

ABSTRACT

Title of Dissertation: LEARNING NEWTON'S SECOND LAW USING A
MICROCOMPUTER BASED LABORATORY
CURRICULUM

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This study investigated the effect of theory-based Microcomputer Based Laboratory instruction on high school students' understanding of Newton's second law in a high school physics course taught by the teacher-researcher. The study focused on 1) the effect of the theory-based MBL instructional design on student understanding of Newton's second law, 2) on the changes in conceptual understanding that occurred, and 3) on the effect of student learning beliefs on conceptual change. Data sources included pretest and posttest measures of conceptual understanding, audiotape debriefings of students during a seven day unit, and pretest and posttest measures of students' motivational and self-regulated learning beliefs.

The design of the instructional unit was based on prior research and theory. It is important to specify the characteristics as well as the

content of the knowledge we would like students to construct. Desirable characteristics of physics knowledge are that it be accurate, extendable, integrated with other knowledge, recognized as knowledge, related to experience and experiment, strategic, and available in multiple representations including verbal, graphical, algebraic, pictorial, and story representations. Proponents argue that appropriately designed Microcomputer Based Laboratory instruction can promote construction of such knowledge.

The theory-based instructional unit employed real-time computer graphing of force and motion variables in a novel "iconographic" experiment which enabled students to determine the relationship between force and motion variables by simple recognition. The study found that the nature of students' conceptual change was consistent with the mechanisms postulated for MBL instruction, that the short chain of reasoning in the iconographic force and motion experiment allowed students to readily identify and focus on the goals of the experiment rather than be distracted by a profusion of sub-goals, that this instruction is more effective than some traditional instruction and as effective as some other theory-based instruction in Newton's second law, based on Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) and Force and Motion Concept test (Thornton, 1992a) scores. The study failed to achieve the goal of relating motivational, cognitive and performance measures using the Motivated Strategies for Learning Questionnaire (Pintrich & DeGroot, 1990).

LEARNING NEWTON'S SECOND LAW USING
A MICROCOMPUTER BASED LABORATORY
CURRICULUM

by
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Robert Alan Morse

1995

DEDICATION

To my parents, Norman and Martha Morse
my children, Richard, Alan and Danielle,
and especially
to my lovely wife, Mimi.

My thanks and love go to my children, Elroy, Alan and Danielle,
who have helped and encouraged me through many years.
Finally, I could not have done this without the encouragement, support
and love of my wonderful wife, Mimi.

Thank you all.

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
CHAPTER ONE	1
Introduction.....	1
Rationale	2
Goals.....	6
Research Questions.....	8
CHAPTER TWO.....	10
Background, Definitions and Review of the Literature.....	10
Overview.....	10
Newton's Second Law: Definition of Terms	10
Terms Describing the Motion or Kinematics of an Object	11
Terms Describing the Dynamics of an Object.....	15
The Importance of Newton's Second Law in Classical Mechanics.....	17
The Importance of Understanding Newton's Second Law	17
Cognition, Learning and Physics.....	18
Theory-Based Instruction	19
Knowledge	21
Declarative, procedural and conditional knowledge.....	21

Conceptual knowledge.....	22
Metacognitive knowledge.	22
Tacit and explicit knowledge.....	22
Forms of knowledge representation.	23
Constructing Knowledge	24
Goals for Student Knowledge Outcomes	26
Student Difficulties in Learning Physics: Prior	
Knowledge.....	27
Nature of Prior Conceptual Knowledge.....	27
1) Incomplete knowledge.....	28
2) Undifferentiated knowledge.....	28
3) Incorrect knowledge.	29
4) Simplistic knowledge.....	29
5) Cognitive and epistemological beliefs.....	30
Details of Students Prior Conceptual Knowledge	
Related to Concepts of Force, and the	
Relationship Between Force and Motion.....	31
A Taxonomy of Misconceptions	32
Microcomputer Based Laboratory Tools.....	36
Microcomputer Based Laboratory Instruction	38
MBL–Assertions by Proponents.....	38
1) Reduced drudgery.	39
2) Immediate representation.....	39
3) Simultaneous kinesthetic and abstract	
representation.....	40
4) Rapid repetition of results.....	41

5) Encourages exploration.....	41
Research on MBL Effectiveness.....	42
Implications of Cognitive Theory for Theory-Based MBL Instruction	46
Conceptual Change Teaching Strategies in Instructional Design	50
Relating Motivation, Self-Regulated Learning and Performance to Theory-Based MBL Instruction....	54
Three Alternative Teaching Sequences for Newton's Second Law	58
A traditional teaching Sequence for Newton's Second Law	59
An Inquiry Based Teaching Sequence for Newton's Second Law	60
A Theory-Based MBL Sequence for Teaching Newton's Second Law	64
CHAPTER THREE.....	71
Research Design and Procedures.....	71
Overview.....	71
Methodology.....	72
Participants.....	72
Timing of Instructional Activities.....	73
Data Sources.....	74
Audio Tape Debriefing Questions	76
Preparatory experiences.....	78
Pilot group.....	78

Experimental group.....	79
Data Analysis.....	79
Analysis For Research Question 1a.....	81
Analysis Procedure.....	81
Detailed Analysis Procedures.....	82
a) Initial knowledge state.....	82
b) Immediate knowledge change.....	84
i) Force-acceleration relationship.....	84
ii) Force-acceleration application: verbal responses.....	85
c) Force-acceleration application: immediate posttest.....	86
d) Force-acceleration application: final exam.....	87
Analysis For Research Question 1b.....	90
Analysis Procedure.....	90
Evaluating students' initial conception.....	91
Evaluating understanding of the description and purpose of the experiments.....	91
Immediate Conclusion and Graphs.....	92
Persistence of conclusions.....	95
Summary table.....	95
Analysis For Research Question 1c.....	97
Analysis Procedure.....	97
Description of activities and objectives.....	99
Analysis For Research Question 1d.....	101
Analysis Procedure.....	101

Analysis For Research Question 2a	103
Test Instruments.....	103
Statