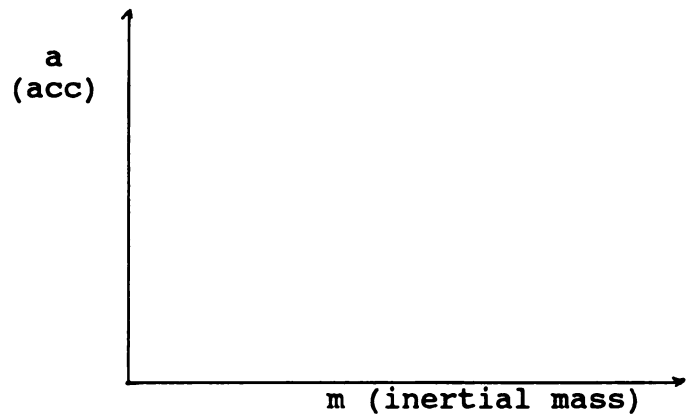
Mr. Howard initiated the lesson by doing "a quick review on the procedures" (Part 1). He insisted students did not need to plot the whole tape, but they needed to check in which part of the tape "they did the best job on pulling" as to obtain two consecutive velocity values to compute the acceleration that corresponded to the respective pulling (or force).

9:20 a.m.

Mr. Howard added the procedures that went along with purpose two of the experiment (i.e., how masses affect acceleration). Students were to run this part today. "This is procedure 5," he said. "Use one rubber band and vary the number of bricks . . . one, two, three, four. Also, graph acceleration versus mass. . . . have four points here." These two procedures were added to the four previous procedures that had remained on the board since yesterday. Having explained these procedures, Mr. Howard suggested that students move to their tables and continue the experiment. Most students worked on part 1 (varying the force) either repeating the trials and beginning from the point they left off the previous day, or analyzing the tapes they had obtained.

9:50 a.m.

While students worked at the lab tables, the teacher sketched the following graph on the board:



With respect to the graph, he commented: "In this graph, this is inertial mass . . . may I have everybody's attention for a minute . . . I'm trying to get a conclusion here on what the acceleration should do as you put more bricks" (few students had even run this experiment yet). A discussion continued as to whether the acceleration increased or decreased with the mass until Mr. Howard suggested that it appeared to be an "inverse relation" between mass and acceleration. In view of these situations, students were advised to "add a new procedure . . . . (7) to plot a versus inertial mass . . . instead of a versus mass" (as indicated in procedure 6).

The previous discussion created some confusion among the two students who had run part 2 of the experiment because they thought they had to repeat the experiment again.

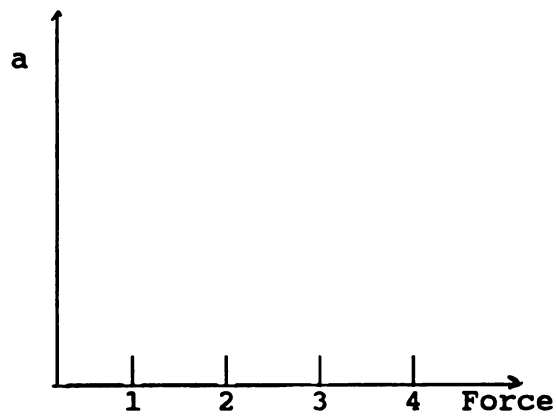
10:05 a.m.

During the last 15 minutes of the class period, most students worked on part 2 of the experiment: varying the mass of the load (one, two, three and four bricks) and pulling the cart with one rubber band stretched at 30 cm as measured with the meta stick. (Videotape and fieldnotes, February 9, 1987.)

Day 5 **Conclusions on Experiment 21**

9:10 a.m.

Having checked attendance and taken care of students' individual questions, Mr. Howard sketched the following graph on the board (students had already started working on their graphs):



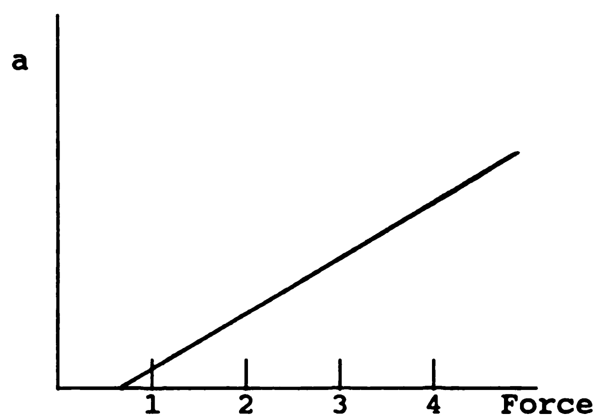
He also wrote down the following statement:

Acceleration and mass: large mass has small acceleration and constant force . . . this suggests an inverse function that plots force (1) over acceleration (a) versus inertial mass.

Without any further discussion on the information presented on the board, Mr. Howard began to move around supervising students' work and answering individual questions.

9:13 a.m.

Mr. Howard: "Any question on this graph (a versus force)? I'm going to try the conclusion of this today. I'm going to see if we can come out with something . . . No. 20 (lab report) is due." Seconds later he asked for an acceleration versus force graph and sketched it on the board:



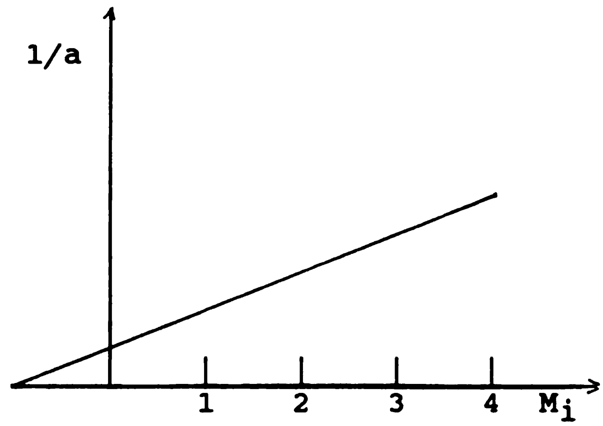
He commented that "the graph shows that two-thirds of the force was lost to friction . . . with the lab table" and that from the previous graph a general conclusion could be reached: "Force is directly proportional to the acceleration if one inertial mass (M_i) is constant." He further indicated that this (statement) could be mathematically formulated as: $F \propto a$.

Mr. Howard went on to say that "the question left to be answered is to find out how the two variables (F and a) are directly related. If we double F, do we also double a?" He then placed a question mark on the expression "$F \propto a$" and added that "more work needed to be done."

9:30 a.m.

Following the previous discussion, Mr. Howard moved to the right hand-side board where yesterday he had sketched a graph of "1/a versus M_i."

He commented that "one, two, three and four represent inertial mass . . . and we have not really defined these terms . . . but that's one of our jobs this week." He then borrowed a student's graph and sketched it over the previous one.



As most students had not finished this graph yet, Mr. Howard decided to delay a full discussion of the graph because, "some further thinking was needed . . . specifically in trying to interpret what the intersect meant . . . and about the kind of relationship between 1/a and M_i."

9:26 a.m.

While students worked on their analyses, Mr. Howard suggested that they "try to wrap it (lab report) up today." Some of them, after consulting with Mr. Howard, had to repeat some parts of the experiment again. But this time they were focusing on that part of the experiment that dealt with varying the mass.

10:00 a.m.

As the end of class was approaching, and the students were preparing to leave, Mr. Howard said: "All ready to conclude this devil? We'll spend a little time on HDL's tomorrow." During the last 20 minutes, he had been circulating around, reading students' graphs and assisting them in the analysis of the ticker tapes. (Videotape and fieldnotes, February 10, 1987.)

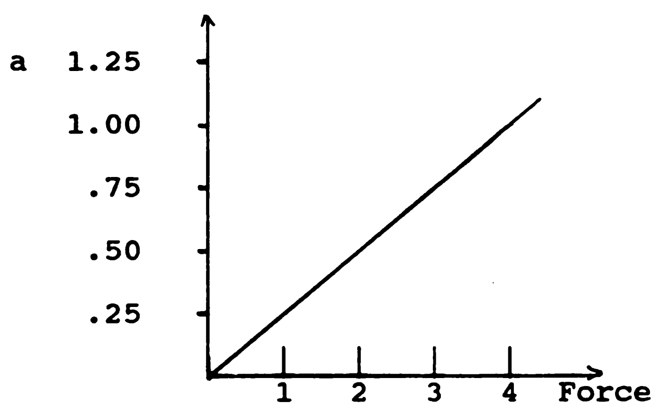
Day 6 "Wrap Up" of Experiment 21 (F = ma)

9:10 a.m.

Beginning the class period, the teacher stated: "Let's try to wrap up today. Take a look at page 229 to 231 please" (PSSC textbook). Students and teacher then talked about a set of strobe photographs that showed the motion of a body under the influence of a constant force.

9:12 a.m.

Mr. Howard put his PSSC book away and exclaimed: "Okay. Here we go. Now yesterday we tried to generalize . . . who's got a graph?" (moving around the room). He went to the board and sketched the following graph: (see Appendix G.)



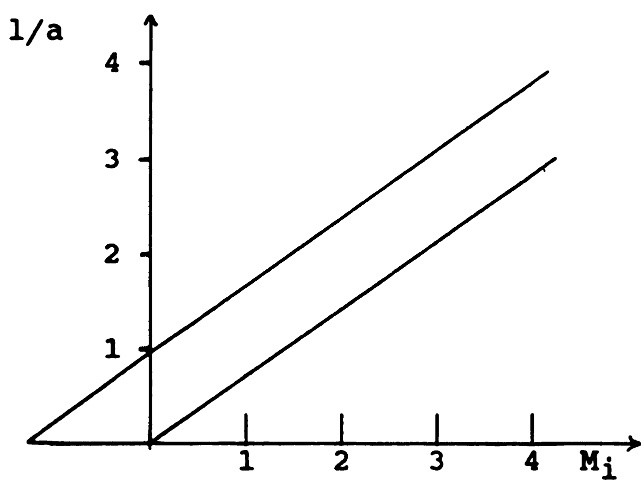
He indicated that, "it does not show 'friction' . . . because I have translocated it" (i.e., move the straight line toward the left so that it passes through the origin). He remarked that since these were a one-to-one correspondence between force and acceleration, then a "big conclusion" could be drawn from that graph:

> Acceleration is directly proportional to the applied force if the mass is constant" ($M_i = K$).

He added that the above statement could be numerically expressed as: "$F \propto a$."

9:16 a.m.

Having explained the force versus acceleration graph, Mr. Howard sketched "1/a versus M," which appeared as: (see Appendix H)



As in the previous analysis, Mr. Howard indicated that "if we doubled the mass then 1/a also doubled." This led him to conclude that: "The acceleration is inversely proportional to the inertial mass if force is constant." He went on to assert that numerically, this could be expressed as: "$1/a \propto m$."

9:20 a.m.

Mr. Howard again referred to the above two statements on both sides of the board and explained that they could be considered in a mathematical expression such as: "$F \propto M_i a$."

Finally, from his last expression, it could be concluded that "force was equal to mass times acceleration" or $F = M_i a$.

10:05 a.m.

Having established the force equation, Mr. Howard substituted the units of acceleration (m/sec^2, cm/sec^2) and mass (Kg_1, gr) to obtain the units of force (Newtons and dynes). The next major activity was to assign HDL's that required the application of the equation $F = ma$. As the class period was about to conclude, he pointed out that tomorrow they would be starting on Experiment 22 dealing with "gravitational mass" versus "inertial mass." (Videotape and fieldnotes, February 11, 1987.)

Day 7 Inertial Versus Gravitational Mass

9:10 a.m.

As soon as students arrived and without even checking attendance, Mr. Howard directed their attention to the equation: $F = M_i a$. He remarked that the next task was Experiment 22, and that they "would be dropping that 'i' . . . today from that equation." He then wrote down the purpose of the experiment (how gravitational and inertial mass compare to one another) followed by five procedures.

9:36 a.m.

After fully explaining each procedure and demonstrating to the students how to operate the equipment, Mr. Howard suggested that they move to the lab tables and start working. At each lab table, Mr. Howard had placed clamps, chronometers, balances and an inertial balance. Students first familiarized themselves with the inertial balance, and then they began to take measurements of the frequencies (of the inertial balance) as the mass hooked to it was varied. The obtained values were put into a table of data given in the procedures.

10:05 a.m.

By the time the bell rang, students (under Mr. Howard's supervision) were still taking measurements. (Videotape and fieldnotes, February 12, 1987.)

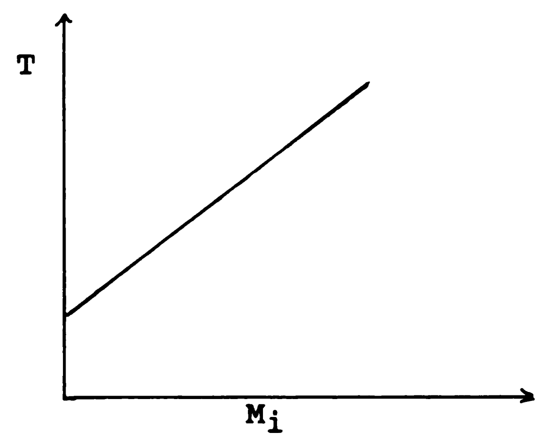
Day 8 **More on Experiment 22**

9:10 a.m.

Upon arrival, the students went straight to the lab tables where they continued the work they had started the previous day. They worked at the lab tables for about 30 minutes before starting to analyze the data they had gathered.

9:50 a.m.

At this point in time, Mr. Howard, who had been assisting and checking students' work, called their attention to the kind of graph (outcome) they should get. He sketched a T (period) versus M_i (inertial mass) graph as follows: (see Appendix I.)



Using this graph, students could compare the period of known mass (in kilograms) and find out that "inertial and gravitational mass are proportional but not equal." In this sense, grams and kilograms were proportional to clamps, bricks, etc., which are examples of inertial mass.

Day 9 Conclusion of Experiment 22.
Mass and Weight. Solving Problems.

9:10 a.m.

After reminding students about the set of HDL's assigned two days earlier (students should be working on this task), Mr. Howard checked on the final conclusion with respect to Experiment 22. After sketching a graph of "period versus mass" he had borrowed, he concluded that "gravitational (M_g) mass is proportional to the inertial mass (M_i) ($M_i \times k = m_g$). From this point, Mr. Howard elaborated on the difference between mass and weight: "mass does not change with position, weight depends on gravity."

9:31 a.m.

Having gone through the difference between mass and weight, the teacher pointed out: "Let's take a look at HDL's." Students immediately found their textbook and began to skim over the assigned problems. However, instead of focusing on the task at hand, Mr. Howard went on to talk about everyday life situations that required the application of the idea of force as a vector quantity. These situations included: "swinging," "standing on a rope," "pulling an object uphill," etc.

9:42 a.m.

Mr. Howard: "Let's go back to HDL's." From this time on until the bell rang (10:05), Mr. Howard worked on the first six problems (HDL's) he had assigned two days earlier. (Videotape and fieldnotes, February 17, 1987.)

Day 10 Solving HDL's

This day's class was devoted to solving most of the problems he had assigned earlier. The problems required the application of the equation: F = ma, as well as the concepts and relations students had learned in the previous two units (kinematics and vectors). Halfway through the class, while students worked on their own, Mr. Howard called to their attention, by listing on the board, a summary of the major fundamental physics equations they had learned thus far. These equations would be useful in solving most of the assigned problems. (Videotape and fieldnotes, February 18, 1987.)

Day 11 Review on HDL's

The first 40 minutes of the class period were spent reviewing all of the previously assigned HDL's. Students were constantly given the opportunity to ask questions or raise concerns about the tasks at hand. Fifteen minutes before the bell rang, Mr. Howard was already introducing the new unit: "Motion at the earth's surface . . . it's what we are going to take a look at next." This statement was followed by Mr. Howard elaborating on the major issues dealt with in this unit.

Interpretation of Mr. Howard's Story-Line

As pointed out before, and as it has been described in the story-line, Mr. Howard's construction of the theme on dynamics was carried out through a series of three consecutive lab experiments. Three major topics were clearly identified: (a) Galileo's constant motion (equivalent to Newton's First Law), (b) the effect of a force on velocity (F=ma) (equivalent to Newton's Second Law), and (c) inertial versus gravitational mass. Figure 5.6 shows a summary of the information content delivered by Mr. Howard in the unit on dynamics.

In the construction of the above sequence, the story-line also indicates a common pattern indicating how the coherence across topics is determined. In this sense, Mr. Howard first established the procedures to follow for each experiment, then analyzed the properly gathered data, and finally established the conclusions. Through this strategy, Mr. Howard was able to deliver the information content described in the story-line. At each of these phases, Mr. Howard constantly drew on information from previous events. For example, when introducing Experiment 20, he refreshed students' memories about how to determine velocity and acceleration from the ticker tape. Similarly, he introduced Experiment 21 by indicating that Experiment 20 was inconclusive in determining the relationship between force, mass and acceleration. At the time he introduced Experiment 22, he again referred to the need to work on the relation: $F = m_i a$ by "dropping that i."

1.0. Galileo's constant motion and friction.
   1.1. "The velocity of a body is constant if there is no friction."
   1.2. "Small forces (friction) cause a small constant decrease in velocity or deceleration.

2.0. The effect of a force over the velocity of a body.
   2.1. A force causes a constant change on velocity (or acceleration).
   2.2. A force is directly proportional to the acceleration if the "inertial mass" is constant ($F \propto a$).
   2.3. The acceleration is inversely proportional to the inertial mass if force is constant ($a \propto 1/m_i$).
   2.4. Force is equal to mass times acceleration ($F = m_i a$).

3.0. Inertial versus gravitational mass.
   3.1. Inertial and gravitational mass are proportional ($M_i xk = Mg$).
   3.2. Mass and weight.

Figure 5.6. Mr. Howard's macro-sequence

A look at the nature of the "global coherence" (Van Dijk, 1985) imbedded in the information content enacted by Mr. Howard in his daily interaction with students and the immediate environment, reveals some degree of discreteness among the different topics being taught. In Grimes' terms, we are in the presence of a "logically loose sequence" (Grimes, 1975). In this sense, the teacher's discourse on dynamics shows some discontinuity.

The following vignette sheds light on the above assertion. Having established (after Experiment 20) that "small forces cause a small constant decrease on velocity or acceleration" and that "friction forces do not depend on speed," Mr. Howard had the students study the effect of force and mass on acceleration. At this point in time the connection between these two instructional events was logically consistent since the data from Experiment 20 was not sufficient enough to draw any conclusion on the relationship between mass, acceleration and force. As they moved along, Mr. Howard explained that the mass that students were working with was, in fact, inertial mass, and it would be the topic of the following experiment.

At the time in which Newton's Second Law was formally established based on the graphs students had obtained, the term inertial mass was being used without having elaborated on its meaning. This situation led Mr. Howard to indicate that "force is equal to mass times acceleration" if the units of acceleration, mass and force were appropriately chosen. In this sense, after having indicated that "force is proportional to mass (inertial) times acceleration" ($F \propto m_i a$), Mr. Howard ignored the nature of the proportionality and moved on to indicate that force could be defined as "mass times acceleration."

Even though Mr. Howard explicitly referred (in Experiment 21) to the need "to drop the 'i' from Newton's Second Law," a close look at the events that took place around that experiment, indicate that no further reference was made with respect to Newton's Second Law and its relation to mass or inertial mass.

Summary and Conclusions on the Theme "Dynamics" as Taught by Teachers

As has been described in the previous vignettes, teachers usually act on school knowledge (e.g., dynamics), and structure them into macro-sequences. These macro-sequences vary in terms of the topics being delivered and the nature in which these topics are organized through instructional events. In this sense, teachers act upon bodies of existing knowledge (discipline) and individually organize them to communicate the information they consider necessary for students to learn. In doing so, they purposely anticipate the instructional events and control the process through which that information needs to be delivered (Magoon, 1977; Kelly, 1954) for learning to take place. As Kitchener (1986) put it, teachers construct the cognitive schema, categories, concepts and structures necessary for learning.

The analysis of how three experienced teachers constructed their unit on dynamics yields several conclusions with respect to subject matter, organization and sequencing in high school physics. These conclusions will be summarized under the following headings: "The Nature of the Global Coherence on Dynamics," and "The Nature of the Information Content and the Immediate Environment."

The Nature of the Global Coherence

Topics can be organized in macro-sequences, as a convenient way to represent the overall (global) coherence of a theme. These macro-sequences vary across teachers with respect to the information content enacted. The micro-sequences on dynamics developed from a discourse analysis of the way three physics teachers actually dealt with such a theme over a period of several days, indicates that each individual teacher delivered different sets of information content for the same theme. Table 5.1 shows a summary of the different topics delivered by each of the participant teachers.

Table 5.1 clearly indicates a distinction between Mr. Howard's and both Mr. Ellis' and Mr. Simon's macro-sequences. The fact that Mr. Howard relied on a different textbook may explain such a difference. Mr. Howard followed the PSSC textbook while Mr. Ellis and Mr. Simon relied on Harvard Project Physics. Neither Mr. Ellis nor Mr. Simon included the topic on "gravitational versus inertial mass." In addition, Mr. Howard did not explicitly address Newton's First Law and inertia, though he talked about Galileo's constant motion. Furthermore, while the notion of friction was considered as a consequence of bodies "not being able to keep at constant motion" in the case of Mr. Howard, the same topic is discussed under Newton's Second Law by Mr. Ellis who defined friction as a "net force that affects acceleration."

Table 5.1: Topics Delivered by Individual Teachers on the Theme Dynamics.

Teacher	Topics
Mr. Simon	Principle of inertia Vectors Newton's First Law Newton's Second Law - Mass and Weight Newton's Third Law
Mr. Ellis	Newton's First Law -- Inertia Newton's Second Law - Friction - Mass and Weight - Free Fall and Terminal Velocity Newton's Third Law
Mr. Howard	Galileo's Constant Motion and Friction Newton's Law (F = ma) Inertial Versus Gravitational Mass

A second topic, not included in Mr. Howard's sequence was Newton's Third Law. When asked about this issue in an interview, Mr. Howard responded: "There was no need to . . . teach that concept and that the chapter dealt only with Newton's law."[1] However, he pointed out that he would be dealing with the topic (i.e., Newton's Third Law) later in the unit on momentum. How can one account for the fact that Mr. Howard spent more class periods on the unit on dynamics than the other two teachers? First, he dealt with each topic at a much deeper level than the other two teachers. Secondly, during the whole school year he does not "go beyond the unit on Kinetic energy" -- a topic covered by the other teachers by mid-February. In this sense, Mr. Ellis and Mr. Simon covered a larger number of topics during the whole school year.

There were also other differences in the content delivered by both Mr. Ellis and Mr. Simon. The first teacher, for example, introduced Newton's First Law once he had finished a unit on vectors. For Mr. Simon, the information content on vectors was presented as a prerequisite to introduce Newton's Second Law. Another striking difference is the idea of friction. The story-lines show that the idea of friction was not fully considered by Mr. Simon. It was a

[1]This issue has been addressed by Aaron who stated that one of the weak points of the PSSC textbook is that it does not deal with Newton's laws in a coherent manner.

fundamental issue in the case of Mr. Ellis, who constantly made reference to it as he moved through the unit on dynamics. A second topic discussed by Mr. Ellis was that of "free fall and terminal velocity." There was no indication that Mr. Simon referred to this topic. Several reasons may account for this difference in information content between two teachers using a similar textbook. One reason is that Mr. Ellis covers a smaller number of units throughout the school year (as explained in an interview). On the other hand, Mr. Ellis rarely covers the units on atomic and nuclear physics. A second explanation is Mr. Ellis' reliance on a "package" of instructional material that is used daily to complement the information given in the textbook. The use of this package allows Mr. Ellis to treat individual topics in more depth than Mr. Simon.

The way different topics were logically connected varied among teachers and, hence, the nature of the global coherence across topics. The following vignettes show how topics were put together in the theme on dynamics as taught by three different teachers.

The first teacher, Mr. Simon, structured the theme on dynamics as follows. He explained that inertia is the principle by which "objects in motion remain in motion unless acted upon by an external force." But objects accelerate under the influence of a force, and forces are vectors. The principle of inertia is the same as Newton's First Law which holds that if there are no "unbalanced forces acting on the body, the velocity is constant and the acceleration is zero." If there are unbalanced forces acting upon it, then an acceleration is produced in the same direction (vector) and proportional to the net force. This acceleration is also inversely proportional to the mass (of the body being moved). Under the action of such a force, objects would accelerate, decelerate or change direction.

The previous discussion was then followed by two loosely connected topics, mass and weight and Newton's Third Law. Weight is a force caused by gravity and it varies from place to place (as gravity does) while mass is the same as inertia and it is constant. The discussion of mass and weight was followed by Newton's Third Law according which is: "to every reaction there is always an equal and opposite reaction" or "forces always exist in pairs."

Mr. Ellis structured the theme on dynamics in a rather different manner. He first introduced Newton's First Law as the property by which "an object at rest stays at rest unless there is a net (unbalanced) force acting on it." However, if there is a net force acting on a body, it creates an acceleration (Newton's Second Law): friction is a net force that also affects motion. The introduction of Newton's Second Law was then followed by Mr. Ellis' elaborating on the idea that in the case of Newton's Second Law: (a) the acceleration is proportional to the net force, and that (b) acceleration is proportional to the inverse of the mass. Newton's second law can be applied to explain the difference between mass and weight. Mass "measures inertia," "it is an intrinsic property" which "does not change with position." Weight, on the other hand, is a special case of Newton's Second Law where the acceleration of the body is equal to the acceleration of gravity. Weight changes as position changes. It follows that "an object if in free fall then the net force acting on it is equal to its weight and the air resistance is zero." If the air resistance becomes equal to the driving force, the object would move at a constant speed called "terminal velocity."

As in the case of Mr. Simon, Mr. Ellis introduced Newton's Third Law in a loosely connected manner. It was presented immediately after an experiment on Newton's Second Law. The argument went as follows: for every force there is an equal and opposite force. These forces are equal in size, opposite in direction and act on different objects.

Finally, Mr. Howard, presented the subject matter-content information as follows. The velocity of a body is constant if there is no friction (Galileo's constant motion). In cases where friction exists, it then causes a small constant decrease in velocity or deceleration. In general, forces cause a constant change in velocity or acceleration, and the rate of change can be (experimentally) determined by the numerical equation: $F = M_i a$, where M_i is the inertial mass of the object being moved. Inertial mass (measured in bricks, marbles, etc.) can be compared to gravitational mass measured in kilograms.

The previous discussion concerning the nature of coherence in the teaching theme dynamics by three experienced teachers led to the opinion that physics lessons are not preset entities, but that they are differentially constructed by teachers and students to achieve their goals. In this sense, "classroom conversations" in high school physics are not scripts to be followed rotely by teachers and students (Green & Harker, 1982). This situation, as Green Harker stated, allows for "breaches" in the cohesion of the lesson as conversations develop. The idea that classroom conversations are not scripts seems to explain why the three participant teachers ended up enacting differently organized bodies of knowledge for a common unit. In organizing this knowledge, each individual teacher employed different types of "coherent relations" (Hobbs, 1983) to connect the topics being delivered in the unit on dynamics. For example, some topics were linked to previous ones, others were introduced once and eventually ignored. Others were carried over into new topics and still others emerged without explicit connection with what had been presented before.

In the story-lines we observed that Mr. Howard initiated his teaching on Newton's Law (i.e., Newton's Second Law) by making explicit reference to the experiment on "Galileo's coasting," and to the lack of data from that experiment to establish a relationship between mass, acceleration and force. The other two teachers (Mr. Ellis and Mr. Simon), however, elaborated on Newton's second law by making explicit reference to "net force" and its effect on the acceleration of a body. These are examples of "linkage relations" (Hobbs, 1983) among topics. These were also examples of linkage relations between topics and subtopics, for example between "Newton's Second Law" and "mass and weight" as taught by Mr. Ellis and Mr. Simon. The story-lines indicate that in the case of Mr. Ellis, there was a strong linkage relation between Newton's Second Law and the difference between mass and weight since the latter was derived by applying the first one. In the case of Mr. Simon, the relation was weak in the sense that he elaborated on the same subtopic without making explicit reference to "Newton's Second Law." Another example was the subtopic friction. Friction as taught by Mr. Ellis was taught as a net force that affects acceleration (direct application of Newton's Second Law). However, in the case of Mr. Simon, he introduced the idea of friction in the context of Newton's First Law as something that "needs to be eliminated" to make objects move at a constant speed.

There are also topics that were introduced once in the classroom discourse and eventually ignored. As Tanner (1984) stated, "they eventually decay." Examples of these topics were vectors and the difference between mass and weight (Mr. Simon's class) and friction (Mr. Howard's case). However, there were topics that, once introduced, were carried over into subsequent events dealing with different topics or with the application of topics already discussed. In this sense, we talk about "strong temporal relations" (Hobbs, 1983) between topics in which previous information has a strong impact on what happens next in the discourse. Examples of this situation were the instructional events that led Mr. Howard to establish Newton's Second Law. He first had students experimentally derive the relations between acceleration and mass and acceleration and force before concluding that "force is equal to mass times acceleration." A similar event took place in Mr. Ellis' sequence on dynamics. This happened when he was conducting the experiment on Newton's Second Law. During the development of the experiment, Mr. Ellis' made explicit reference to the concepts of inertia, friction, mass and weight and Newton's Second Law. Coherent relations of this nature were very rare in Mr. Simon's sequence on dynamics.

The final point to be made is with respect to topics that are not properly linked to what was presented before, or in other words, the non-existence of explicit linkage relations between topics. Examples of this situation were Mr. Simon's elaboration on Newton's Third Law as an entity in itself without making explicit reference to Newton's First and Second Law or Mr. Howard's elaboration on the topic "inertial mass versus gravitational mass" without explicitly referring to Newton's Second Law, which was the immediate antecedent topic.

In summary, teachers in their daily interaction with students and classroom materials construct, for similar instructional units, different structures of subject matter (macro-sequences) by breaking those units into topics which may or may not be logically connected. In this sense, teachers enact different underlying structures (or macro-structure) for themes that are usually expected to convey the same type of information. In Grimes' (1975) terms, the three macro-sequences can be categorized as "logically loose" sequences in the sense that teachers enact topics in a theme, following a temporal and logical order without an explicit connection among them.

In effect, if one looks at the theme dynamic as a organic instructional unit, it can be observed that there was no direct connection between the topic of Newton's Second Law" and "vectors" and Newton's Third Law as taught by Mr. Simon. Similarly, there was not a direct logical link between the topic of Newton's Second Law and the topic "difference between inertial mass and gravitational mass" as taught by Mr. Howard. Perhaps the link was that the term inertial mass (M_i) appears in the equation of Newton's Second Law, however, this issue was not explicitly addressed in Mr. Howard's discourse. The story-lines do indicate that teachers establish logical connections among some of the topics such as vectors, Newton's First Law and Newton's Second Law (Mr. Simon); between Newton's First Law and Newton's Second Law (Mr. Ellis); and between Newton's First Law (Galileo's coasting) and Newton's Third Law (Mr. Howard).

This analysis seems to support the idea that "there is not one logical sequence in which the truths of a subject must be communicated" (Hirst, 1975).

The data also support the assertion that important logical connections among topics of an instructional unit are not made clear to students. Generally, these connections are subtle and to miss them is to miss the "logical grammar" (Hirst, 1975) of physics, making it incomprhensible to high school students.

The Nature of the Information Content and Environment

The macro-analysis of the teachers' discourse on dynamics indicated that the information content was differentially enacted by teachers. There were variations in the subject matter organization as well as variations in the nature of the "environment through which tasks were accomplished." These environments were enacted in fundamentally different ways. Tables 5.2, 5.3 and 5.4 show an overview of the physical materials individual teachers used when delivering similar and different topics related to the unit on dynamics. As Erickson (1971) pointed out: "These materials contain cues towards steps and strategies that are necessary in the completion of the subject matter task (p. 171). The story-lines above give evidence that these steps and strategies are context-specific.

It can be observed, for example, that Mr. Simon relied on a worksheet that the students needed to fill out, as he simultaneously elaborated on Newton's three laws. He also performed classroom demonstrations on Newton's First Law. However, compared to Mr. Ellis, Mr. Simon did not perform classroom demonstrations while elaborating on Newton's Second Law. It can be observed, for example, that Mr. Ellis

Table 5.2: Mr. Simon's Enacted Topics and Physical Materials.

Topic	Physical Materials
Principle of inertia	Worksheet, textbook; balls, strings, wooden blocks, dry ice, metal desks.
Vectors	Worksheet
Newton's Second Law	Worksheet, bricks, carts, ticker timers, ticker tape, weights and pulleys.
Newton's Third Law	Worksheet

Table 5.3: Mr. Ellis' Enacted Topics and Physical Materials.

Topic	Physical Materials
Newton's First Law	Package of materials, textbook, wooden blocks, weights, strings and balls.
Newton's Second Law	Package, schedule sheet, scales, balances, carts, rubber bands, bricks, darts, weights, stop watches and rulers.
Newton's Third Law	Package, cloth balls, cart, rope, and scales.

Table 5.4: Mr. Howard's Enacted Topics and Physical Materials

Topic	Physical Materials
Galileo's Constant Motion	Textbook and lab reports; rubber bands, carts, bricks, ticker timer, ticker tape, graph paper and rulers.
The Effect of Force Over Velocity (Newton's Second Law)	Textbook and lab reports; rubber bands, carts, bricks, ticker timer, ticker tape, graph paper and rulers.
Inertial Versus Gravitational Mass	Textbook and lab reports; clamps, balances (inertial), chronometers, weights, graph paper.

carried out demonstrations with carts, rubber bands and bricks to show how mass and force relate to acceleration. Mr. Simon initially established the relationships among these variables as given though they were tested the following day in a class experiment that yielded inconsistent results. On the other hand, Mr. Ellis conducted a "hallway experiment" to calculate the mass of a student from the relation $m = F/a$. In both cases, they were applying the already established Newton's Second Law in two different specific situations.

The third teacher, Mr. Howard, produced a different kind of environment in which the information content was delivered. The story-line on Mr. Howard shows a different type of organization with respect to the "physical stuff"

(Erickson, 1982) through which the information content was delivered. He relied on the textbook materials (textbook and lab manual) and lab equipment such as carts, bricks, ticker tape and graph tape, etc. as he elaborated the information content on "Galileo's Constant Motion" (equivalent to Newton's First Law in Mr. Ellis' and Mr. Simon's terms) and "the effect of force over velocity" (equivalent to Newton's Second Law). The equipment changed again for the demonstration on inertial and gravitational mass. When Mr. Howard and Mr. Ellis and Mr. Simon are compared, as shown in the story-line, it is clear that even similar physical materials have different purposes and usages as teachers construct subject matter for topics and units that convey the same information. Mr. Howard, for example, had students interact with the equipment in order to gather data that would be represented in the graph papers for later use. The information contained on these graphs was eventually used to draw the conclusions on the topics being dealt with at different instances. The story-line on Mr. Howard gives evidence of three lab reports elaborated by students and borrowed by Mr. Howard to establish these conclusions.

The above discussion shows that teachers enact different environments as they organize similar pieces of classroom subject matter. And even though the environments may be similar (e.g., same physical stuff), sometimes its organization and purpose varied across teachers. In this sense the "steps and strategies" (Erickson, 1982) imbedded the physical materials through which subject matter is delivered are not only context-specific but also topic-specific. This finding is consistent with a constructivist view of teaching in which teachers enact different environments to communicate the necessary information students need to learn.

Part II -- Constructing Macro-Sequences on Newton's Second Law

The previous account does not specifically focus in detail on the variation in the way particular pieces of academic work are constructed by teachers. Its purpose was to give a sense of the overall structure (global coherence) of a unit of dynamics as constructed by the three participant teachers. It gives the reader a story-line of how that theme was sequenced across time. To begin to probe on specific details, the researcher has selected videotape segments that contain information concerning how teachers dealt with a common topic. The micro-analysis that follows will primarily shed light on the following guiding question: What is the nature of the coherence of the information content delivered in a single topic as taught by high school physics teachers? The analysis is geared towards more specific questions that focus on: (a) how is the selected topic connected to other topics within the unit; (b) how is the topic introduced and concluded; and (c) what are the enacted logical relationships being delivered in a common topic across teachers. The analysis will also focus on the question: What is the nature of the task environment through which the topic was delivered?

The topic selected for micro-analysis is Newton's Second Law ($F = ma$). This topic is considered to be a fundamental concept in the study of dynamics and the causes of motion. In addition to its importance within the theme on dynamics itself, Newton's Second Law is a physics concept that is carried over and linked to teaching other topics such as: circular motion, Kepler's laws, momentum and energy. It can be assumed that understanding how such a concept is taught can have strong implications on how future concepts are also organized and connected to the concepts already taught.

For the purposes of the analysis, it was decided to select out the teachers' discourses on Newton's Second Law from the entire data source on dynamics. In this sense, a careful scrutiny of the data sources was carried out so as to partition (Brown & Yule, 1983) the discourse in segments which would indicate the precise moment at which Newton's Second Law commenced being a topic as well as the moment at which it was no longer a topic. For example, even though two of the teachers (Mr. Simon and Mr. Ellis) performed an experiment on Newton's Second Law after the discourse had taken place, it was not considered as part of the discourse on Newton's Second Law. Instead, these a-posteriory instructional events can be categorized as applications of Newton's Second Law. In the selection of the discourse segments on Newton's Second Law, specific attention was focused on the moment in time when teachers explicitly dealt with the relations between mass, force and acceleration for the first time. The micro-analysis of Newton's Second Law will now be discussed.

The analysis will proceed as follows. First, the data for each of the teachers will be presented, followed by an interpretation based on the interpretive framework that guides this study. Second, a comparison of the three participant teachers use of the topic of Newton's Second Law will follow. The comparison is fundamentally based on how the topic is connected to other topics within the same unit (i.e., dynamics), how the topic is concluded, and what is the nature of the task environment or physical stuff (Erickson, 1982) through which the topic is delivered.

The segments on Newton's Second Law are presented in tables that have three main columns: verbalizations, participants' actions and immediate interpretation of these actions as seen by the researcher (after Yorke, 1987). Though the micro-analysis could be focused on particular utterances, a global view of the segments has been pursued in order to compare the "grown" (Agar & Hobbs, 1985) micro-sequences that result from the micro-analysis of these segments. Analysis of the coherence of a text (discourse) can be appropriately used as a tool to derive how the "intended meaning" has been "grown" from the participant's actions and the analysis of these actions. A micro-sequence, then, can be viewed as the intended meaning implicit in the teaching of a single topic (e.g., Newton's Second Law).

The micro-analysis of the discourse segments on Newton's Second Law leads to a consideration of the following general assertions: Newton's Second Law, as taught by three experienced high school teachers is differentially constructed. A careful analysis of the teachers' discourse reveals the existence of variations in the process of how such a law is connected to other topics and how the same law is formally introduced and terminated to students. In addition, Newton's Second Law is enacted through a series of logical steps (micro-sequence) which vary among teachers.

Mr. Simon's Discourse on Newton's Second Law

Mr. Simon introduced Newton's Second Law immediately after reviewing Newton's First Law, which was a topic he had enacted three days earlier. Before beginning to elaborate on Newton's Second Law, Mr. Simon referred to the conditions and results of applying Newton's First Law. In this case, after stating Newton's First Law as: "Bodies at rest remain at rest . . . bodies in motion remain in motion . . . straight line . . .," Mr. Simon indicated that this law holds under the condition that there are no unbalanced forces ($\Sigma F = 0$), and that the result of these balanced forces is that a body moves at a constant velocity and the acceleration is zero. During the events that surrounded the teaching of Newton's Second Law, Mr. Simon first established the given relations that "acceleration is proportional to net force" and "acceleration is inversely proportional to mass." However, this was not followed by a discussion on the conditions and results of applying Newton's Second Law. Before concluding with the mathematical equation that defines Newton's second Law, examples of both Newton's First and Second Laws were solicited from the class. The formulation of this equation was followed by a brief discussion on the difference between mass and weight, and a short lecture on Newton's Third Law.

Mr. Simon's discourse on Newton's Second Law (see Table 5.5) lasted about 20 minutes and students followed it with a worksheet with spaces to be filled in as the lecture progressed (see Appendix B).

Table 5.5

Mr. Simon's Discourse Segment on Newton's Second Law

Source: Videotape, September 26, 1986

Time: 7:45-8:55 a.m.

Background Information: The following account was preceded by a review of Newton's First Law; a topic that had been introduced three days earlier. The teacher restated the law and referred to the "conditions" on which that law holds as well as the "results" of applying it. Students followed him, throughout the lecture, with a worksheet that had been distributed at the outset of the class.

Verbalization	Action	Interpretation
8:05 a.m.		
T: Okay. Well, the law of inertia we spent some time on that so . . . you have a pretty good idea . . . of what that's all about . . .let's go to the second one . . . this is the biggy one. This is the big one. The second law . . . it says that if you do have an unbalanced force, then you have an acceleration . . . and these are Newton's words . . . these are on your sheet an unbalanced force . . .causes an acceleration . . . in the same direction as . . . and proportional to . . . the net force . . . That means . . . that the acceleration is proportional to the force . . . but the net force . . . (5 sec) . . . These are vectors (arrows) . . . and whatever . . . direction the force is in . . . acceleration is in that direction . . . If I make the force bigger I make the acceleration bigger . . . that's reasonable . . . that's intuitive . . . because there is ( ) . . . yeah, that works out yeah . . . If you want to make a ( ) . . . for example . . . what did you use? . . . a long engine . . . a small engine . . . a Cadillac engine . . . or a truck diesel engine . . . something that has a lot of force and capability. Right? . . . you want a big acceleration . . . you have to have a big engine . . . Right? . . . so that's intuitive. (5 sec)	Mr. Simon is at the board, while student follows him with the worksheet (Appendix B) Mr. Simon reads from his worksheet. T writes: $a \propto F_{net}$	The teacher refers to the immediate previous topic (i.e., law of inertia) or Newton's First Law. Topic shift to introduce Newton's Second Law. The shift begins with a linkage between "unbalanced force" and acceleration. The logical relationship between these two variables is established as "given." It is followed by an anaphoric reference to the vectorial nature of force and acceleration. The relationship between acceleration and force is expanded through an example.
Now the other part of that (equation) is inversely proportional to mass . . . That's to say . . . acceleration is proportional to the inverse of the mass . . . If you make the mass bigger the value of	T goes back to his worksheet and writes down on the board: $a \propto 1/m$	Discussion on the relation a F_{net} ends and the discourse shifts to a lecture dealing with the logical relationship between acceleration and mass.

Table 5.5, Cont'd.

Verbalization	Action	Interpretation
this fraction ($a \propto 1/m$) becomes less . . . doesn't it? . . . You make the bottom side of the fraction bigger . . .one over two . . . one over three . . . one over four . . . one over five . . . As you make the bottom part of the fraction bigger the value of the fraction decreases . . . so if you make the mass bigger . . . acceleration slows down . . . it decreases . . . so if you want to make a ( ) . . . you need a big engine and a small mass . . . small mass as possible (5 sec).		
T: Okay . . . well there are ways in which you can write that . . . and I'll come back to where it says . . . a little box . . . on the sheet . . . where it says "written" . . . I'll come back to that in a second . . . Let's go on to the conditions . . . under which this thing works out . . . and the results . . . and then I'll give you some examples . . . Look at some examples of the law . . . Okay.		
Girl: Examples of the first law?		Though, Mr. Simon elaborated (some minutes ago) on the "conditions" and "results" of Newton's First Law, he had not yet discussed the "examples" of the first law as shown on the worksheet.
T: Not yet, I'll come back to that.		
8:07 a.m.		
T: Conditions . . . okay . . . there is an unbalanced force acting . . . an unbalanced force act in this case . . . That's to say . . . the sum of the forces is not equal to zero . . . There is a net force . . . and that's what causes it to accelerate . . . (3 sec) . . . The result then of this . . . is that the speed is not constant . . . The acceleration is not zero . . . but that is either plus or minus or something . . . Acceleration is not zero . . . and an object either will accelerate . . . what is another possibility?	T moves back to the board and begins to summarize these conditions which are copied down by the students on their respective worksheets.	

Table 5.5, Cont'd.

Verbalization	Action	Interpretation
Paul: Decelerate.	T waits for response.	
T: Deceleration . . . that's another possibility . . . okay . . . I'm to throw you a curl ball next. There is another option?		
Steve: Zero.		
T: Zero is not an option . . . since zero will be . . . the speed is constant . . . can't do that . . . the third one is going to surprise you . . . The other possibility is to change the direction that it is going . . . Now . . . that probably doesn't make much sense . . . at this point . . . but obviously later on we'll say . . . here is exactly what we were talking about . . . If you have a force . . . that force will cause a speed . . . It won't be constant . . . acceleration won't be zero . . . and it will cause the object to accelerate . . . decelerate or change in direction. (7 sec)	At this point in time, the board reads: Conditions $\Sigma F \neq 0$ Results $V \neq$ constant $a \neq 0$ Object change: 1. accelerate 2. decelerate 3. change in direction	The teacher made cataphoric reference to "change in direction." (This idea would be eventually expanded on next week in the unit on projectile motion.)
8:10 a.m.		
T: Okay . . . Let's think of some examples . . . of where . . . Newton's First Law is working . . . and where Newton's Second Law is working . . . Help me out on this . . . Give me some examples where force is unbalanced . . . and you have either acceleration		After restating the results of Newton's Second Law, Mr. Simon changes pace by introducing a new activity: examples of Newton's First and Second Laws together. Here Mr.

Table 5.5, Cont'd.

Verbalization	Action	Interpretation
or deceleration . . . or change in direction . . . or change in direction . . . three examples of that.		Simon "goes back" to exemplify Newton's First and Second Laws.
Girl: A car. T: A car doing what? (5 min)	For a five-minute period, Mr. Simon asked students to give examples of both laws. At the end of this time, the board showed:	
	Examples of first law: 1. Car at constant speed. 2. Ball on the shelf. 3. Weight on table. Examples of second law: 1. Speeding car. 2. Burning rocket. 3. Baseball as hit by a bat.	The first three examples had previously been mentioned in discussions related to Newton's First Law. Both sets of examples were presented randomly and independent of each other.
8:15 a.m.		
T: Okay . . . there is a distinction . . . (between these two laws). Now let's test ourselves . . . I know in your sheet some of these (examples) are not very clear . . . the printing did not turn out very well . . . in some of them . . . some of them are very nice . . . what I have is okay (5 sec) what about "a" where the speed is zero . . . acceleration is zero . . . Is that describing a condition of first law . . . second law?	Mr. Simon refers to the first graph (Appendix B-Part II)	The "break" on Newton's Second Law continues as more examples are posed to the class. This time the examples are not given by the students, but they have been printed on their work-sheets for students to recognize whether they are cases of Newton's First or Second Law.
St: First law		
T: First law . . . anybody disagree or question or wonder how we got that? (10 sec)		

Table 5.5, Cont'd.

Verbalization	Action	Interpretation
	From here on and for three consecutive minutes, eight graphs ("a" versus "t" and "v" versus "t") (see Appendix B) were used to probe the students' understanding on whether they were cases of Newton's First Law or Second Law. At the end of the discussion, the board showed: a b c d e f g h 1 1 2 2 1 2 1 2 (1 stands for first law and 2 for second law)	
8:18 a.m.		
T: Let's go back to look at the equation form of Newton's Second Law (8 sec) . . . I think . . . on your sheet . . . there is above "test yourself" and it says "written" . . . Newton's Second Law is written this way . . . acceleration is proportional to "f" and inversely proportional to "m" . . . And if I choose the units right . . . I can make that (proportion) an equal . . . not a proportionality . . . what does the letter "a" represent?	Mr. Simon moves back to the board and erases the information written there, and calls the students' attention to the worksheet. At the same time, he writes down: $a \propto F/m$	Mr. Simon goes back to the discussion of Newton's law that he had started a few minutes earlier. In this sense he established the mathematical equation of Newton's Second Law without explicitly making reference to the two logical relationships he had already talked about.
Steve: Acceleration	$a = F/m$	
T: Acceleration . . . units of acceleration . . . are going to be . . . meters per second squared (3 sec) . . . Joanne am I confusing you?	Joanne is caught talking to her neighbor.	The subtopic on "units" is introduced. The unit of force (Newton) is derived from a direct application of Newton's Second Law.
Joann: No, I just ( ).		

Table 5.5, Cont'd.

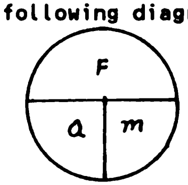
Verbalization	Action	Interpretation
T: Okay . . . we are jumping out a little bit . . . all right . . . "a" stands for acceleration . . . and the units are meter per second squared . . . "m" stands for mass . . . and the units will be kilograms . . . Now if we express mass in kilograms . . . acceleration in meters per second . . . then our unit of force is going to be a kilogram times meter divided by second squared . . . a unit named in honor of the person who put this stuff together . . . Isaac Newton . . . and it is called a Newton . . . and it is abbreviated capital N . . . no period . . . okay . . . That's where the Newton's business comes in . . . that we told you about before.	At this point in time, the board showed: a $\propto$ F/m a = F/m a $\doteq$ acc:m/sec^2 m $\doteq$ mass:kg f $\doteq$ force:kg m/sec^2 (Newton) N	In the previous segment, Mr. Simon acknowledged the use of the word Newton before formally introducing it (this term created some confusion last week). Also, the student's question is ignored in spite of the fact that there is not a blank space in the worksheet for writing the word Newton.
St: Where do we write that (Newton)?		
T: So . . . that's our equation (a = F/m) that we are going to use . . . for the second law . . . You see it is a very simple equation to use . . . first order equation . . . and we can write it . . . in this simplified sort of way some of you like to use . . . that some of you said that if you don't have an equation written this way . . . you really have a hard time figuring out what to do with it. (5 sec)		Newton's Second Law equation is restated as Mr. Simon moves on to sketch a diagram to help students figure out the values of acceleration, force and mass from such equation.
T: In this one (diagram) . . . we are going to run it with force out here (up) . . . acceleration down . . . here (left) and mass there . . . So if we want to calculate acceleration . . . get force divided by mass . . . If you want to calculate mass (tapping mass) . .	Mr. Simon begins to sketch the following diagram. 	He used the same format with the equation: a = v/t.

Table 5.5, Cont'd.

Verbalization	Action	Interpretation
. force divided by acceleration . . . If you want to calculate force . . . you multiply . . . acceleration . . . by mass.	T taps acceleration (a), mass (m) and force (F), one at a time and shows that the untapped part is a resultant equation for either a, m or F.	
8:22 a.m.		
T: That's Newton's Second Law . . . now we get back to that in just a minute . . . I want to give you a sheet with some problems on it . . . in just a minute . . . but I want . . . to continue with the sheet . . . I want to have you write something down and you probably won't get it out of your mind . . . The prejudices or the curious ideas that you sometimes have involving these two terms . . . It takes a while for us to settle in . . . as to what these things are . . . how they differ . . . I want you to write down the difference between what we call weight and what we refer to as mass . . . I want to make a distinction between these two quantities.		The statement "that's Newton's Second Law" seems to mark the end of the discussion on this topic. The numerical problems that followed were concerned with application of that law to specific situations dealing with a calculation of acceleration, mass and force.
	From here on, Mr. Simon spends about three minutes talking about the distinction between mass and weight. The discussion was then followed by an 8-minute lecture on Newton's Third Law. Having concluded this topic, the students were assigned the set of numerical problems on Newton's Second Law.	

Discussion of Mr. Simon's Micro-Sequence on Newton's Second Law

The purpose of this section is to discuss Mr. Simon's discourse on Newton's Second Law in terms of the interpretive framework of this study. As has been indicated before, an analysis of people's discourse as well as the actions enacted simultaneously with a discourse can lead the discourse analyst to "map out" the intended meaning (Brown & Yule, 1983) being communicated. Specifically, one can study the nature of the coherence or the "underlying task structure" (Erickson, 1982) being displayed in the discourse. As Erickson (1982) has indicated in the case of classroom events, this task structure is simultaneously enacted and manifested through a series of steps and strategies contained in the "physical stuff" used by teachers and students to deliver information.

In the case of Mr. Simon, the immediate "physical stuff" used to deliver information relative to Newton's Second Law consisted of a worksheet (see Appendix B) and the blackboard. Students were expected to fill out the worksheet as the teacher explained the content on the board. As Appendix B indicates, the worksheet contained a series of steps that were carefully followed by Mr. Simon as he delivered Newton's Second Law. Specifically, it contained a written statement about Newton's Second Law as well as black spaces under the headings: conditions, results and examples applied to Newton's Second Law. In addition, it contained a series of examples, or self-tests, to be completed by the students. It also contained cues as to the location in the worksheet where students were expected to write down the mathematical equation of Newton's Second Law.

A careful look at the way the information content is organized through time yields evidence about the nature of the local coherence (Brown & Yule, 1983) imbedded in the teacher's discourse on Newton's Second Law. The discourse segment shows that not all that is said is strictly related to Newton's Second Law. It is also related to Newton's First Law as illustrated by the fact that he discussed Newton's First Law immediately after he had finished talking about the results of Newton's Second Law. In spite of these breaks (Brown & Yule, 1983), it was possible to map out the structure of the information content he delivered. One is able to determine the structure from the teacher's verbalization and actions (e.g., what was written on the board), as well as the immediate interpretation of them. The following statements determine the nature of the coherence of the information content being delivered by Mr. Simon:

> The second law . . . it says that if you do have an unbalanced force, then you have an acceleration . . and these are Newton's words . . . that means that the acceleration is proportional to the force" (written $a \propto Fnet$).

> Now the other part of that (equation) says . . .that it (acceleration) is inversely proportional

> to mass . . . that's to say . . . acceleration is proportional to the inverse of the mass . . . if you make the mass bigger the value of this fraction a $\propto$ 1/m) becomes less.
>
> Let's go back to look at the equation form of Newton's second law (8 sec) . . . I think . . . on your sheet . . . there is above "test yourself" and it says "written" . . . Newton's second law is written this way . . . acceleration is proportional to "f" and inversely proportional to "m" (written a $\propto$ F/m) . . . and if I choose the units right . . . I can make that (proportion) an equal (written a = F/m).

As has been indicated before, the enactment of Newton's laws, as taught by Mr. Simon, was not done in a linear type of fashion. Instead of organizing the information content in a linear fashion, Mr. Simon initiated a break in which he elaborated on the conditions under which the law applies, the results of applying that law, and examples of the law. All this took place immediately after the first two statements ($a \propto 1/m$ and $a \propto F_{net}$) indicated above. A second related break took place when Mr. Simon probed students' understanding of Newton's First and Second Laws. It was not until this last instructional event ended that Mr. Simon finally established the mathematical formulation of Newton's Second Law (see Figure 5.7).

		Break	Break		
$a \propto F_{net}$	$a \propto 1/m$	conditions and results of Second Law	examples of Newton's First and Second Laws	$a \propto \frac{F_{net}}{m}$	$a = \frac{F_{net}}{m}$

Figure 5.7. Temporal representation of Mr. Simon's micro-sequence on Newton's Second Law.

The nature of Mr. Simon's local coherence on the topic of Newton's Second Law indicates that even though not all of the instructional events are logically connected to one another, there are events that strictly depend on what has been said before (Grimes, 1975). In Grimes' terms, Mr. Simon's sequence on Newton's Second Law can be categorized as a logically loose one. Even though he elaborated on the relations $a \propto F_{net}$ and $a \propto 1/m$ before concluding that $a = F_{net}/m$, in a logical manner, Mr. Simon introduced two breaks (Jefferson, 1972). The first one was to explain the conditions and results of Newton's Second Law, and the second one was to engage students in a problem solving activity dealing with the application not only of Newton's Second Law, but also of Newton's First Law (see Figure 5.7). In this sense, Mr. Simon could have waited to formally establish Newton's Second Law, and then engage students in an activity dealing with the application of it or comparing it with other laws. This interpretation is consistent with Hirst's (1974) jig-saw metaphor. It is Hirst's view that "the logical order does not prescribe a series of steps which must be taken. There are a variety of ways in which the jig-saw can be made up and the same is true in teaching science" (Hirst, 1974:122).

Mr. Ellis' Discourse on Newton's Second Law

Mr. Ellis' discourse on Newton's Second Law (see Table 5.6) took place over a period of two consecutive class sessions of 50 minutes each. In the first period, after elaborating on the concept of inertia and Newton's First Law, Mr. Ellis established, as given, the numerical equation that defined Newton's Second Law ($F_{net} = ma$). He next gave the students a set of numerical and qualitative questions in which they were required to apply the equation. In the discussion that followed the solution to these problems, one of the topics that emerged was the notion of friction, a net force which affects the acceleration of a body.

During the second class period, Mr. Ellis further elaborated on the logical relations that can be derived from Newton's Second Law. He conducted two classroom demonstrations that led him to conclude that "force (net) is proportional to acceleration" ($F_{net} \propto a$) and "acceleration is inversely proportional to mass" ($a \propto 1/m$). Each of the above equations was later applied to a set of numerical problems, and students were called on to answer questions posed in each problem. Next Mr. Ellis summarized the topics already covered, and referred to the future activities (experiment) related to Newton's Second Law and other unit topics. Ten minutes before the end of class, the teacher assigned problems that required the application of topics they covered, and more specifically, Newton's Second Law.

Table 5.6

Mr. Ellis' Discourse on Newton's Second Law

Source: Videotape, Oct. 22 & 24, 1986

Time: 10:00-10:50 a.m.

Background Information: The following account was preceded by a review of Newton's First Law that had been dealt with during last Friday's meeting (October 17). The last time the class met (October 20), students took a test on vectors. The account describes Mr. Ellis, from the moment he introduced Newton's Second Law and the logical relationships that derive from it until the moment he was about to begin teaching the about mass and weight.

Verbalization	Action	Interpretation
10:27 a.m.		
T: Newton's First Law deals with equilibrium . . . and deals with the case where net force is zero . . . For us net force is the same thing as unbalanced force, resultant force . . . If the net force is zero . . . objects don't change what they are doing . . . but resting . . . stay at rest . . . If they are moving . . . they stay moving at same speed . . . same direction (5 sec) . . . It takes an unbalanced force to cause things to move . . . and that's Newton's Second law. (14 sec)	During the previous minutes, Mr. Ellis has been talking about Newton's First Law, a topic he started last Friday.	Previous topic is restated.
	Mr. Ellis goes back to board and writes down (withholding the "a"). $F_{net} = m$	New topic (Newton's Second Law) is introduced. In this "topic shift," Mr. Ellis anaphorically refers to the need of an unbalanced force to make things move. Obviously this is not Newton's Second Law as it should say "to make things accelerate."
T: Many times you see this (net) written when you see Newton's Second Law . . . What this means is net force . . . unbalanced force . . . resultant force . . . force acting on something . . . And the reason I hold the vector sign . . . students say . . . well I talked to students last hour . . . If the net force is eastward . . . what direction would you expect the acceleration to take place? . . . Eastward . . . same direction . . . that's what this means (putting the arrow above "a") . . . We have a cause . . . an unbalanced force . . . and have some type of effect. (4 sec)	Mr. Ellis places a small arrow over F_{net}. Mr. Ellis completes the equation above. $F_{net} = ma$ Mr. Ellis wrote down on board: cause-affect	The term resultant force was introduced in the vector unit a week earlier. He refers to the vectorial nature of the net force. Newton's Second Law equation is formally introduced for the first time as a given relation between net force, mass and acceleration.

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
10:30 a.m.		
T: Well, let's look into units . . . In the metric system we always measure forces . . . in what units?	The teacher looks for "the package" and writes down: force = mass · acceleration	Subtopic on units begins. The units of force (Newton and pound) are established in terms of the units of acceleration and mass already known to the class. In this case, the units of force are derived from a direct application of Newton's Second Law.
St: Newtons		
T: Newton . . . Capital N is the abbreviation for Newton . . . We always measure mass in kilogram and we measure acceleration in meters per second per second . . . You need to be consistent in units . . . If you want to apply Newton's Second Law . . . if the force is a Newton there the mass must be a kilogram and the acceleration must be a meter per second per second . . . Unfortunately, we have another system of unit called the English system . . . Force is measured in?	The board shows "N = kg·m/sec^2 as Mr. Ellis moves on to elaborate on the second type of unit.	
St: Pounds.		
T: Pounds . . . I mean if you go to McDonald's . . . you buy a quarter-pounder, you don't by a Newtoner (laugh) . . . You measure force . . . you step on the scale . . . and you don't say I weight 200 Newtons . . . You read how many pounds you weigh . . . So the unit of force in the English system is pound . . . acceleration in the English system . . . ?		
St: Feet.		
T: Feet per second per second . . . Did I mention this in class yesterday . . . unit of mass in the English system . . . ?		
St: Oh . . . Oh.		

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
T: I'm going to tell you right now . . . (writing) . . . slug . . . very descriptive . . . inertia . . . resistance to movement sluggishness . . . so the basic unit is called the slug . . . We will work with it later. (3 sec)	The board shows: F = mass · acceleration $N = kg\ m/sec^2$ $Pounds = slug\ feet/sec^2$	
T: For dimensional analysis . . . mass is measured in kilogram . . . acceleration is measured in meters per second per second . . . Actually the way a Newton force is defined is that force which accelerates one kilogram mass . . . giving it an acceleration of one meter per second per second . . . so one kilogram mass accelerates at one meter per second . . . A Newtoner is a kind of nickname . . . kind of awkward to say it . . . (5 sec)	Mr. Ellis moves away from the board and looked for his "package" on the desk.	The discussion on units is over at this point. Mr. Ellis is about to move on to a different activity.
T: Ten years . . . from now if a reporter down the street grabs you and says what do you remember about the high school physics class . . . the one thing that most of you have to remember is there (F = ma) . . . Newton's Second Law of Motion . . . You will say "I think that F is equal to mass times acceleration . . . can't get away from it . . . (10 sec)	Mr. Ellis skims through his package while restating Newton's Second Law.	At this point of the discourse, Mr. Ellis seems to be evaluating the essence of the topic being delivered.
T: If you open your package . . . in Handout 32.	Both teacher and students skim through Handout 32 (see Appendix L) for several seconds.	Change of activity begins here. From now on students and teacher engage in a problem solving activity involving the application of both Newton's First and Second Laws.
T: 4a . . . A ball is rolling at 20 cm/sec and no net force acts on it . . . What will the speed of the ball be after 5 seconds?	From now until 10:40, Mr. Ellis leads a discussion on four problems dealing with Newton's First and Second Laws. Concepts, such as net force, unbalanced force and	During this discussion, the idea of "force of friction" emerged as a subtopic. Force of friction is introduced as an unbalanced force that affects acceleration. This notion of force of friction and

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
	force of friction were dealt with during this problem solving activity. The force of friction between the desk and a lead block was first determined with a scale, pulling it at a constant speed. Also the force of friction between a cart and the floor was determined by having a girl stand on a cart while Mr. Ellis pulled here across the room at a constant speed. In this case, the girl was asked to hold a large scale that showed a force of 15 Newtons. The last problem involved the application of the kinematic equations developed in the previous units.	how to measure it would later be applied in a experiment involving the application of Newton's Second Law.
10:40 a.m.		
T: Okay . . . We do not meet tomorrow . . . We do meet on Friday . . . and to keep you busy . . . they are questions involving Newton's Second Law . . . very similar to the ones there (solved on board).	Mr. Ellis refers here to the set of assigned problems (21 and 22) he earlier wrote on the right-hand side of the board (see Appendix C and Appendix L). For 10 minutes, until the bell rang, students worked quietly on the set of assigned problems.	This statement marks the beginning of a new activity.

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
October 24, 1986 (Friday)		
10:00 a.m.		
	At the outset of the lesson, Mr. Ellis distributed a handout entitled "Physics Assignment Sheet - Ch. 3" (see Appendix C). The teacher's desk was prepared with a demonstration set up: a plain wooden surface resting on two green buckets. At both sides of the board, the following set of equations could be seen: $F_{net} = ma$ $V^2 = Vo^2 + 2\ ad$ $Vf = Vo + at.$	The equation F = ma had been recently added.
	In the first two or three minutes after students had arrived, Mr. Ellis talked about his last night's meeting with parents and joked about putting students on the "spears."	
10:02 a.m.		
T: Okay . . . Newton's Second Law (pointing to the first equation on the board) just rewriting it . . . now in terms of acceleration . . . standing below . . . equal to . . . the net force . . . divided by mass . . . (5 sec) now a couple of examples . . . applying Newton's Second Law . . . Are there any gymnasts here?	Mr. Ellis writes down: $a = F_{net}/m.$	Newton's Second Law is restated and rewritten in terms of acceleration as: $a = F_{net}/ m$

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
	For three consecutive minutes, Mr. Ellis referred to two newspaper articles about how Russian athletes are treated with hormones to retard their development and keep their weight down to make them go faster and about the problems faced by old Russian "migs" built of heavy metal.	During this 3 minute discussion, Mr. Ellis elaborates on the relation $a = F_{net}/m$ by explicitly forming on the variation of the mass of the object and its affect on the acceleration. No comments are made with respect to the relation between acceleration and force, though.
10:05 a.m.		
T: If you will turn to Handout 32 . . . (20 sec) . . . Okay . . . I'm going to ask for Mellisa's assistance . . . You read about . . . on radio programs this morning . . . Now you see it . . . Melissa hold this cart . . . My son has papers . . . and many mornings . . . the papers are covered by rubber bands like these . . . I'm assuming . . . they are all identical . . . I've just hooked three of them together here (on the board frame). (10 sec) . . . Now, once you release it . . . and the rubber band starts subtracting in real life . . . the forces have to be constant . . . right? . . . and the rubber band is shorter and shorter . . . up to the last we are just looking at . . . Of course we know what's going to happen . . . going to accelerate . . . Let it go (to Melissa) . . . (4 sec)	Students looked for Handout 32 (see Appendix L) and began to skim through it while waiting for Mr. Ellis to start. Mr. Ellis finds a cart and places it on the plain wooden surface. Mr. Ellis attaches a rubber band to the cart and extends to Melissa to hold it at the other end. The rest of the class watches attentively to what's going on at Mr. Ellis' desk.	On what follows, Mr. Ellis elaborates on the idea that acceleration is proportional to force. This statement is not explicitly verbalized until the demonstration with carts, rubber bands is over.
T: Once more . . . (10 sec) . . . This time it's going to be better . . . Okay . . . Let it go . . . (3 sec)	Melissa lets the cart go and it is caught in the air at the other end by Mr. Ellis Melissa holds the cart again. Mr. Ellis catches the cart at the other end again.	

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
T: Now . . . Newton's Second Law . . . gives a relation between three variables. . . To examine two of them we have to keep the third one constant . . . Now what we are going to keep constant . . . The mass of the cart . . . keep the mass of the cart constant . . . (2 sec) I want to double the force . . . You tell me how I am going to double the force . . . Okay . . . (5 sec)	Mr. Ellis waits for an answer. Students keep silent.	Mr. Ellis interrupts the demonstration to examine what he is doing in terms of Newton's Second Law. Here Mr. Ellis already assumes students are aware of the mathematical formulation of Newton's Second Law.
T: The force here (first example) is one (rubber band) . . . Instead of pulling with one going to pull with two . . . Would not that double the force? (5 sec) I thought it was obvious . . . instead of one rubber band pulling . . . have two of them . . . I won't stretch them (to Melissa) . . . It's not that I don't trust you . . . If the force doubles, what would you like to have happen to the acceleration . . . to make life easier . . . if the net force doubles . . . it would be twice the acceleration.	Mr. Ellis hooks a second rubber band to the end of the cart and hands it over to Melissa.	Mr. Ellis moves back to the demonstration. This time he doubles the force and has students observe what happens to the acceleration of the cart.
St: Double.		
T: That's the way this baby begins (laugh) . . . ready (to Melissa) . . . Now your eyeball here can't tell if this is double . . . but you can see something is happened . . . Okay . . . (to Melissa).	Melissa keeps holding the cart at the other end.	
Melissa: I'm ready.		
T: Let it go. (6 sec) . . . Okay . . . It's getting better . . . one more.	Students laughed as Mr. Ellis caught the cart on the other end.	T repeats the demonstration when the force is doubled.
St: Oh . . . Oh.		

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
T: It is becoming a missile . . . almost (5 sec) . . . Okay . . . now Melissa is worried about me . . . where am I going to go (laugh)?	Mr. Ellis hooks a third rubber band and gives the cart to Melissa to hold.	Here the force is equivalent to three rubber bands and the cart is expected to move faster this time (three times faster).
Melissa: I don't know.		
T: Well, I'll stand about this side . . . now.		
Melissa: Oh . . . my . . .		
T: Now . . . three times the force . . . what the acceleration is going to be.		
St: Three times (laugh)		
T: Three times . . . let it go . . . let it rip . . . let it rip.	Melissa sets the cart free and a second later Mr. Ellis catches it at the other end.	
St: Oh . . . what a guy . . . what a rider. . .	Mr. Ellis puts the cart away and finds his "package."	
T: If you would look at the chart here (Handout 32) and those of you that have read section seven (in textbook) . . . on Newton's Second Law . . . recognize where that chart comes from . . . I got the idea from the textbook . . . I've just expanded it a little bit . . . hopefully a little better (3 sec) . . . Now if you go back and think . . . today what we are going to will be harder for some of you . . . If you don't think it is hard . . . great . . . fine. (5 sec)		Activity shifts from demonstration to problem solving. Here Mr. Ellis assumes students have already read section 3.7 in the text (see Appendix C).

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
T: If you keep the mass constant then we have a direct proportion . . . between acceleration and the net force . . . If the mass is constant . . . that is why we tried to use the same cart . . . constant mass . . . so if the force doubles the acceleration doubles . . . force triples . . . the acceleration triples . . . (3 sec)	Mr. Ellis moves to blackboard and points to the equation: ($a = F/m$). He then writes down: $a \propto F_{net}$	Mr. Ellis restates that the mass (of the cart) has been kept constant and finally concludes with the logical relation between acceleration and mass. This relation is the conclusion derived from the demonstration above.
T: Another way of writing that . . . would be that . . . the ratio of the acceleration is the same as the ratio of the forces . . . where this (F1) . . . is the first force . . . this is the first acceleration . . . second acceleration ma_2 . . . So if the ratio of forces is twice as great . . . the ratio of acceleration is twice as big . . . direct proportion. (5 sec)	Mr. Ellis writes down: $\frac{a_2}{a_1} = \frac{F_2}{F_1}$ Mr. Ellis finds his package again.	The expression $a \propto F_{net}$ is expanded and written in a "ratio" format which would eventually be applied in the solution of a numerical problem stated in the "package."
10:15 a.m.		
T: Now you look at the table (in Handout 32) . . . we start with four (m/sec^2) . . . what we are saying for this nebulous force "F" . . . the resilient acceleration is 4 meters per second per second . . . (3 sec) . . . Okay . . . We go to the second entry. (5 min)	For the next five minutes Mr. Ellis engages in a turn-taking session with the class in which he calls on individual students to tell about the values of "F" and "a" that correspond to each entry in the table given in Handout 32, Problem 1.	On this part of the discourse, Mr. Ellis expands the general conclusion between force and acceleration by applying it to a specific numerical problem.
10:21 a.m.		
T: Okay . . . Melissa . . . (10 sec)	Melissa gets up and goes in back of Mr. Ellis's demonstration desk. While Melissa waits, Mr. Ellis	The previous discussion on force and acceleration closes and a new demonstration begins. This time the discussion revolves around the idea

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
	finds some bricks (1 1/2kg) and puts them on the desk.	that "acceleration is inversely proportional to mass if the force is kept constant." (This hasn't been explicitly stated yet.)
T: We are going to do this out in the hall . . . next year with students . . . with surgical tubings (laugh) . . . just so that you can see this again . . . let it go (to Melissa) . . . (5 sec)	Mr. Ellis hands the car to Melissa to hold while he stretches the rubber band and prepares himself to catch the cart at the other end.	
T: Now . . . there is a direct proportion . . . between force and acceleration . . . I'm going to keep the force constant . . . I'm going to pull with one rubber band and vary the mass . . . real bricks (holding a brick) . . . Put it on the cart . . . Now roughly that brick has the same mass as the cart . . . so what we've done is doubled the inertia . . . doubled the mass . . . "Hold it there" (to Melissa).	Mr. Ellis puts the first brick on top of the cart and indicates that he has doubled the mass.	Mr. Ellis restates the logical relation between force and acceleration and proceeds to demonstrate what happens when the mass (of the cart) varies and the force (a rubber band) is kept constant. On this segment he anaphorically refers to "mass as a measure of inertia," a topic already discussed in class.
Melissa: Yeah . . .		
T: I'll pull with the same force . . . okay . . . Double the mass. . . If you want to get a consulting fee . . . your advice was solicited ((....)) If you double the mass what would you like to have happen? (2 sec) . . . Again I know you cannot catch this (movement) by eyeball . . . but let it go (to Melissa) (3 sec)	Melissa lets the cart free and seconds later Mr. Ellis catches it at the other end of the table.	

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
T: You can tell . . . acceleration once it started was just half of it . . . and we are going to take one more . . .	Mr. Ellis' demonstration went on for five minutes assisted by Melissa. After the first brick, he added two bricks and then three bricks observing that the acceleration was smaller each time.	
10:23 a.m.		
T: Because you always work . . . with direct proportion . . . reciprocal relationships can give you a little bit more problem . . . Now if the force is constant . . . the relationship between acceleration and mass is a reciprocal one . . . as one (mass) gets bigger . . . the other (acceleration) gets smaller . . . we can say then . . . not they go like this . . . (5 sec) . . . I can't have them like the first one (F1/F2 = a1/a2) . . . because this is a direct proportion . . . so the subscripts have to be switched . . . reciprocal relationships . . . (5 sec)	Mr. Ellis puts cart and bricks away and moves back to the board and writes down: $a \propto 1/m$ $\frac{a_1}{a_2} = \frac{m_2}{m_1}$	The logical relation between acceleration (a) and mass (m) is finally established by drawing from the demonstration. In doing so, Mr. Ellis compared the logical relationships between acceleration and force and acceleration and mass. The expression: $a \propto 1/m$ is also written in a ratio format, similar to the expression: $a \propto f$.
10:24 a.m.		
T: Okay. . . In this class . . . we went over question 4 already . . . did we not? . . . So go on to question 5 . . . Again, this has been taken from the chapter in the textbook . . . I've just tried to add some more interesting questions (5 sec) . . . Now the force is kept constant and we vary the mass . . . We start with a mass (m) . . . The resultant acceleration is 30 meters per second per second . . . Now in the first entry . . . we see the mass doubled to 2m . . .	Mr. Ellis moves to his desk and looks for his "package" again. Mr. Ellis skims through his package (Handout 32) and refers to Problem 5.	Activity shift begins. This time, Mr. Ellis expands the general relation between acceleration and mass and applies it to solve a numerical problem drawn from the textbook.

Table 5.6, Cont'd.

Verbalization	Action	Interpretation
the mass gets two times bigger . . . the acceleration gets two times smaller . . . one-half of 30 is 15 . . . then the next entry is missing in my book . . . Tim . . . if the mass triples . . . to 3m . . . the acceleration is . . .?		
Tim: 10 (6 min)	From here until 10:30 Mr. Ellis poses a series of five questions to individual students dealing with the relationship between acceleration and force when the mass varies. He then takes questions.	
10:30 a.m.		
T: Block one . . . I believe . . . we did it last Friday . . . block two last time . . . we met on Wednesday . . . block three . . . the hallway experiment . . . we'll probably get it next Thursday . . . if at all possible, I'll like to have the experiment on the double hour . . . I won't take the double hour . . . but it makes the double hour more powerful . . . block . . . second law . . . another day on second law (today) . . . and these four questions (on the sheet) 10, 11, 14 and 27 . . . They are not complete . . . but you have to think your way through ((....) 27 . . . it is just a curious problem . . . and you need to apply kinematic laws again.	As soon as Mr. Ellis stops talking about question 5, he looks for a copy of the pink sheet he distributed yesterday (see Appendix C). From here on and until the end of the hour (10:50) students work (silently) on the set of assigned problems.	Mr. Ellis begins to summarize activities already accomplished and refers to future activities (global coherence). These statements also act as a shift into a new topic and/or activity (e.g., problem solving).

NOTE: Next topic was mass and weight.

Discussion of Mr. Ellis' Micro-Sequence on Newton's Second Law

The focus of this section of the study will be on the nature of the "enacted task environment (Erickson, 1982) and the nature of the coherence across the information content being delivered by Mr. Ellis. At this point of the discussion, it is pertinent to remind the reader that Mr. Ellis used the same textbook (Project Physics) as Mr. Simon.

The enacted task environment through which the subject matter was delivered, in Mr. Ellis' case, consisted of "the package" of written materials, and a set of laboratory equipment made up of carts, rubber bands, bricks and a piece of plywood. Each one of these materials played an important role in the teacher's subject matter organization as it relates to Newton's Second Law. For example, Handout 32 (in the "package") (see Appendix J) was referred to on three occasions. These instances usually marked a change of activity which generally consisted of having students work on a particular problem or set of problems related to either Newton's First or Second Law.

The lab equipment, however, served a different function. It was used to qualitatively demonstrate that acceleration is proportional to net force and that acceleration is inversely proportional to mass. The second part of the segment on Newton's Second Law (October 24, 1986) contained information that describes how the lab equipment was organized to enact the two statements mentioned. With respect to the first statement, Mr. Ellis had students observe how the acceleration increased as he increased the force (number of rubber bands) being applied to the cart moving along a horizontal surface of wood. The force varied from one to three units. Similarly, the second statement was elaborated by having the students observe how the acceleration of the cart decreased every time the number of bricks was increased.

Through the interaction with the immediate environment and the students, the teacher was able to communicate a series of logical relationships between force, mass and acceleration. These relationships were not enacted in a linear fashion but were intertwined with other instructional events that were not necessarily related to Newton's Second Law. In Mr. Ellis' case, the following statements could well determine the underlying subject matter structure imbedded in his teaching of Newton's Second Law.

> It takes an unbalanced force to cause things to move . . . and that is Newton's Second Law . . ." (written $F_{net} = ma$).
>
> Newton's Second Law . . . in terms of acceleration . . . standing below . . . is equal to the net force divided by mass . . ." (written $a = F_{net}/m$).
>
> If you keep the mass constant then we have a direct proportion . . . between acceleration and the net force . . . (written $a \propto F_{net}$).
>
> Now if the force is constant . . . the relationship between acceleration and mass is a reciprocal one . . .

as one (mass) gets bigger . . . the other (acceleration) gets "smaller" (written $a \propto 1/m$).

The above statements yield evidence as to how Mr. Ellis structured the relations between acceleration, mass and force. Although these statements were taught in that order, a careful look at the discourse segment shows the existence of several "breaks" (Brown & Yule, 1983) in which subsequent "pieces" of subject matter were linked to Newton's Second Law (see Figure 5.8). For example, he introduced Newton's Second Law equation as $F_{net} = ma$, where the force is measured in pounds and Newtons. He then engaged in a problem solving activity in which Newton's First and Second Laws were applied. Several related concepts were dealt with on that occasion, such as: net force (or unbalanced force), acceleration and force of friction. The force of friction was a subtopic that was manifested through a couple of demonstrations using a cart and a scale.

	Break		Break	
$F_{net} = ma$	Problem solving (friction)	$a = F_{net}/m$	Demonstration leading to $a \propto F$	$a \propto F_{net}$

Break	Break		Break
Example on $a \propto F$	Demonstration leading to $a \propto 1/m$	$a \propto 1/m$	Example on $a \propto 1/m$

Figure 5.8. Temporal representation of Mr. Ellis' micro-sequence on Newton's Second Law.

The last three statements given above were elaborated in a sort of linear fashion. Their elaboration depended heavily on the already established Newton's Second Law. So, the three events that surrounded these statements were logically connected to the first event. The whole sequence could be categorized as a logically loose connected sequence in which one event does not necessarily have another as a consequence (Grimes, 1975). In this sense, the problem-solving activity, that had taken place the day before the last two statements above were delivered, were not logically connected. What this means is that Mr. Ellis could have elaborated on these two important statements without having students engage in the problem-solving activity dealing with Newton's Second Law. From an educational point of view it would be better to "unravel" the logical relations that derive from Newton's Second Law before engaging in instructional events that require the application of such a law.

Mr. Howard's Discourse on Newton's Second Law

Mr. Howard's discourse on Newton's Second Law (see Table 5.7) lasted about 13 minutes. It took place during a class period in which Mr. Howard announced the need to reach the conclusions of the experiment: "The effect of force and mass on acceleration." Students had been working on the experiment for four class periods. The two major purposes of the experiment were "to find out how forces affect the acceleration value" and "how masses affect the acceleration" (Videotape, February 6, 1987). Assisted by Mr. Howard, students were expected to derive two different graphs, one for each purpose: One was a representation of the "acceleration versus force" when a brick was pulled by stretched rubber bands, and the other was a representation of the "inverse of the acceleration versus the mass (inertial)" of a set of bricks being pulled by a stretched rubber band.

During the discussion of the experiment's conclusions, Mr. Howard borrowed a student's set of graphs and sketched them on the blackboard. He first derived the logical relationship between acceleration and force ($F \propto a$), and secondly, the relationship between acceleration and mass ($1/a \propto M_i$). From here, Mr. Howard moved on to establish that "force is equal to mass times acceleration" ($F = M_i a$). Throughout the entire discourse, most students took Mr. Howard's suggestion and copied the notes he had written on the blackboard.

Table 5.7

Mr. Howard's Discourse on Newton's Second Law

Source: Videotape, Feb. 10, 1987

Time: 9:10-10:00 a.m.

Background Information: Students had been working on an experiment on the "effect of force and mass on acceleration." No conclusions had been reached yet and Mr. Howard was about to establish them. The day before he had briefed students about the possible conclusion. He also answered students questions on the graph they were preparing and suggested students "clean up the loose ends" so that tomorrow (today) they will be able to reach the conclusions.

Verbalization	Action	Interpretation
9:10 a.m.		
T: Before we go to the graphs . . . take a look at page 229 please . . . and 231 and 229 . . . Figure 11.9. Here we see the old flash photograph ((.......)) . . . the top page. The strobe was actually separated by 10/24 of a second . . . A constant force is applied by keeping the loop steady. ((.......)) That's all what's pulling . . . a constant force is applied . . . We look at the photograph . . . now what would you say definitely about that photograph? What's the body doing?	Mr. Howard finds his textbook after attending a few individual questions. Just before the class came in, he wrote on the board "conclusions on Experiment 21" Students also find textbook and look at Figure 11.9 which shows a constant force applied to a body (see Appendix J).	Mr. Howard links the experiments done during the last five days with the textbook information (global coherence).
St: (whispering) Accelerating.		
T: Yeah, definitely accelerating . . . notice the relative closeness of each of the views . . . footpage . . .		
St: Is this going in circles?		
T: No, this is in a straight line . . . it is accelerating but notice the difference in Figure 11.11 . . . here we have two forces applied. Again . . . what do we notice when a force is applied to a body . . . What happens to the velocity?		
St: Acceleration (whispering)		

Table 5.7, Cont'd.

Verbalization	Action	Interpretation
T: It is accelerating . . . notice the number of views now. They decrease . . . in the same length of a meter stick . . . What does it tell you about the way this body is accelerating as compared with the previous picture?	T keeps skimming over his book.	Mr. Howard begins to elaborate on the idea that acceleration is related to force: "bigger value of force . . . the larger the acceleration."
St: Bigger.		
T: Definitely bigger value . . . (3 sec) It's going faster and faster (12 sec) the faster you gain speed the larger the acceleration . . . (5 sec). Okay, knowing that . . . what do we get for graphs? Does anybody get a full set of graphs? (10 sec)	Mr. Howard put the textbook aside and searches around for a graph students were working on yesterday (acceleration versus mass). Seconds later he goes back to the board.	At this point in time Mr. Howard shifts to a different physical material (graphs) to continue elaborating on the relation between force and acceleration.
T: Okay . . . here we go. Now yesterday we tried to generalize.		He begins to elaborate on the idea that "acceleration is proportional to mass."
St: ((......))		
T: This one (graph) he's got no friction . . . He's got a non-friction practically graph. (5 sec) Those of you who do not have it . . . don't have this graph finished might want to take some notes. I'm going to try to read this graph as I'm sketching the lines in here . . . one force . . . I'm reading about . . . two two (.22.) . . . may be two five (.25) . . . Now when I double it . . . what should I expect to happen?	At the board Mr. Howard inspected the graph (see Appendix E) Mr. Howard begins to sketch the diagram below:	Anaphorically drawing from the discussion on friction that took place last Friday and Monday, reference is made to lab data previously gathered. Students are already familiar with these types of graphs since Mr. Howard has been referring to them during the last six days.
St: Double		
T: Very close . . . let's see . . . It's actually about four eight (.48) close to five . . . Okay. What can we expect at three . . . then?		
St: .75.		

Table 5.7, Cont'd.

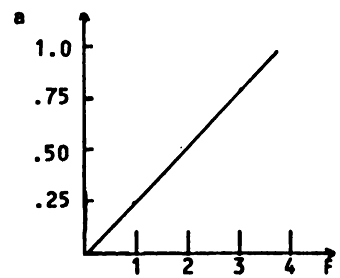
Verbalization	Action	Interpretation
T: .75 . . . down here . . . guess what? St: There is no friction. T: "If there is no friction . . . No, we have to get rid of friction. St: ((........)) T: Do what? . . . no . . . you guys spent a lot of time in math class doing translocation in graphs. Now you know why you are doing it . . . How do you eliminate friction? . . . You pick up the graph and move it over here (right). As it turns out he did not have friction there . . . But in general knowledge what can we have here for a conclusion? St: That friction . . . T: Oh . . . Oh . . . Let's get friction out of the way.	At this point in time the board (left) shows:  	A similar graph was sketched yesterday (with friction). In this graph, "1 force," "2 forces" and "3 forces" mean the force being applied by one, two or three rubber bands. Also, acceleration is measured in $cm/tock^2$. Mr. Howard's makes reference (anaphorically) to the discussion on friction that took place two days earlier.
St: Acceleration is directly proportional . . . (10 sec) T: Right (10 sec) the statement is that . . . if mass is constant . . .	Mr. Howard begins to write down the following: acceleration is directly proportional to the applied force if the mass is constant ($M_i = k$).	A generalization is made (first conclusion) to indicate the logical relationship between acceleration and force.
T: Right . . . the same thing you said . . . if mass is a constant . . . Okay . . . That's a fact of our life . . . you say that "F" is proportional to "a" meaning in fact that it if you double the force what happens to the acceleration . . . Theresa? Theresa: ((.......))	Mr. Howard writes down: $F \propto a$	He refers to the inertial (m_i) mass, a term that has been cataphorically introduced and that will be discussed as a new topic beginning next Friday. (By mass, he means the "mass of a brick.")

Table 5.7, Cont'd.

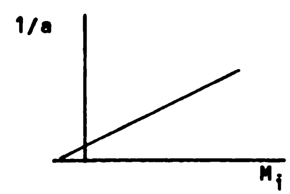
Verbalization	Action	Interpretation
T: The force is? (to Theresa) . . . What happens if I double the force? . . . What happens to the acceleration?		
Theresa: Double . . .		
T: Bingo . . If I double the force I double the acceleration . . . so we can go two times this (F) two times this (a) three times this (F) . . . three times this (a) . . . that's exactly what we need and that's why we have to try to eliminate friction . . . Okay . . . That's what Galileo said in the coast . . . I know the velocity may decrease . . . but I can imagine it not decreasing . . . why did it decrease? Because that little back force . . . is acting . . . check!	Mr. Howard points to the graph he has just sketched and writes down: 2F 2a	Anaphoric reference to last Friday's discussion on Galileo's coasting.
9:16 a.m.		
T: Now . . . this one is more sticky (10 sec) right there . . . one . . . two . . . three (M_i). It (a straight line) cut through right there that point of intersect . . . with the X-axis called the inertial mass . . . Oh . . . got to take a look at that one (graph) the same way . . . What can we do to the graph to make it read to see how that (1/a) and this (M_i) are related . . . notice the straight line . . . so that (1/a) and that (M_i) are related how?	Mr. Howard moves to the righthand side of board and sketches the following graph on the board. 	The statement: "This one is more sticky" marks the beginning of the discussion on how acceleration and mass are related. Notice that he shifts to the information contained in this second graph he borrowed. Students worked on the construction of the graph in the last two days.
St: Directly . . .	Mr. Howard again inspects the graph he borrowed minutes ago. (See Appendix F)	
T: Directly . . . it is an exact direct proportion . . . Let's see what happens (10 sec) same thing again.		

Table 5.7, Cont'd.

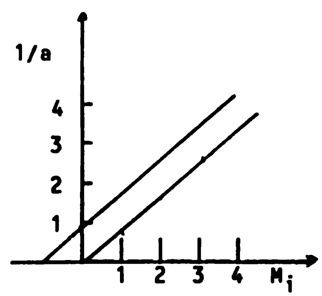
Verbalization	Action	Interpretation
At one (M_i) oh . . . oh . . . ((.......)) bear with me got the wrong line . . . got to draw another line (8 sec) . . . bear with us . . . ((.......))	He sketches a second straight line (through the origin) and stops to inspect the student's graph.	Mr. Howard inspects the graph as he prepares to continue elaborating on the relation between 1/a and M_i.
St: What is this graph?		
T: One over a.		
T: To see what this (1/a) does to that M_i . . . to see . . . if it's really direct got to eliminate this odd effect of not passing through the origin . . . (5 sec) 25 . . . 50 . . . and 75 . . . double this (mass) get a double there (1/a) . . . here we go again . . . one is very close to 70 (.70) . . . point seven. At two . . . ho . . . ho . . . very close to 1.5 . . . probably. This (.70) is very close to .75 . . . At three . . . oh . . . oh right on . . . about two two (.22) (5 sec) What does that tell you? What do we get again?	At this point the board shows the following graph:	The second straight line he had drawn through it passed through the origin it was not parallel to the first one as expected when doing a "trans-location" of straight lines.
St: Direct.		
T: When we double the mass, what do we have here (1/a). What was in here giving us this trouble all the time? What mass? . . . the cart. I got rid of that mass and ended up . . . say here . . . one brick I get .75 . . . two bricks I get 1.50 . . . three bricks 2.5 . . . how did we do it? . . . ((.......)) so we can say here . . . now the actual equation . . . The acceleration here (graph) how is it related to the mass?		In the teacher's reconstruction of this graph he refers to "M_i" and the mass in "bricks" used during the experiment. The information contained in the graph is now used to establish the logical relation between mass and acceleration.
St: Inversely		
T: What is that function called right there? . . . 1/a (10 sec) . . . if what is kept constant in that graph.	Mr. Howard begins (silently) to write on the board the following statement:	This is the second big conclusion or generalization to indicate the logical relationship between mass and acceleration.

Table 5.7, Cont'd.

Verbalization	Action	Interpretation
St: Force	the "a" is inversely proportional to the inertial mass if F is K.	Mr. Howard anaphorically refers to the equations $F \propto a$ and $1/a \propto M_i$ and proceed to relate them.
T: Yes, if the force is constant . . . yeah . . . How do we state that (5 sec) . . . I can also write that another way . . . ($1/a \propto M_i$) (5 sec). We have to combine these two ideas . . . right there. How are these two quantities directly related? . . . Their quotient is a what? (5 sec)	Mr. Howard goes on to write: $1/a \propto M_i$	
St: ((.......))	The teacher points at the two equations he has just devised.	
T: That one rubber band really represents what?		
St: Force		
T: Right? . . . so . . . in effect I combine the whole thing that way (sketching arrows) . . . right? (5 sec) . . . It says exactly the same thing . . . quantities which are direct . . . What do we say here . . . ((........)) their quotient that's the key . . . their quotient is a what? (5 sec)	Teacher writes: $F/a \propto M_i$	Mr. Howard collapses the previous logical relationships between acceleration and force and acceleration and mass, into a single on in the form of: $F/a \propto M_i$.
St: Constant.		
T: In this case it is mass . . . two things to remember . . . if quantities are indirect their product is a what?		
St: The product?	Momentarily the board shows:	
T: It is a K (constant) . . . If their quotients are indirect . . . their product is a constant . . . If they are direct . . . their quotient or division is a constant . . . (3 sec).	(see diagram below)	

$$\begin{tikzcd} F \propto a \arrow[dr] & & 1/a \propto M_i \arrow[dl] \\ & F/a \propto M_i & \end{tikzcd}$$

Table 5.7, Cont'd.

Verbalization	Action	Interpretation
9:20 a.m.		
T: Let's take a look at this ($F/a \propto M_i$) (equation) . . . I can rewrite this in a form something like that ($F = M_i a$) . . . If we take a serious look at that I can make life easier by defining . . . If I define force as the product of mass and acceleration . . . I resolve the only problem . . . I can search around like crazy and find a proportionality constant here that will make force equal to mass times acceleration . . . or I can define force . . . In this experiment we define force . . . as the product of the acceleration and mass "m" "a".	Mr. Howard writes down: $F = ma$	Mr. Howard resorts to the definition of force as "mass times acceleration" in view of the "only problem" he has, that is to find the constant of proportionality between force and mass times acceleration. A general statement ($F = ma$) is derived without explicitly linking it to previous information.
9:22 a.m.		
T: Let's see what it looks like unit wise . . . well you know that . . . Any problems with that?	Up to this moment the board shows: $\begin{array}{ccc} F \propto a & & 1/a \propto M_i \\ & \searrow \quad \swarrow & \\ & F/a \propto M_i & \\ & \downarrow & \\ & F \propto M_i a & \\ & \downarrow & \\ & F = M_i a & \end{array}$	Change of topic (topic shift) begins at this time. Here Newton's Law is applied to formally derived units of force (Newton and dynes).
St: ((........))		
T: We did not have to define it that way . . . As a matter of fact . . . the name of a given force honors . . . one of the best men called Newton . . . Mass is in what kind of units . . . that you commonly think of . . . no bricks (laugh) . . . grams and . . .		Mr. Howard refers to the use of inertial mass in bricks.
St: Kilogram		
T: Kilogram . . . Okay . . . Let's take a couple of those . . . If we take the mass of a kilogram . . . we call this gravitational mass . . . similar to something in chemistry. (5 sec)		
St: Atomic weight.		

Table 5.7, Cont'd.

Verbalization	Action	Interpretation
T: Bingo . . . that's the gravitational mass . . . (5 sec) acceleration is given in meters per what?		
T: Second squared . . . The multiplication of these two is called a Newton . . . Now we use a smaller unit than this . . . I hope I get the name right on this one . . . Don't forget to check me out . . . I can't put grams and meters together . . . What do we put . . . What is the ((........)) . . . ?		
St: Centimeters.		
T: Centimeters (5 sec) . . . centimeter per second per second . . . I think we call that what . . . somebody check this one out.		
St: Dyne.		
T: A dyne . . . Is that right? Have you heard of it? . . . Dave . . . Well, in electricity we need a dyne . . . dynonometer. . .		
St: Dynamo.		
T: Dynamo . . . I think we are right on. (5 sec) . . . This dyne is not a commonly used unit . . . at least for this class . . . we will stick to the Newton . . . That means if you get grams, you have to change it into kilograms, right? That's our defined term . . . Why is it important . . . because this ($a \propto 1/M_i$) does come out to be an exact inverse quantity . . . This ($F \propto M_i a$) does come out to be an exact direct quantity or very close to it . . . so from these two ideas ($F \propto a$, $a \propto 1/M_i$) we put together . . . we get that one ($F = M_i a$) . . . same idea as in ((........)).	The board shows: Newton = kg m/sec^2 dynes = gram cm/sec^2	Having established the units of force, Mr. Howard briefly evaluates the synthesis of Newton's Law he has just concluded. Here he reinforces the idea that if units are properly chosen than force can be appropriately defined as mass times acceleration?

Table 5.7, Cont'd.

Verbalization	Action	Interpretation
9:23 a.m.		
T: What I'd like you to play around with today is with this idea about acceleration and force . . . Don't forget Newton . . . these are the ones (problems) . . . I think you can handle . . . page 239 (5 sec) people if we do this kind of work all year long . . . have to watch the units.	Mr. Howard finds his textbook and assigns problems HDL's 3, 6, 8, 9, 10, 11, page 239-240.	Activity shift begins in which students are expected to apply Newton's Law to solve a set of numerical problems or HDL's.

Discussion of Mr. Howard's Micro-Sequence on Newton's Second Law

The focus of this section of the study is the nature of the local coherence in the subject matter delivered by Mr. Howard, as he taught Newton's Second Law, as well as the nature of the "physical stuff" or "materials" (Erickson, 1982) through which the subject matter was delivered to students. The segment on Newton's Second Law yields evidence to the effect that Mr. Howard first established logical connection between acceleration and mass and acceleration and force before deriving Newton's Second Law. In this sense Newton's Second Law (F = ma) was "chained" (Brown & Yule, 1983) or linked to previously derived relations between acceleration, mass and force.

The enacted task environment through which Newton's Second Law was delivered will be considered first. As shown in the discourse segment above, Mr. Howard relied on the textbook (PSSC) particularly pages 228 and 231. He also relied on a set of graphs he borrowed from one of the students. These graphs contained a substantial amount of information that was eventually used by Mr. Howard to draw the major conclusions with respect to Newton's Second Laws. It is important to point out that these graphs were the result of two consecutive lab experiments in which students were expected to find out about the relationships between force and mass and acceleration and mass, in that order.

This instructional event lasted five consecutive class periods.

A second important point to consider is the nature of the local coherence or structure of the subject matter organization imbedded in the teaching of Newton's Second Law. Several statements, either written on the board or verbalized by Mr. Howard give a sense of the nature of the coherence between acceleration, force and mass as follows:

> Acceleration is directly proportional to the applied force if the mass is constant ($M_i = k$) (constant)" (written $1/a \propto M_i$).
>
> The "a" (acceleration) is inversely proportional to the inertial mass if "F" (force) is "K" (constant) (written $1/a \propto M_i$).
>
> If we take a serious look at that ($F/a \propto M_i$) I can make life easier . . . if I define force as the product of mass and acceleration . . . I resolve the only problem . . . I can search for a constant of proportionality . . . that will make force equal to mass times acceleration . . ." (written $F = m_i a$).

The three statements above were delivered by Mr. Howard without having to resort to breaks in the discourse. The first statement was a conclusion he had drawn from the graph on force versus inertial mass, which he had borrowed and sketched on the board. The second statement was the conclusion he arrived at, after discussing the graph "inverse of acceleration versus inertial mass." The third statement was a direct derivation from the first two statements.

In a sense, Mr. Howard's micro-sequence on Newton's Second Law could be categorized as a "logically tight" sequence (in Grimes' terms), meaning that the events dealing with the construction of the equation $F = M_i a$ were logically linked to the previous events dealing with $F \propto a$, and $a \propto 1/m_i$ which led Mr. Howard to conclude that "force is equal to mass times acceleration." In Mr. Howard's segment on Newton's Second Law (see Figure 5.9), it could be observed, that compared with the other two teachers, there were no "breaks" (Jefferson, 1972) that engaged the students in an application of the logical relationships being established. Table 5.7 shows that "problems" or "HDL" were assigned once the conclusions on Newton's Second Law had been reached.

$F \propto a$	$1/a \propto M_i$	$F/a \propto M_i a$	$F \propto M_i a$	$F = M_i a$

Figure 5.9. Temporal representation of Mr. Howard's micro-sequence on Newton's Second Law.

A Comparative Analysis on Newton's Second Law as Taught by Teachers

This section of the study offers a comparative analysis on the way the three participant teachers organized the subject matter, as they delivered the topic of Newton's Second Law. It also compares the nature of the immediate task environment through which the subject matter was manifested. With respect to the first issue, a description of how Newton's Second Law was presented, in the context of the unit on dynamics, is given. Emphasis is made on how the topic was connected to others within the unit and how the topic of Newton's Law was "closed" (Brown & Yule, 1983). Related also to the first issue, this section also provides a comparative analysis of how the information content on Newton's Second Law was structured through time. Finally, this section discusses the nature of the enacted environment through which each individual teacher delivered the topic.

Connecting Newton's Second Law to Previous Topics

In order to guide the discussion that follows, "previous topics" will refer here to the main concepts that preceded the teaching of Newton's Second Law. These concepts include acceleration, velocity, vectors, inertia and unbalanced net force. The concepts of acceleration and velocity as well as the operations that they imply are considered to be background information already taught by the three participant teachers in the unit on kinematics.

A look at the discourse segments shows that both Mr. Ellis and Mr. Simon introduced Newton's Second Law immediately after Newton's First Law of inertia. Both teachers drew from the concept of "unbalanced force" that produces an acceleration.

Both teachers also indicated the vectorial nature of Newton's Second Law. After introducing Newton's Second Law

(F = ma), Mr. Ellis discussed the "units" of force. On the other hand, Mr. Simon preferred to elaborate on two main statements: "acceleration is proportional to the net force," and "acceleration is proportional to the inverse of the mass." This was followed by a discussion of the conditions under which Newton's laws hold as well as the results and some examples of that law. This discussion would be considered to be a "break" that was terminated once the numerical equation of Newton's Second Law was formally introduced (a = F/m). At this point, it is important to point out the difference in the way both teachers formulated Newton's Second Law.

Mr. Ellis shifted gears to do a problem solving activity that involved the application of Newton's First and Second Laws. During this activity, the concept of friction (force) was fully explained. The following class period he picked up on Newton's Second Law again and relied on classroom demonstrations to show that "acceleration is proportional to the net force" and that "acceleration is inversely proportional to the mass." The following day, he moved on to a discussion of mass and weight.

The third teacher, Mr. Howard, did not explicitly introduce Newton's Second Law as such. (In an interview with him, he referred to the expression F = ma as "Newton's Law.") Before deriving the relation F = ma, Mr. Howard summarized, in two major statements, the information gathered from the laboratory work the class had been engaged in during the previous six consecutive days. These statements were as follows:

1. Acceleration is directly proportional to the applied force if the mass is constant ($F \propto a$).
2. Acceleration is inversely proportional to the inertial mass if F (force) is constant.

The two previous statements were "collapsed" into a single mathematical relation in the form of $F = ma$.

Topic "Closing" or Termination

A topic is considered to be "terminated" when the speaker moves on to a subject of a different nature (Brown & Yule, 1985). In this case, it was pragmatically decided to "close" a topic as soon as a topic-shift occurred in the teacher's discourse. Precautions were taken to find evidence that the teacher was not elaborating on Newton's Second Law as an indication that such a topic had been terminated. For example, Mr. Simon "closed" his formal introduction of Newton's Second Law as follows:

> Let's go back to look at the equation form of Newton's Second Law (8 sec) . . . I think your sheet . . . there is above "test yourself" and it says "written" . . . Newton's Second Law is written this way . . . acceleration is proportional to "f" and inversely proportional to "m" ($a \propto f/m$) . . . and if I choose the units right . . . I can make that (proportion) an equal

> . . . not a proportionality. $(a = f/m)$ (see page 204)

The previous segment was then followed by a subtopic dealing with the unit of force and an operational rule on how to operate the variables "F", "a" and "m" when applying the equation $F = ma$ in the solution of numerical problems.

Mr. Ellis' closing on Newton's Second Law was rather different. Immediately after elaborating on the idea that the relationship between acceleration and mass is a reciprocal one, he summarized the block he had already covered to indicate the tasks to come (global coherence). The following excerpt clarifies this point:

> Block one . . . I believe we did it last Friday . . . block two last time we met on Wednesday . . . block three . . . the hallway experiment . . . we'll probably get it next Thursday . . . if at all possible, I'd like to have the experiment on the double hour. (see page 210)

The above event was followed by a problem solving activity that focused on the application of Newton's Second Law. The following class period Mr. Ellis dealt with the distinction between mass and weight.

The third teacher, Mr. Howard, closed the discussion on Newton's law ($F = ma$) after collapsing the two statements: "Force is proportional to acceleration," and "acceleration is inversely proportional to mass" into a single statement: "Force is the product of mass and acceleration." After he established this equation, he made a topic shift to derive the units of force by substituting the units of acceleration (M/sec^2) and mass (kg) in the already established Newton's law (F = ma). The following excerpt shows how the topic of Newton's Law was terminated: "In this experiment, we define force . . . force is the product of the acceleration and mass (F = ma) . . . Let's see what it looks like unit wise . . . well, you know that . . . any problem with that. . ." (see page 225).

The discussion on units was followed by Mr. Howard assigning a set of problems in which students would apply the equation: F = ma.

The Structure of the Information Content

The micro-analysis of the nature of the coherence on Newton's Second Law showed an important variation on the way academic information content is organized in real time. This variation emerged from a detailed analysis of the synthesis imbedded in the discourse segments on Newton's Second Law. A synthesis is a sequence strategy that shows how concepts are logically related (Van Patten et al., 1986). The analysis that follows shows how teachers synthesized the concepts of mass, acceleration and force when they taught the relation: "Force is equal to mass times acceleration."

Figure 5.10 shows how the three micro-sequence structures vary among teachers. These structures or cognitive maps represent a global view of how Newton's Second Law was logically organized by the participant teachers. They represent the underlying organization of the information content (Erickson, 1982) included in the teaching of Newton's Second Law. The maps have been developed from a detailed analysis of the logical connections between the different pieces of segments dealing with Newton's Second Law. Attention was paid to the content given in the discourse, the actions that such a discourse conveyed as well as the researcher's immediate interpretation of these actions.

A close look at Figure 5.10 indicates that both Mr. Howard and Mr. Simon's micro-sequences are strikingly similar, in spite of the fact that different textbooks were used. However, this similarity is very superficial in terms of how each sequence was constructed. While Mr. Howard, for example, spent six consecutive class periods empirically deriving Newton's Second Law, Mr. Simon spent about 15 minutes. In addition, Mr. Simon started off from the given statement of "unbalanced force which produces acceleration." Mr. Howard's notion of force was represented by rubber bands used to pull objects. A third important comparison between the two sequences lies on the idea of mass. In the case of

Mr. Simon's Micro-Sequence

$$
\begin{tikzcd}
a \propto F_{net}\ (200) \arrow[dr] & & a \propto 1/m\ (203) \arrow[dl] \\
& a \propto F/m\ (207) \arrow[d] & \\
& a = F/m\ (207) &
\end{tikzcd}
$$

Mr. Ellis' Micro-Sequence

$$
\begin{tikzcd}
& F_{net} = ma\ (215) \arrow[d] & \\
& a = F_{net}/m\ (219) \arrow[dl, no head] \arrow[dr, no head] & \\
a \propto F_{net}\ (215) \arrow[d] & & a \propto 1/m\ (225) \arrow[d] \\
\dfrac{a_1}{a_2} = \dfrac{F_1}{F_2}\ (223) & & \dfrac{a_1}{a_2} = \dfrac{m_2}{m_1}\ (225)
\end{tikzcd}
$$

Mr. Howard's Micro-Sequence

$$
\begin{tikzcd}
F \propto a\ (234) \arrow[dr] & & \dfrac{1}{a} \propto m_i\ (237) \arrow[dl] \\
& \dfrac{F}{a} \propto m_i\ (237) \arrow[d] & \\
& F \propto m_i a\ (237) \arrow[d] & \\
& F = m_i a\ (238) &
\end{tikzcd}
$$

Figure 5.10. Micro-sequence structures on Newton's Second Law compared.

Note 1: The numbers in parenthesis show the page location of that statement in the respective discourse segment.

Note 2: i stands for inertial, $\propto$ stands for proportional to, m stands for mass, F stands for force, and a stands for acceleration. F is given in Newtons and pounds, a in m/sec^2, and m in kg and slugs.

Mr. Simon, mass is a measure of inertia or resistance to move; and it is accelerated when an unbalanced force is applied to it. Instead, Mr. Howard introduced the idea of inertial mass measured in bricks (later inertial mass and gravitational mass would be compared).

Mr. Ellis' micro-sequence is also surprising, particularly when it was compared with Mr. Simon's sequence (both teachers used the same textbook: Project Physics). Both teachers introduced Newton's Second Law as a given relationship. However, Mr. Simon first elaborated on the facts that "acceleration is proportional to force" and that "acceleration is inversely proportional to mass" (gravitational). These two expressions were then combined to form a single one ($F = ma$). To the contrary, Mr. Ellis first stated Newton's Second Law and then elaborated on the same given facts ($a \propto F_{net}$ and $a \propto 1/m$). While elaborating (using a class demonstration) on these two relationships, Mr. Ellis made use of exactly the same laboratory equipment used by Mr. Howard's students to derive the graphs that would show the relationships between "acceleration and force" and between "acceleration and inertial mass." This is also an indication that the enacted environment was different among teachers.

<u>Information Content and Environment</u>

The micro-analysis of the discourse segment on Newton's Second Law indicates that teachers not only enact different sequences of logical operations when teaching a similar topic, but also that these logical operations are simultaneously manifested through distinct environments. The following vignettes will shed light on the above assertion. The vignettes describe the nature of the environment (as defined by Erickson, 1982) being simultaneously enacted as the three participants/teachers elaborated on the relations between acceleration, mass and force. As shown in Figure 5.7, the four major mathematical relationships teachers referred to when constructing Newton's Second Law are: $F = ma$, $a \propto F$, $a \propto 1/m$ and $F \propto m/a$.

The first teacher, Mr. Simon, delivered the topic of Newton's Second Law by having students follow along with a worksheet entitled "Newton's laws of motion" (see Appendix B). (It was usually the case that students had to copy down relevant statements which, for the most part, were expressively written on the board.) This worksheet contained blank spaces for students to fill in. As indicated in the discourse segment, Mr. Simon first established (as "given"), the relation $a \propto F_{net}$ and for a few seconds elaborated on it by making reference to the relation between acceleration and force in cars with big engines. The second step was to elaborate on the relation $a \propto 1/m$.

It is important to point out that the worksheet did not contain blank spaces for these relationships to be written down. However, in the next step that followed, space was provided to write down the conditions under which Newton's Second Law held, it's results, examples and the written format of the proportionality $a \propto F/m$. Having established this proportionality, Mr. Simon immediately moved on to state that "if I choose the units right . . . I can make the (proportion) an equal" ($a = F/m$). He then identified each one of these variables before explaining the units in which acceleration, mass and force are expressed. At each one of these steps, students filled in the corresponding blanks on the worksheet.

Mr. Ellis' story on Newton's Second Law and the immediate environment through which it was delivered was rather different (remember that both Mr. Ellis and Mr. Simon used the same textbook). He spent two consecutive class periods in the enactment of the information content delivered on Newton's Second Law. In the first meeting (October 22, 1986), Mr. Ellis first reviewed Newton's first law before introducing the equation: $F_{net} = ma$, and elaborating on the units of force, mass and acceleration. His lecture on this subtopic was followed by a problem solving activity initiated by having students "open their package . . . in handout 30." Four problems were worked dealing with Newton's First and Second Laws. The third problem was of particular significance, since on this occasion, the idea of friction was discussed. It was important because this topic would be linked to other events that happened afterwards. The problem consisted of calculating the force of friction between the teacher's desk and a wooden block, and between a cart (with a girl standing on it) and the classroom floor.

In the second meeting (October 24, 1986), Mr. Ellis' enacted environment was even more complex because he elaborated on two relations linked to Newton's Second Law, that is: $a \propto F_{net}$ and $a \propto 1/m$. He had already added the equation of Newton's Second Law to the list of kinematic equations on both sides of the blackboard. After rewriting (on the board) Newton's Second Law in the form: $a = F_{net}/m$, Mr. Ellis suggested that students "open their package in Handout 32." While students read the first problem assigned, he called for Melissa's assistance to run a demonstration. On this occasion, he gave Melissa a wooden cart being to be pulled by a rubber band. He first tried one rubber band (first force), then two rubber bands (second force), and finally, three rubber bands (third force). The cart accelerated faster each time. After the demonstration, Mr. Ellis called students' attention to the package and elaborated on the idea that "if you keep the mass constant (one cart), then we have a direct proportion between acceleration and the net force" ($a \propto F_{net}$). The above event was followed by a numerical exercise.

Having established (qualitatively) that acceleration is proportional to net force, Mr. Ellis next engaged in a second demonstration dealing with the idea that acceleration is inversely proportional to mass. Assisted by the same student as before, Mr. Ellis added onto the cart one, two and then three bricks (varying the mass) and had students observe that the acceleration was smaller each time, if the cart is pulled with one rubber band (constant force). Next, he finally established the relation to be: $a \propto 1/m$.

As before, the demonstration with carts, rubber bands and bricks was followed by a numerical problem from the package in which the relation ($a \propto 1/m$) was applied. Mr. Ellis then briefly referred to the blocks (from the schedule sheet) already covered as well as to future activities (lab work and assignment).

The history of how Mr. Howard enacted the information content on Newton's Second Law, through "physical materials" (Erickson, 1982), is different from Mr. Simon's and Mr. Ellis' accounts. The sequencing of the physical materials and the cues that they contained to accomplish the task at hand ran parallel to the sequencing of the information content being delivered. At a general level, the segment on "Newton's law" (as he later called it) shows that Mr. Howard referred students to information in the textbook (page 229 and 231) (see Appendix H) and questioned students on the information indicated there. He next borrowed two graphs that students had been working on during the previous three class meetings. Mr. Howard sketched the first graph on the board. He showed that acceleration was directly proportional to the applied force if the mass was constant ($F \alpha a$). The next step was to sketch the second graph that contained information on the relation between acceleration and mass. On this occasion he sketched the inverse of the acceleration (1/a) versus mass (one, two, three and four bricks). The graph led him to conclude that: "a" (acceleration) is inversely proportional to the inertial mass, if "F" (force) is "K" (meaning constant).

The two statements indicated above were combined by Mr. Howard into one single expression given by: $F \propto m_i a$, after which he would define force as $F = m_i a$.

It is important to point out the events just described were preceded by other series of events that were considered to be already known to the students (and to the readers, too). For example, the graphs indicated above had been obtained from a laboratory experiment whose purpose was to determine how a force affects acceleration and mass. Each graph contained information being derived from the procedures. On the discourse segment, Mr. Howard referred several times to "one, two, three or four" (reading the horizontal axis). In the case of the first graph (acceleration versus force), he was making reference to "one rubber band, "two rubber bands," "three rubber bands" and "four rubber bands." For the second graph (inverse of acceleration versus mass), the meaning was different. He meant: "one brick," "two bricks," "three bricks" and "four bricks" (examples of inertial mass:m_i).

We can observe here that both Mr. Howard and Mr. Ellis relied on practically the same physical stuff to elaborate on the relations $F = ma$, $F \propto a$ and $a \propto 1/m$. The difference lies in how the materials were sequenced through time. On one hand, Mr. Ellis preferred to qualitatively show the nature of these relations, without having students take measurements or draw graphs. On the other hand, Mr. Howard had students discover by themselves the relations by having them measure accelerations (on a ticker tape) and plotting the acceleration versus force and mass.

Results and Conclusions on Newton's Second Law

The preceding vignettes and assertions describing how teachers organized the presentation of the topic Newton's Second Law reveals several conclusions. In general terms, it can be stated that Newton's Second Law was differentially constructed (Magoon, 1977) by teachers. First, teachers "differ from each other in their construction of events" and in doing so they anticipate and organize these events accordingly (Kelly, 1955). We have observed how three experienced physics teachers structured a series of instructional events as they strove to communicate the possible logical relationships that could be derived from the concepts of acceleration (a), mass (m) and force (F). Indeed, a micro-analysis of the teacher's discourse on Newton's Second Law revealed the existence of different patterns with respect to how teachers structured and organized logical relationships over time. In one case, for example, Mr. Simon, who started out by elaborating on the given relationships: "force is proportional to acceleration" and "acceleration is inversely proportional to mass" until he eventually concluded that "force is equal to mass times acceleration." A second teacher, Mr. Ellis, using the same textbook as Mr. Simon, began by indicating that "force is mass times acceleration." From here, he demonstrated (qualitatively) that "force is proportional to acceleration" and "acceleration is inversely proportional to mass." The third teacher, Mr. Howard, who relied on a different textbook, structured Newton's Second Law in a different manner. His first step was to have students experimentally determine the relationships between acceleration and force and acceleration and mass. From here, Mr. Howard synthesized that "force is equal to mass times acceleration."

A second major conclusion related to the one above lies in the nature of the local coherence (Agar & Hobbs, 1985) among the different events dealing with a specific topic. The fact that teachers anticipate different instructional events as a specific topic such as Newton's Second Law is enacted, results in story-lines whose temporal and logical sequence vary in terms of the information content delivered and the logical relationships imbedded in that content. In this sense, the teachers made use of "coherent relations" (Hobbs, 1983) to connect the different pieces of information content they want to communicate. As the segment on Newton's Second Law indicated, one of the most common coherent relations put in practice by the three participant teachers was that of "expansion relation" (Hobbs, 1983). Teachers very rarely stopped to evaluate their discourse (evaluation relation) to explain what happened before (temporal relation) or to explicitly explain what the actual message was about (linkage relation). Expansion relation in a discourse refers to statements are made by teachers to move between specific and general statements (Hobbs, 1983). This idea can be expanded as follows.

A close look at the teacher's discourse on Newton's Second Law shows, for example, that a common expansion relation is to make a general statement and then exemplify it by having students work on numerical problems. This was the case of Mr. Ellis and Mr. Simon, who after elaborating on the statements $F = ma$, $F \propto a$ and $a \propto 1/m$ had students work on a set of numerical problems where these relations were applied. The difference between the two teachers lay in that Mr. Ellis, for example, gave out a first set of problems right after he had established the equation $F = ma$, and a second one after he had elaborated on the other two relations. On the other hand, Mr. Simon presented the examples (problem) immediately after he had elaborated on the ideas that "force (net) is proportional to acceleration" and "acceleration is proportional to mass." He also posed a second set of problems after he had eventually established the relation $F = ma$.

The third teacher, Mr. Howard, delivered Newton's Second Law following a rather different organization. He first established the general statements that surrounded Newton's Second Law and eventually assigned a set of numerical problems for students to work on. The shifting from a general statement to an exemplification situation can be categorized as a break (Jefferson, 1972). In this sense, one could say that both Mr. Ellis and Mr. Simon, after elaborating on a general statement introduced a topic shift (Brown & Yule, 1983) by having students work on numerical problems until they eventually returned to the topic being enacted. However, this was not the case of Mr. Howard, who decided to quickly lay down the general statements that surrounded the teaching of Newton's Second Law. It is through the use of breaks (Jefferson, 1972) and coherent relations (Agar & Hobbs, 1985) that teachers enact different types of logical sequences when delivering a common topic. We have observed that in the cases of Mr. Ellis and Mr. Simon, both constructed logically loose sequences when enacting Newton's Second Law. However, Mr. Howard enacted the same law by following a "tight logical sequence" (Grimes, 1976).

A third major conclusion with respect to how teachers construct a single topic in physics is related to the inclusion of breaks, the type of logical sequence, and the way information is actually derived. For example, Mr. Simon and Mr. Ellis, who frequently introduced breaks in their discourses on Newton's Second Law, established the logical relationships that surrounded Newton's Second Law as if they were "given" statements that could be empirically (through demonstration) supported. However, Mr. Howard, for whom breaks were infrequent, experimentally derived the logical relationships that surrounded the deviation of Newton's Second Law. In this sense, breaks seem to be associated with logically loose sequences in which logical statements are established as "given," and as such, they need to be expanded through specific examples.

Finally, there is a conclusion that needs to be made. As had been indicated in Chapter II, teaching is a constructivist process (Magoon, 1977; Green & Harker, 1983; Yorke, 1987) in which teachers act upon the subject matter and organize it accordingly to be able to communicate (verbally and nonverbally) the information content which the students are expected to learn. In this process, teachers and students interact with the immediate environment (books, worksheets and lab equipment) through which such information is delivered. In the micro-analysis of Newton's Second Law, it was found that the elements of immediate environment varied among teachers with respect to: (a) their location in the discourse sequence, (b) the steps and strategies implemented by teachers with respect to their location in the discourse sequence, and (c) the steps and strategies implemented by teachers to communicate information. In the case of Newton's Second Law, one teacher (Mr. Simon), for example, relied on a worksheet with spaces to fill in and the blackboard. Mr. Ellis relied primarily on a package of written materials and lab equipment for classroom demonstration. Finally, the third teacher, Mr. Howard, made use of students' graphs to establish Newton's Second Law.

The preceding conclusions lead to the consideration of a final question, "Why do teachers organize the teaching of a single topics and units differently?" One possibility is that teachers (such as Mr. Ellis and Mr. Simon) have different interpretations of the information content imbedded in the textbook and the use of equipment for delivering that information content (through classroom demonstrations, handouts, worksheets, etc.), so that they enact different relationships among the concepts and generalizations. A second possibility is that teachers bring into their classroom information from their own experience drawn from previous courses, readings and the like. This information, added to the textbook information, undoubtedly leads to discourses with different underlying structure in terms of the organization of the subject matter being delivered.

A third possibility is that teachers change the textbook structure in order to assist students in the comprehension of subject matter. This modification of the textbook structure takes place at unit level (macro) and at topic level (micro). Detail analysis of the teacher's discourse of Newton's Second Law showed, for example, that teachers construct logical sequences in ways that are not directly prescribed in the textbooks. In doing so, teachers introduce "breaks" in the sequence in order to carry out demonstrations or solve numerical problems that illustrate and expand specific logical relationships imbedded in the sequences.

One important point to be made here is that even though the participating physics teachers modified the textbook's logical sequence (as they constructed subject matter), the purpose of this modification was not explicitly geared towards changing students' previous conceptions of the subject matter being constructed as was the case of Minstrell's (1984) work on Newtonian dynamics. Based on empirical research on students' own conceptions about the relationship between force and motion, Minstrell modified the traditional way of sequencing Newton's Laws in order to help high school students to overcome the preinstruction idea that "a constant unbalanced force should result in constant velocity" and instead be able to accept the view that "a constant unbalanced force would produce a constant acceleration." In trying to help students overcome the idea that an unbalanced force results in constant velocity, Minstrell (1984) designed an instructional sequence for teaching Newton's Laws that basically consisted of four major points: (a) engagement of initial conception, (b) firsthand experiences relating to their initial conception, (c) treating the concrete constant acceleration case before the abstract logical consequence of the constant velocity case, and (d) the discussions encouraging rational thought to resolve discrepancies between initial ideas and firsthand experiences.

In conclusion, what Minstrell did in terms of organizing subject matter for students' comprehension was to change the traditional sequence in which Newton's Laws are presented in high school textbooks. In this sense, he started off by first introducing Newton's Second Law and then treating Newton's First Law (or law of constant velocity) as a particular case of the second law.

Contrary to what Minstrell (1984) did, the three participating teachers of this study did not explicitly address students' conceptions as they constructed their units on dynamics. However, this does not necessarily lead to the conclusion that students did not overcome the conception "an unbalanced force results in constant velocity." This is an issue that needs to be further explored through more empirical research as will be described later.

CHAPTER SIX

OVERVIEW, CONCLUSIONS AND IMPLICATIONS FOR PRACTICE AND RESEARCH

This final chapter is divided into three main parts. The first part describes an overview of the study and includes research questions, methodology and findings. The second part discusses the major conclusions of the research. The third part addresses the implications the study has in terms of the effects it may have on areas such as: inservice and preservice teacher education and future research.

Overview

The present study has been an empirical effort to learn how teachers construct and enact classroom academic content. This issue has been established as a fundamental problem in research on teaching and teacher education (Doyle, 1986). It has been said that school knowledge is constructed as teachers and students interact to achieve their goals (Yorke, 1987; Erickson, 1982). This study was carried out with the intention of learning how school knowledge is made available to students and how that knowledge is organized. This is what Cazden (1986) referred to as a "micro-sociology of knowledge" or "how educational knowledge is socially defined and made available."

In order to shed light on the above question, the researcher "negotiated entry" (Erickson, 1986) with three experienced physics teachers to study and learn about their teaching. During the six months of intensive observation, the researcher recorded classroom observation on different topics in high school physics including optics, waves, kinematics, dynamics, electricity, etc. For the purpose of analysis, the theme on dynamics was chosen in order to describe the way school knowledge is differently enacted by teachers.

The primary questions addressed in this ethnographic study had to do with the organization of physics topics by high school teachers. The general question remained the same throughout the school year (see Chapter Three); however, during the data analysis process it was soon discovered that the specific questions were too broad to be answered. The literature review that followed and "the understanding of events" (Erickson, 1986) under analysis led to a more focused set of questions. Three main questions that guided the final analysis as follows:

1. What is the nature of the coherence of the subject matter-information content (story-line) in the

unit on dynamics as enacted by three high school physics teachers?

2. What is the nature of the coherence of the subject matter information content delivered on a single topic (dynamics) as taught by three high school physics teachers?
3. What is the nature of the enacted environment through which the information content is delivered?

These questions remained constant during the final analysis. The first question was methodologically addressed through the construction of "story-lines" which showed how teachers dealt, through time, with different topics, and the way the topics gradually emerged and decayed (Tannen, 1984) as the target theme (dynamics) was developed. The purpose of the story-line was to describe, not only the topics being enacted but also how they were enacted. The second question was addressed by carrying out a micro-analysis of the segment on Newton's Second Law that was common to the three participant teachers. These two analyses led to the establishment of "the underlying structure" (Erickson, 1982) of the subject matter being enacted at two different levels: macro-level and micro-level. At the macro-level, it was noticed that the topics taught in a unit on introductory dynamics, as well as its organization, vary among teachers

-- even those teachers following the same overall curriculum. At the micro-level, it was found that the teachers enact different sequences of "logical operations and steps" (Erickson, 1982) when dealing with common topics. The third question was also addressed at both levels. The conclusions will now be discussed.

Conclusions

Erickson (1982) pointed out that the school "subject matter" can be defined according to four constitute aspects: (a) the subject matter information content; (b) the sequencing of recursive steps in logic of subject matter comprehension; (c) the "meta content" cues toward completion of the task; and (d) the physical materials through which tasks are accomplished. This section of the study presents some of the major conclusions in terms of how the three participant teachers dealt with the above four aspects.

The study of the global and local coherence (Agar & Hobbs, 1985) as these three participant teachers delivered a theme on introductory dynamics, revealed that "school knowledge" (Doyle, 1986) or school "subject matter" (Erickson, 1982) was differentially enacted by teachers, as shown by the subject matter content and its organization. The subject matter content, manifested in the form of topics, and organized in macro-sequence and micro-sequence, vary in terms of what topics are delivered by teachers and in the form in which each individual topic is enacted. Also, the study of global and local coherence in teacher's discourse, as well as the actions being displayed as the discourse was elaborated, yielded evidence with respect to subject matter organization and its enactment through physical materials.

A general conclusion that can be drawn from this study is that experienced qualified physics teachers differentially organize subject matter at both macro-level and micro-level. At a macro-level, teachers constructed different structures of subject matter by breaking a piece of knowledge (i.e., unit) into topics which may or may not be logically connected. The way in which individual topics were treated varied among teachers, even among the two teachers who were using the same textbook. Also, the topics enacted by one teacher were not necessarily the same as those enacted by a different teacher. In addition, the logical connection between successive topics, as carried out by a teacher, were totally different to the connections made by another teacher, even though they may be dealing with similar topics taught in the same temporal order. In this sense, teachers generally relied on different "coherent relations" (Hobbs, 1983) to properly connect the topics in similar units of instruction. A topic may be initially introduced and eventually ignored, or it may be transferred and used in the context of an instructional event dealing with another topic or set of topics. This situation is somehow similar to Jefferson's notion (Jefferson, 1972) of "termination" and "break." In a termination, a topic is shifted from one area to another, and the first area is never picked up again in the development of the discourse's general theme. In a break, a topic is elaborated, then a "topic shift" (Brown & Yule, 1983) occurs that shifts the discussion into a different area and later another topic shift eventually brings the initial topic back. It is through this process of connecting topics that teachers enact subject matter structures which vary with respect to the nature of the information content being communicated to students.

The analysis of the unit on dynamics' global coherence as constructed by the three participant teachers of this study yields evidence as to how "breaks" and "topic shifts" emerged while individual teachers actively engaged in the process of communicating the information content imbedded in that unit. The story lines that described the nature of the global coherence, indicated that teachers made use of "topics shifts" as they constructed subject matter, and they eventually ended up ignoring the logical connections between related topics. The end product of these actions was the construction of "logically loose sequences" (Grimes, 1976) with gaps that students were expected to interpret and comprehend. Three specific instances of "topic shifts" in which three participants ignored the logical connection between two contiguous topics are worth mentioning.

In the following three instances, the three participant teachers did not make explicit reference to the preceding topic (Newton's Second Law): Mr. Simon's elaborating on the difference between mass and weight, Mr. Ellis dealing with Newton's Third Law, and Mr. Howard's teaching the difference between inertial mass and gravitational mass.

At a micro-level, the nature of how school subject matter is differentially organized by physics teachers becomes more detailed. In effect, a micro-analysis of the "local coherence" (Agar & Hobbs, 1985) of the way three experienced teachers strived to communicate the topic of Newton's Second Law revealed that teachers enacted subject matter through a series of successive steps containing information organized under different underlying structures (Erickson, 1982) which do not necessarily follow the same logical and temporal order.

In this study, we have defined the term micro-sequence as of the underlying structure imbedded in the teaching of a particular topic. A macro-sequence gives a sense of the synthesis of the topic that teachers tried to communicate through their discourse. In effect, this study showed that teachers break topics into small pieces of knowledge (statements) and organize them under different logical steps.

As in the case of global coherence, teachers relied on "coherent relations" (Hobbs, 1983) to construct on specific topics. At a micro-analysis level, these relations are easier to detect. In the case of the discourse analysis on Newton's Second Law, the most frequent relations being used were linkage relations, temporal relations and expansion relations (in Hobb's terms). Expansion relations were frequently used by the two teachers (Mr. Simon and Mr. Ellis) who established Newton's Second Law in a series of successive logical relationships between acceleration, mass and force. However, strong temporal relations and linkage relations were more common in Mr. Howard's discourse on Newton's Second Law. The fact that teachers implement expansion relations, such as examples after establishing a general statement (e.g., $a \propto F$ or $a \propto 1/m$) leads teachers to establish "breaks" (Jefferson, 1972) or "breaches" (Green & Harker, 1982) in the discourse as conversation develops. This way, teachers leave the impression that they establish logical relationships in a "jig-saw" (Hirst, 1974) fashion. That is, there is a great variety of ways in which a topic can be taught and the logical order emerges as you go along (Hirst, 1974).

In the construction of Newton's Second Law, breaks were introduced by teachers and the discourses served different purposes. For example, Mr. Simon made use of breaks to exemplify specific logical "given" relations ($a \propto F_{net}$ and $a \propto 1/m$) before establishing the equation that defined Newton's Second Law. On the other hand, Mr. Ellis first established Newton's Second Law, and then exemplified it by solving numerical problems. His next major step was to carry out empirical demonstrations that led to the conclusions of two logical relations as indicated above. The third teacher, Mr. Howard, did not introduce breaks in his discourse when he constructed similar logical relationships. The difference between Mr. Howard and the other two teachers was his reliance on students' lab reports to elaborate the logical relationships that surrounded the construction of Newton's Second Law.

The above discussion suggested that breaks are more common in micro-sequences constructed out of a given relationship and for which no empirical work is previously anticipated by teachers. This study also shows that when breaks are introduced in the construction of specific topics, the result is a "logically loose sequence" (Grimes, 1976) in which teachers need to clarify each one of the statements begin made. However, in the absence of breaks, the result is a "logically tight sequence" (Grimes, 1976) in which teachers rely on empirical information already available for its construction.

In addition to variations in the order in which logical relationships are enacted by teachers at a micro-level and a macro-level, there are also variations on the nature of the enacted environment through which these logical relationships are manifested and delivered. The enacted environment is determined by the physical materials through which subject matter is manifested (Erickson, 1982). The steps and strategies imbedded in these materials are important ingredients in the structuring of subject matter and play a fundamental role in how information is delivered. In the teacher's discourse on Newton's Second Law (F = ma), teachers simultaneously relied on worksheets (Mr. Simon), a package of lab equipment (Mr. Ellis) and students' graphs (Mr. Howard). Each one of these tools contained different sets of information which in conjunction with the teacher's verbalizations and actions determined the intended meaning delivered by the three teachers in the topic of Newton's Second Law.

The previous discussion on findings is quite consistent with Hirst's view of school content, logical organization and sequencing. According to Hirst (1974), similar themes and topics may have different logical organization as they are enacted. He pointed out that "there is . . . no one logical sequence in which the truth of a subject must be communicated, even in these subjects which seem most strictly sequential" (Hirst, 1974:125).

Implications for Educational Research and Practice: Preservice, Inservice Teacher Education and Student Learning

It has been suggested that learning how to construct and enact a classroom curriculum is a fundamental problem in research on teaching (Doyle, 1986). The present study has been an attempt to learn about the way teachers actually construct subject matter in high school physics. Learning about curriculum enactment of school academic content has important implications for teacher education and student learning because one of the main purposes of schooling is the appropriate delivery of knowledge so that students can make sense of it. In the process of making students comprehend such knowledge, teachers not only interact with students, but also with curriculum materials enacting what is usually referred to as the manifest curriculum. Students, for whom this curriculum is directed, acquire skills and learn about logical relations between different concepts, topics and related pieces of school knowledge. In this sense, describing how experienced teachers, on a daily basis, assist students to acquire those skills and the logic of subject matter has strong implications for those concerned with education in general and with subject matter in particular.

Two major important conceptual contributions for curriculum development and research have emerged as a byproduct of the present study. The first contribution, borrowed from discourse analysis, is the notion of <u>topic</u>. In this study, it has been shown how two conceptually organized physics curricula (PSSC, Harvard Project Physics) were transformed by experienced qualified teachers and eventually presented to students in a series of sequential topics. The second major contribution, also borrowed from discourse analysis, is the idea of <u>coherence</u> (local and global) and the notion of how individual topics are logically constructed and connected among themselves as teachers interact daily with students and curriculum materials. Both constructs will hopefully contribute to the language of those concerned with the study of subject matter knowledge and pedagogical training and practice.

Preservice Teacher Education

How experienced teachers actually organize and select different bits of academic content has implications for preservice teacher education. Prospective teachers, for example, can be informed of the content variations that exist as similar pieces of subject matter which are enacted by experienced teachers. Written vignettes and videotapes such as the ones described in this study (see Chapter 3) can be used as sources of information for this purpose. Story-lines of "naturally occurring events" (Erickson, 1982, 1986b) describing the nature of the coherence among related topics delivered over a period of several days can be used for discussion dealing with the way academic content is constructed through the teacher and student interactions with the immediate environment. Similarly, videotaped segments showing how a topic is dealt with by experienced teachers can be used as a learning tool to assist prospective teachers in their understanding that different sets of logical relationships may emerge in the enactment of the topic. This also implies that prospective teachers can implement their own set of relationships from their analyses of videotaped segments.

Another important related implication of this study for prospective teachers, particularly for physics teachers, has to do with the understanding that although teachers may use similar textbooks (such as Mr. Ellis and Mr. Simon) and that the overall coherence of the discourse on a common theme may on the surface look the same, the content organization of specific topics may be enacted in strikingly different ways. This is the case of the well-studied topic of Newton's Second Law discussed in Part II of Chapter Five.

Teacher educators engaged in preservice education, need to recognize that experienced teachers do not follow a particular curriculum in a linear fashion. Instead, they develop their own instructional strategies in order to anticipate what topics to include, what statements to make in each topic, and how to organize them when dealing with a specific instructional unit. This point was recognized by Porter et al. (1986) in their study of mathematics content taught by elementary schools. In addition, teacher educators need to recognize that experienced teachers rely on a variety of physical materials, whose organization and use in the act of teaching play a fundamental role in the nature of the subject matter communicated to students. The purposes and uses of those materials vary among teachers in terms of the "steps and strategies" (Erickson, 1982) implemented as subject matter is enacted.

Day to day accounts of how experienced teachers strive to communicate information to students can also be a resource for staff development (Erickson, 1986b). Indeed, prospective teachers can be properly guided to learn and deliberate about how experienced teachers enact subject matter in real-life through their daily classroom routines. Prospective teachers, then, have the opportunity to reflect on whether or not what is being said makes sense to them. In this reflective process, prospective teachers can be encouraged to suggest changes in the subject matter sequence being enacted in order to make it more understandable and accessible to students.

Inservice Teacher Education

The findings of this study as well as the data presented have implications for inservice teachers. On one hand, there is a need for teachers to reflect and write upon their own practices (Clark & Florio, 1982; Erickson, 1986b) in order to improve their own teaching and "to participate in the generation of a knowledge base on teaching" (Porter, 1986:23). The story-lines described in this study as well as the videotaped transcripts and the videotapes themselves can be made available to participant teachers in order to learn about their own perception of how a particular set of topics was coherently organized and what changes may be needed in future teaching. Teachers, for example, can be asked for their own interpretation of the way topics are segmented through time and how topics are logically connected. Informal conversations with the three participant teachers gave evidence that the teachers' views on how they organize content is rather different from how that content is actually enacted in real life. This point is consistent with Doyle's suggestion that many teachers, including those considered to be effective, do not have a "rich semantic grasp" of their content (Doyle, 1986).

However, this is a matter of empirical verification through further research.

A second implication of this study is concerned with the implementation of knowledge-based inservice programs that are "consultative" (Clark, 1987) rather than prescriptive. In this sense, teacher educators can exemplify through the use of case studies, such as the ones described in this study, how experienced teachers actually organize school academic content, instead of indicating how it should be organized. As Clark (1987) stated, "The best consultants are those who leave us with something interesting and provocative to think about as we continue to wrestle with the complexities of our own local problematic situation" (Clark, 1987:3). Indeed, teachers deal daily with the specific situations that need to be reflected upon. One particular situation is the organization of different pieces of knowledge in a coherent manner to make them understandable to students. Informing inservice teachers concerning the way experienced teachers strive daily to organize content knowledge will contribute to more effective teaching.

Student Learning

The present study also has implications for student learning. In this study, it was observed that contents in three distinct high school physics classrooms are organized differently. The study also indicates that similar high school populations are being delivered differently organized school knowledge. At a macro-level, it has been observed that a topic enacted in one classroom may not necessarily be taught in a second classroom, even in the case in which both classrooms use the same textbook. This is, for example, the case of free fall and terminal velocity that was taught by Mr. Ellis but not by Mr. Simon. When comparison across classes are made, it can be observed that for example. Newton's Third Law, is not taught in the same logical progression by all teachers.

At a micro-level, it can be observed that teachers enacted different sets of logical relationships when elaborating on a topic such as Newton's Second Law. These variations in content organization suggest that each individual group of students is learning different sets of topics and logical relationships among the topics under the theme dynamics. However, the fact that teachers construct different logical relationships between topics and concepts does not necessarily lead to the conclusion that students comprehend those relationships as they are enacted by the teachers. Students possess their own "scripts" (Schank & Adelson, 1977) and "mental models" (Johnson-Laird, 1980) to interpret and understand the subject matter imbedded in the teacher discourse. In this sense, understanding the nature of the subject matter, as constructed by individual students out of a teacher's discourse is and important issue for further research. This difference in learning may have strong implications for research and policy on student testing. As Porter et al. (1979) stated, "Understanding what teachers teach and how they decide what to teach will help educators understand more fully why students differ in what they learn" (p. 3).

Implications for Further Research

The findings from this study point toward new avenues for research in curriculum development and science teaching and learning. In the context of a more general ethnographic work, a constructivist approach has been proposed to interpret and describe how teachers in their daily interaction with students enact subject matter. In this sense, a detailed analysis of three teachers' discourses and actions was conducted in an effort to represent and describe the nature of the logical connections among the topics and concepts enacted in a unit on dynamics taught by the three teachers. One of the first general questions that emerges from this study is the perception that the participant teachers might have about the description and representation of the subject matter as carried out by the research analyst. In this way, we may have the teacher's own viewpoint of the "semantic grasp" (Doyle, 1986) implicit in the content they teach.

A second major theme is related to the notion of coherence among the different instructional units that constitute a whole year's curriculum program. In high school physics, teachers anaphorically enact subject matter by making reference to topics already taught in previous units. How these topics are constructed and eventually link to other topics needs to be empirically studied since any possible gap in previous instructional units may have profound consequences on how students interpret and understand later units. Apart from describing in detail how topics in an early unit are anaphorically linked to later topics in subsequent units, the study of the discourse as teachers move from one unit to the next may give important insights in terms of the nature of the coherence between contiguous units. This shift is usually very short in time, so the use of special devices (audiotapes and videotapes) may be required to capture it.

A third point that needs to be made is related to the nature of the knowledge constructed by students as a byproduct of their interaction with teachers and curriculum materials. It is the teachers' responsibility to evaluate and check for students' understanding and comprehension of subject matter knowledge. The teachers' discourse can give specific details of instructional events in which teachers intervene to evaluate and probe students' understanding of the information content they are expected to learn. In this sense, if a teacher is engaged in teaching for conceptual change (Minstrell, 1984), looking at the relationship between what teachers construct and what students learn can provide us with empirical evidence as to why students change (or do not change) their pre-instructional ideas they bring into the classroom. What has been suggested, then, is to investigate the process by which students come to construct subject matter and the role played by teachers in that process. It is possible that a student resists accepting a new scientific concept, not because the student lacks the cognitive skills required to comprehend and interpret it, but because of possible missing links (Brown & Yule, 1983) in the teacher's discourse, which, if included, would make explicit connection between related topics.

A final issue that needs further research is also related to student learning and subject matter construction. As has been clarified in a series of story-lines and vignettes throughout the body of this dissertation, experienced, qualified teachers create environments in fundamentally different ways when they deliver subject matter to students. In this sense, the elements of the environment and their sequential organization are important ingredients in the process of how subject matter is constructed. In the case of high school physics, one of the most common elements of this environment is the physical equipment used for empirical demonstrations and laboratory work. This study has shown that even similar physical equipment may have different purposes in the organization of similar bodies of subject matter knowledge. Knowing this, an issue that needs to be investigated is the extent to which a specific environment is more helpful than others in assisting students in their construction of subject matter.

APPENDIX A

MR. SIMON'S "UNIT PLAN" ON DYNAMICS

APPENDIX A

MR. SIMON'S "UNIT PLAN" ON DYNAMICS

Chapter 3 Outline

Name ____________________
Hour _____ Date ________

Schedule

Mon Sept. 22	Tue 23	Wed 24	Thur 25	Fri 26
Intro to ch 3 Study Q's Part A	Demo lecture "inertia"	Work session "vectors" Prob. Set	Exp. "force vectors"	Newton's Laws Prob. Set
Mon 29	Tue 30	Wed Oct. 1		
Exp. a = F/m	Egg Day	Quiz Ch3 Papers Due		

<u>Objectives</u>

If Given:	Be able to:
Descriptions	1. Identify those situations in equilibrium or not.
2 vectors	2. Name upper and lower unit of their sums.
	3. Watch defining and description.
	4. Find vector sum (resultant).
	5. Given and resultant, name the equilibrant.
	6. Pick true statements about vectors.
	7. Name 3 vectors and 3 of Newton's Laws.
	8. Identify which applies from: a) strobe photographs or graphs b) word descriptions
F = ma	9. Solve problems including the equation.
List the descriptive phrases	10. Identify which are true for <u>mass</u> and which are true for <u>weight</u>.

Physical situation, object in equilibrium	11.	Identify and describe all forces acting on the body including friction.

<u>Assignments</u>:

1. Study questions, Ch 3, Part A
2. "Inertia" demo notes
3. Vectors work sheets
4. Study questions Ch 3, Part B
5. Force board experiment
6. Newton's Laws notes
7. Newton's Laws problem set
8. Exp. a = F/m
9.

Read all parts of Chapter 3.

(Document, September 22, 1986)

APPENDIX B

MR. SIMON'S WORKSHEET ON NEWTON'S LAWS

APPENDIX B

MR. SIMON'S WORKSHEET ON NEWTON'S LAWS

<u>Newton's Laws of Motion</u>

One of mankind's great achievements. Name ________________
Hour ____ Date _____

I. Newton's First Law of Motion -- otherwise known as the law of ________________.

"Bodies at rest remain at rest,
and bodies in motion remain
in motion in a straight line
by constant speed."

II. Newton's Second Law

	Conditions	Results	Examples
"An unbalanced (net) force causes an acceleration in the same direction as, and proportional to, the net force acceleration is inversely proportional to mass."			

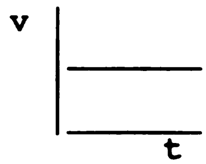
Written:

____

Test yourself . . . are these examples of first law or second law?

a) $V = 0$

$a = 0$

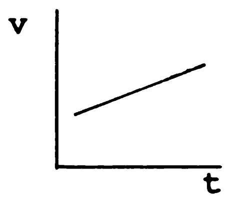
b) 

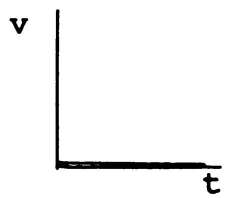
c) $v = 10/m$ sec

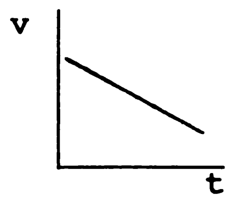
$a \neq 0$

d) o
o
o strobe
o
o

e) o
o
o
o

f) 

g) 

h) 

---

measured in (units)

Where: a =

m =

F =

III. Two confusing terms: (read about this in Chapter 3)

<u>Weight</u> is: <u>Mass</u> is:

III. Newton's Third Law or:

"to every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal and directed to contrary parts."

Samples:

(Document, September 26, 1986)

APPENDIX C

MR. ELLIS' UNIT PLANNING ON DYNAMICS

APPENDIX C

MR. ELLIS' UNIT PLANNING ON DYNAMICS

Physics Assignment Sheet: Chapter 3

1. Newton's 1st law (law of doing nothing different!)
   Text: 3.5-3.6
   HO-31: Selected questions and problems will be discussed and demonstrated in class.
   Bulletin Board: Look! There are some great cartoons illustrating inertia.

2. Newton's 2nd law (Fnet = ma)
   Text: 3.7
   HO-32: 21,22

   Note: The unit of force, the newton (N). dimensionally has units of kg m/s2

   $F = ma$ ---- $N = kg\ m/s^2$

3. Hallway Experiment: Get your mass moving.

4. Newton's 2nd law
   HO-32: 10,11,14,27

5. Mass vs. Weight (causes bald physics teachers)
   Text: 3.8
   HO-33: 9,10,11,12,13 Selected problems will also be discussed in class.

6. Terminal velocity, Atwood's machine and other niceties (putting assignments 1,2 and 5 together)
   HO-33: Examples in class
   HO-34a: Examples in class
   HO-34b: Great exercise for Mickey Mouse

7. Newton's 3rd Law ($F_{12} = -F_{21}$)
   Text: 3.9-3.10
   HO-35: Selected problems will be discussed and demonstrated in class.

8. Test

(Document, October 24, 1986)

APPENDIX D

MR. ELLIS' EXPERIMENT SHEET

ON NEWTON'S SECOND LAW

APPENDIX D

MR. ELLIS' EXPERIMENT SHEET ON NEWTON'S SECOND LAW

"$F_{frictional}$ (F_f) = trial 1   trial 2   trial 3

$F_{pulling}$ (F_p) =

F_{net} (F_n) = $F_p - F_f$ =

Distance traveled (d) =

Journey time (t) =

Kinematic determination of the acceleration (starting from rest)

$d = 1/2\ at^2$ $a = 2d/t^2$

Dynamic determination of the load (mass)

$F_n = ma$ $m = F_n / a$

Embarrassing (perhaps) determination of the mass

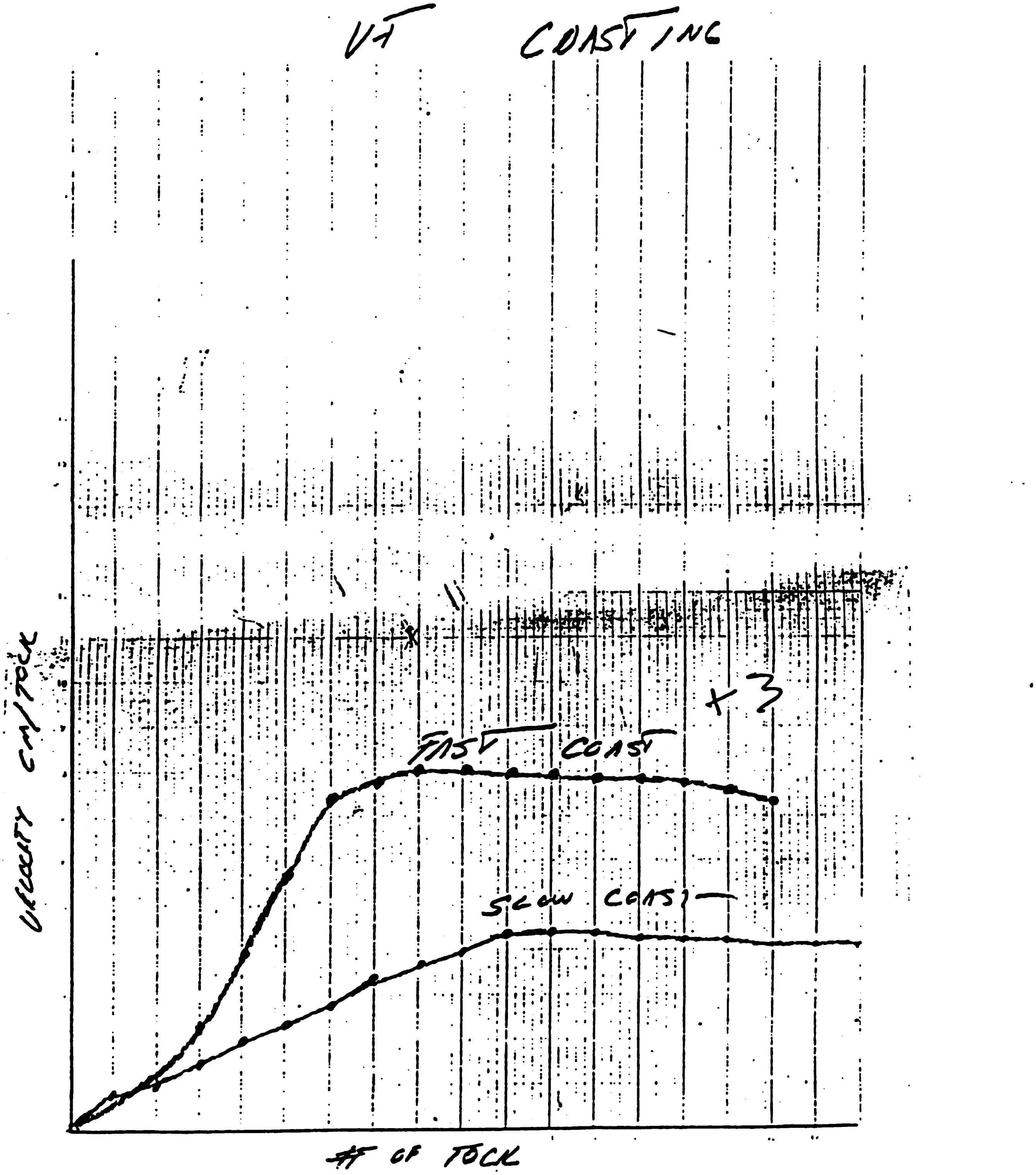
% difference"

(Document, October 30, 1986)

APPENDIX E

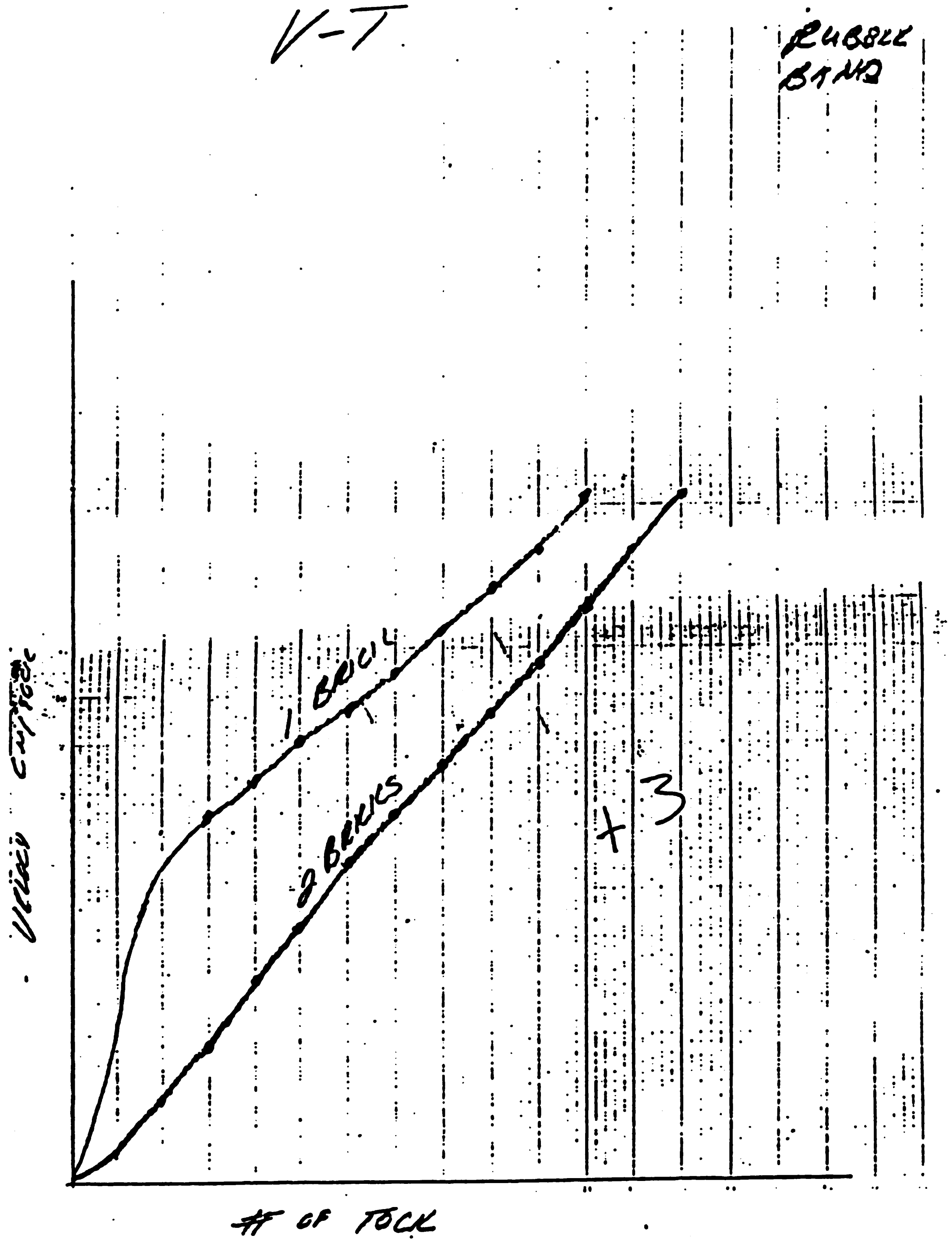
GRAPH OF VELOCITY VERSUS TIME:

"GALILEO COASTING"


VT COASTING
VELOCITY CM/TOCK
FAST COAST
x 3
SLOW COAST
OF TOCK

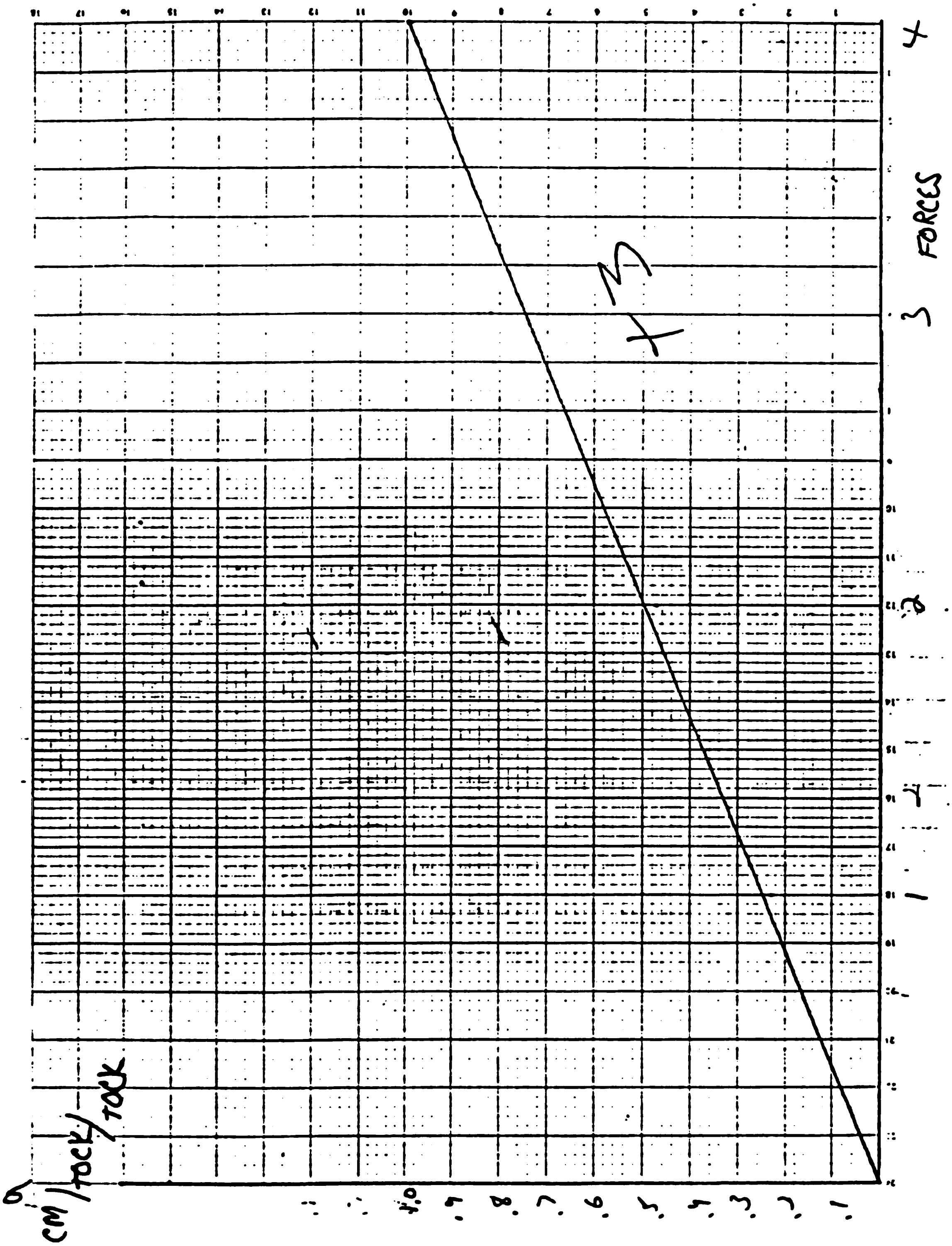
APPENDIX F

GRAPH OF VELOCITY VERSUS TIME: ONE AND TWO BRICKS PULLED BY A RUBBER BAND


V-T
RUBBER
BAND
1 BRICK
2 BRICKS
+3
OF TOCK

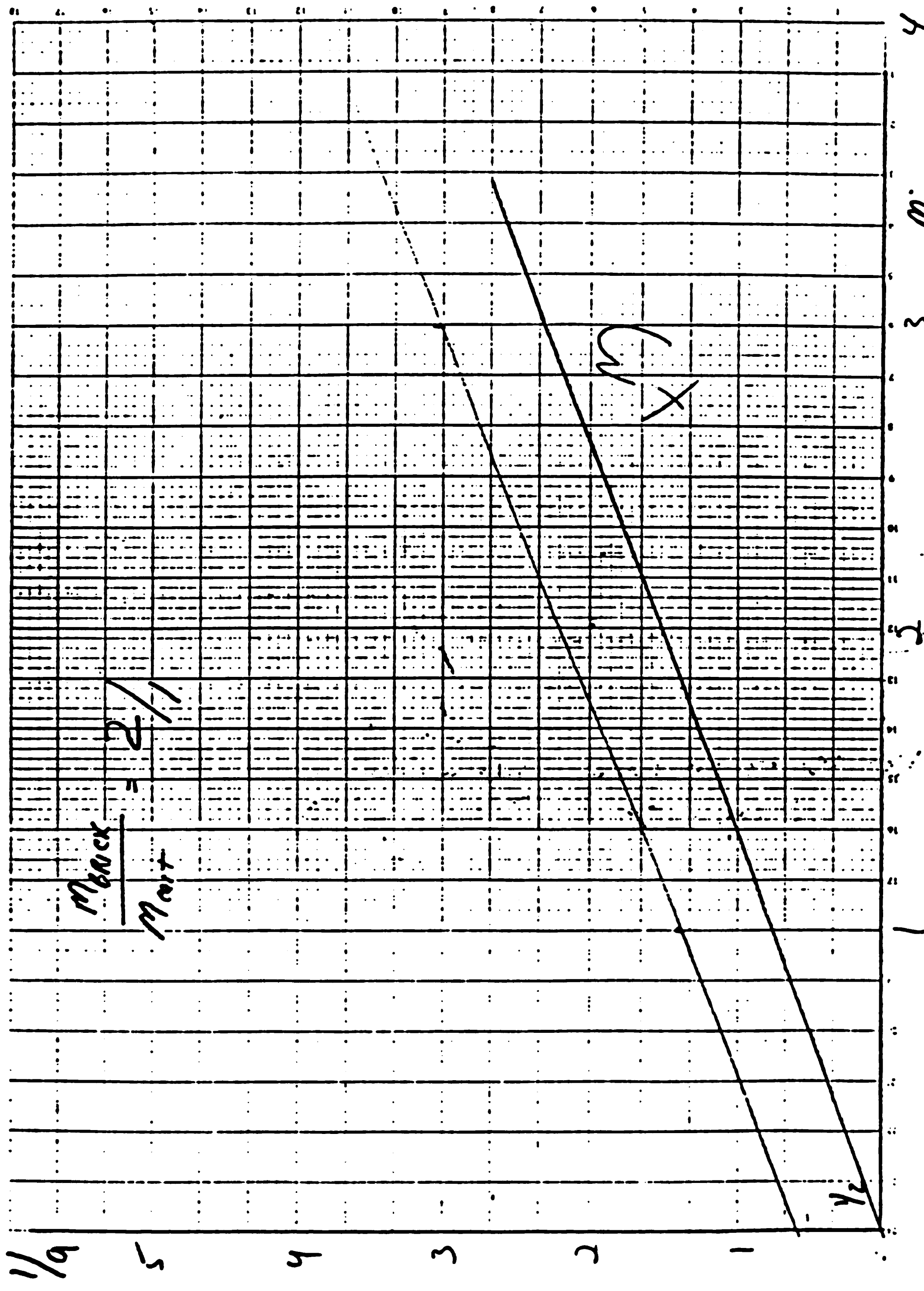
APPENDIX G

GRAPH OF ACCELERATION VERSUS FORCE (MASS CONSTANT)


FORCES
CM/TOCK/TOCK

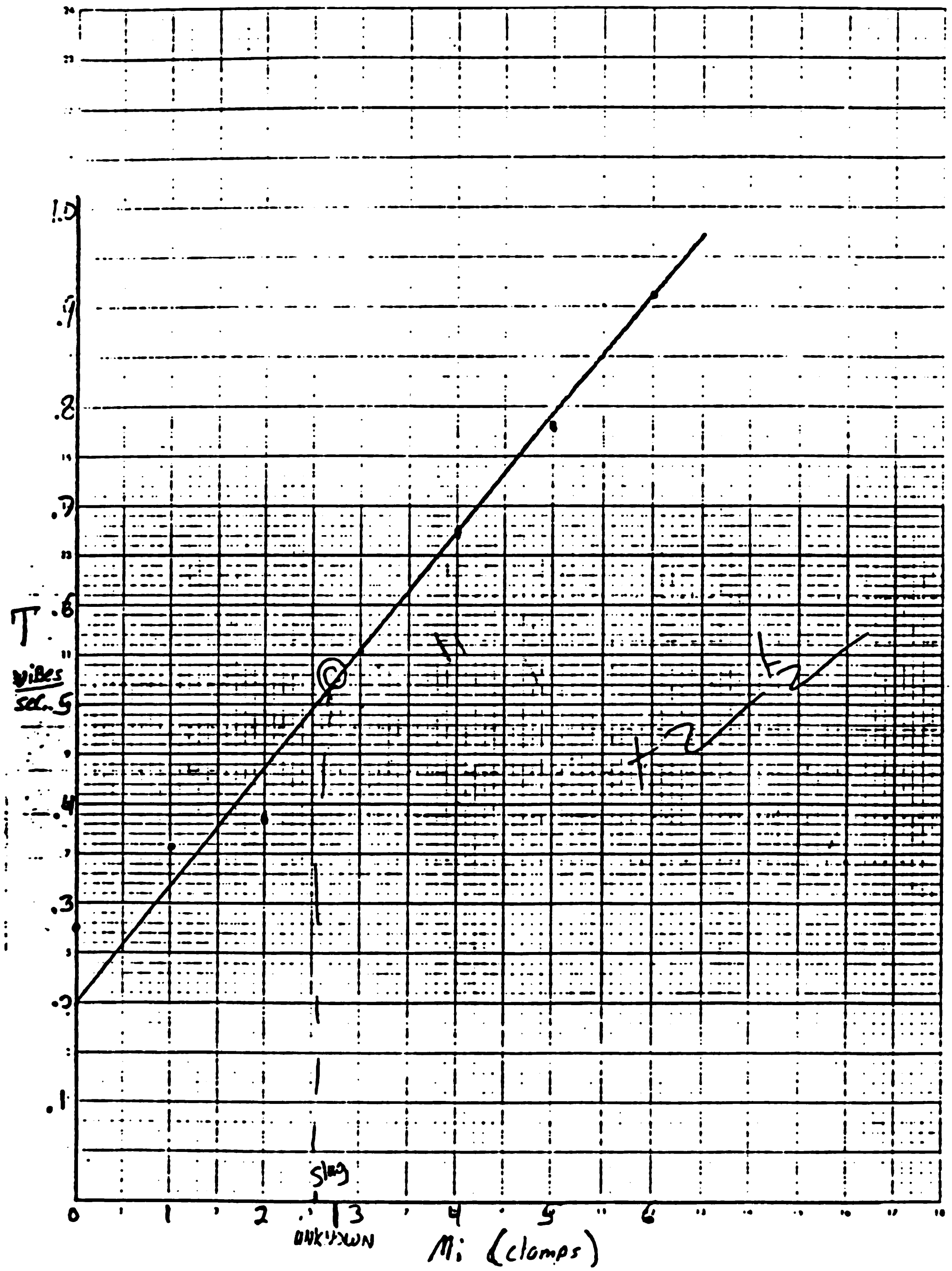
APPENDIX H

GRAPH OF ACCELERATION VERSUS INERTIAL MASS (FORCE CONSTANT)


$\frac{M_{BRICK}}{M_{air}} = 2/1$
$1/a$
m_i
$1/2$

APPENDIX I

GRAPH OF PERIOD VERSUS INERTIAL MASS


1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
T
vibes
sec.
0
1
2
3
4
5
6
slug
unknown
Mi (clamps)

APPENDIX J

THE FLASH PHOTOGRAPHS:

FORCE AND ACCELERATION

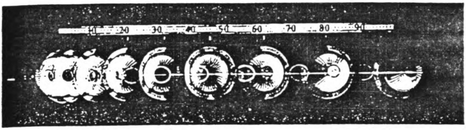


Figure 11-9
The flash photograph shows the puck being pulled to the right. The light flashes were separated by 10/24 sec. A constant force was applied by keeping the loop extension constant. The displacement of the puck in each interval marked on the photograph has been measured and appears in Table 1.

(to the right) in each time interval. By measuring the successive displacements, we can calculate how the average velocity changed. As the caption under Table 1 shows, in each $\frac{10}{24}$ second after the motion started, the average velocity increased by about 5.8 cm/sec, a constant amount within the limits of accuracy of our experiment. Dividing the change in velocity of 5.8 cm/sec by the time interval of $\frac{10}{24}$ sec, we see that the average velocity changed at the constant rate of 14 cm/sec². Since the average velocity changed at a constant rate throughout the motion, we can safely assume that the instantaneous velocity also changed at the same constant rate. That is, the acceleration is constant and equals 14 cm/sec².

Table 1
Data from Experiment Shown In Fig. 11-9

INTERVAL NO.	POSITION x(CM)	AVERAGE VELOCITY IN INTERVAL $\Delta x/\Delta t = v$(CM/FLASH)	CHANGE IN AVERAGE VELOCITY Δv(CM/FLASH)
1	4.1	4.1	
2	10.4	6.3	2.2
3	19.2	8.8	2.5
4	30.4	11.2	2.4
5	44.0	13.6	2.4
6	60.1	16.1	2.5
7	78.6	18.5	2.4

The zero of position was taken as the location of the puck at the instant of the first flash. The value of x is the position of the puck at the end of the given interval. The average velocity, measured in cm/flash, is numerically equal to the displacement during the given interval. The last column simply gives the amount by which the average velocity changed between successive intervals. We find that Δv was constant within the limits of accuracy of our experiment and was 2.4 cm/flash. Since we had 24 flashes in 10 seconds, or 2.4 flashes/sec, the change in average velocity was (2.4 cm/flash) (2.4 flashes/sec) = 5.8 cm/sec between successive time intervals of duration 10/24 sec.

The particular value 14 cm/sec² occurs in this experiment because we pulled with a particular force on a particular object. When we pull with other forces or pull on other objects, we usually obtain other values of the acceleration. But all experiments like the one just described show that under influence of a constant force the acceleration is constant.

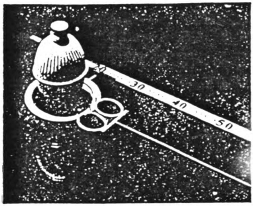


Figure 11–10
To apply twice the original force, we attach two identical loops to the puck.

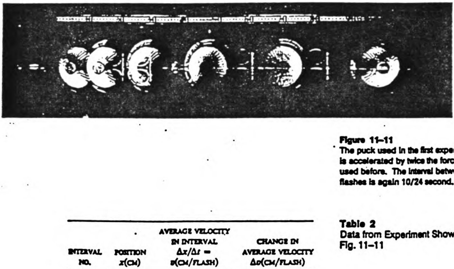


Figure 11–11
The puck used in the first experiment is accelerated by twice the force used before. The interval between flashes is again 10/24 second.

Table 2
Data from Experiment Shown in Fig. 11–11

INTERVAL NO.	POSITION x(CM)	AVERAGE VELOCITY IN INTERVAL $\Delta x/\Delta t = \bar{v}$(CM/FLASH)	CHANGE IN AVERAGE VELOCITY $\Delta \bar{v}$(CM/FLASH)
1	8.4	8.4	
2	21.5	13.1	4.7
3	39.3	17.8	4.7
4	61.9	22.6	4.8
5	89.3	27.4	4.8

These are the results of an experiment in which the applied force was twice that used in the first experiment (Table 1). The flash rate was again 2.4 flashes per second. Note that the change of average velocity and hence of instantaneous velocity is just twice as great as it was before.

APPENDIX K

MR. SIMON'S WORKSHEET ON NEWTON'S SECOND LAW EXPERIMENT

APPENDIX K

MR. SIMON'S WORKSHEET ON NEWTON'S SECOND LAW EXPERIMENT

Class Analysis::::

1. Identify your tape

constant mass / force	with A mass / force	of 1, 2, 3, 4
(circle)	(circle)	(circle)

Tape analysis:

d_1 =

d_2 =

v_1 =

v_2 =

No. of internals

t = ( ) .0083 sec = ________ sec.

$$a = \frac{v_2 - v_2}{\text{total}} = \_\_\_\_\_\_ \text{ cm/sec}^2$$

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.

(Document, September 29, 1986)

APPENDIX L

HANDOUT 32: NET FORCE AND ACCELERATION

HO-32 Net Force and Acceleration "Isaac's 2nd"

1. a) What is the relationship between the net force acting on an object and the acceleration of the object? How could you experimentally test it?
   b) Complete the table in the margin which lists some accelerations resulting from applying varying forces on a given object.

Force	Acceleration
F	4 m/s^2
2F	8
3F	12
$\frac{1}{2}$F	
$\frac{1}{4}$F	
5F	
	10
	3

2. A force F gives a Chevette an acceleration of 5 m/s^2. What force is needed to give the car an acceleration of:
   a) 1 m/s^2 b) 2 m/s^2 c) 7 m/s^2 d) 10 m/s^2

3. A slot car has an acceleration of .5 m/s^2 when a net force of 6 newtons acts on it. What's the acceleration when the net force is increased to 18 newtons?

4. a) If a ball is rolling at 20 cm/s and no net force acts on it, what will its speed be after 5 s?
   b) Suppose that a car increases its velocity so that it travels first at 30 mph, 35 mph at the end of the next second, 40 mph at the end of the next second after that, and so on. What can you say about the net force acting on the car?
   c) If the force of friction acting against a sliding object is 10 newtons, how much force must be applied to maintain a constant velocity? What is the resulting net force in this case? The acceleration?
   d) If we find an object which we know to be acted on by a force, but which is not moving, what inference can we draw?

5. a) What term is used to express the amount of inertia any object has?
   b) How does the mass of an object influence the acceleration of an object? Express your answer both mathematically and in words.
   c) Complete the table in the margin which lists some accelerations resulting from applying equal forces to objects of different mass.

mass	acceleration
m	30 m/s^2
2m	15
3m	
$\frac{1}{2}$m	
.2m	
45m	
	.3
	75

6. a) A pick-up truck can accelerate at 3 m/s^2. What is its acceleration if it is towing another truck like itself?
   b) A coffee can is balanced by three identical soda bottles on a balance. A certain force accelerates the coffee can at 2 m/s^2. How much will the same force accelerate one of the bottles? Two of the bottles?

7. A force gives a 15 kg object an acceleration of 12 m/s^2. What would the acceleration be if the mass were:
a) 5 kg b) 10 kg c) 30 kg d) 40 kg

8. a) What is Newton's 2nd law of motion? Express your answer both mathematically and in words.
b) What are the units of mass in the metric (MKS) system? The units of force?
c) What are the units of mass in the English (FPS) system? The units of force?

9. a) A little league pitcher exerts a net force of 90 newtons (90 N) on a .3 kg baseball. What is the ball's acceleration?
b) An EL athlete exerts a 150 N force on a shot while putting it with an acceleration of 20 m/s^2. What is the shot's mass?

10. How much force is needed to give a 2 kg object the same acceleration that a 25 N force gives to a 6 kg object?

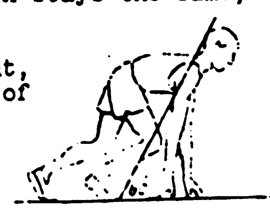
11. A force of 5 N gives a mass m_1 an acceleration of 8 m/s^2, and a mass m_2 an acceleration of 24 m/s^2. What acceleration would it give the two when they are fastened together?

12. A pull P applied to a laboratory cart gives it a measured acceleration. A load of ½ kg is then placed on the cart and now the same pull P is found to give only 3/4 of the previous acceleration. What can you say about the inertia of the cart compared with the inertia of the ½ kg load?

13. a) Explain the concept of <u>net force</u>, and how the force of friction enters into the determination of the net force.
b) A sled having a mass of 10 kg is being pulled by an 18 N force. If the force of friction is 2 N, what is the sled's acceleration?
c) A 6 N force is applied to a 2 kg cart in the lab. The acceleration is measured at 2 m/s^2. Find the frictional force.
d) A 2 kg book is pulled across the table with a 20 N force. It actually accelerates at 6 m/s^2. Find the frictional force.

14. A man pushes a box along a rough horizontal floor, exerting a push of 40 N. Friction exerts an opposite drag of 10 N on the box.
a) What is the actual accelerating force?
b) How hard should the man push, if friction stays the same, to double the acceleration of the box?

15. A 75 kg track star, at the start of a sprint, pushed on the ground with a measured force of 2000 N at an angle of 60°, as shown at the right. What forward acceleration was produced?



22. A 1500 kg car is traveling at 20 m/s and collides with another car during a demolition derby at the state fair. The car moves 3 meters forward while it is being brought to rest. What force (assumed constant) is exerted on the car during the collision?

23. A 6 kg object is moving at a constant speed of 15 m/s. What force is needed to bring the object to rest in 9 s?

24. An astronaut 100 m from his spaceship observes a 200 kg meteroid drift past him toward the ship at 11 m/s. If the astronaut can gain a hold on the meteroid and the astronaut's rocket gun is capable of delivering a force of 100 N, can he stop it before it hits the sp ceship? (Neglect the mass of the astronaut.)

25. The driver of a 600 kg sports car, heading directly for a railroad crossing 100 meters away, applies the brakes in a panic stop. The car is moving at 40 m/s and the brakes can supply a force of 4500 N.
   a) How fast will the car be moving when it reaches the crossing?
   b) Will the driver escape collision with a freight train which, at the instant the brakes are applied, is still blocking the road and still requires 6 s to clear the crossing?

26. A boy runs beside a wagon, pushing it into the wind until the wagon is going 6 m/s; then he jumps on. The combined mass of the boy and wagon is 50 kg. The wind exerts a force of 25 N on the boy and wagon in the opposite direction that the wagon is coasting.
   a) At what rate will the wagon's speed decrease? (Find acceleration)
   b) For how many seconds will the wagon coast forward before coming to a stop?
   c) If the boy stays on the wagon after it stops, how fast will the wind accelerate the wagon backward?

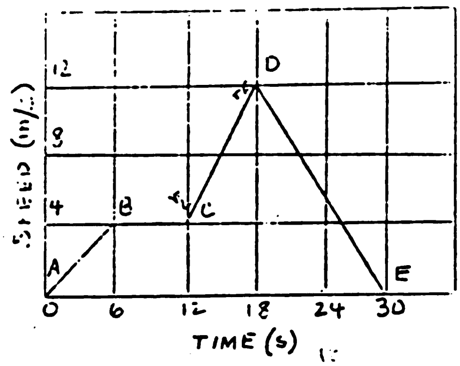
27. A 60 kg boy jumps from a window ledge 1.25 meters above a hard floor. Estimate the force exerted on him by the floor while he is stopping, by answering the questions below. Suppose that he foolishly forgets to bend his knees while landing so that the total "give" of his feet, etc., is only .025 meters (1 inch), in compression of floor, shoes, feet, ankles, spine, etc., during the stopping process.
   a) Show that the time of fall is .5 s.
   b) Find the speed of the boy at the end of his fall, just before landing.
   c) To calculate the time taken by the landing process we must find the boy's average speed during the landing process. Write down his speed just before he lands and his speed when he has finished landing; take the average. Use that average speed to find how long he takes for the process of landing, that is, how long he takes to travel .025 meters.
   d) You know his speed before landing and his speed after landing, so you know his change of speed; and you also know how long he took to make that change of speed. Calculate his acceleration during landing.
   e) Using F = ma, calculate the force the floor exerted on him during landing. Express this force in tons, using 1 ton = 10,000 newtons.

HO-32 (Con't.) "May the Force be with you."

16. All three phenomena - rest, uniform motion, and acceleration - could be more or less reasonable explained by an Aristotelian. Compare the Aristotelian and Newtonian explanation of the following phenomena:

a) an apple sitting on the desk
b) an apple dropping from a tree branch
c) an apple thrown through the air
d) a cart load of apples being transported to market

17. The graph to the right shows the speed at various times of Fonzie cruising the "strip".
a) Which section(s) indicate no net force acting on the "Fonz"?
b) When is the greatest net force in action?
c) Which section(s) indicate a force acting in the opposite direction of motion?
d) Which section(s) indicate that the direction of motion was reversed?
e) If Fonzie and his "chopper" have a mass of 250 kg, find the acceleration and net force during interval CD.



18. A 220 kg rocket-driven sled develops a thrust of 6600 N.
a) What is the sled's acceleration?
b) If the rocket fires for 20 s., how fast will the sled be going?

19. A 1500 kg car is advertised in a popular magazine to accelerate from a standing start to 60 mi/hr (27 m/s) in 10s. Find
a) the car's acceleration
b) the net force exerted on the car
c) the distance traveled in those 10 s.

20. A hockey puck(.25 kg)slides on the ice for 100 meters before it stops. If its initial speed was 20 m/s, what was the retarding force of friction between puck and ice?

21. A 60 kg toboggan is coasting along with a speed of 10 m/s over smooth snow and ice. It enters a rough stretch of ice 6 meters long in which the retarding force of friction is 120 N. With what speed does the toboggan emerge from the rough?

APPENDIX M

TRANSCRIPTION CONVENTIONS

APPENDIX M

TRANSCRIPTION CONVENTIONS
(Adopted from Lemke, 1982a)

Citation: Videotape, Oct. 12, 86 means the videotape was taken on October 12, 1986.

Speakers: The teacher is the speaker unless otherwise indicated. On many occasions the teacher's names are identified by Mr. Ellis, Mr. Simon and Mr. Howard (not their real names). Sometimes the letter T is used, instead.

Students names appear under pseudonyms. If the name cannot be identified, then we see ST (for student) and ST (for another student).

Dialogue: The Dialogues are shown as if speakers (students and teachers) alternate. In this sense, no overlapping is shown in spite of the fact that overlapping is common in classroom dialogues.

Symbols: ((. . .)) enclose analyst's note of nonverbal information.

( ) with blank interior is speech not resolved or unintelligible.

. . . is used for minimal pause or hesitation.

(5) gives time in seconds or longer pauses.

. followed by a capitalized word other than proper name is used to end a sentence and begin a new one.

? questioning intonation.

! exclamatory intonation.

" " speaker's exact wording.

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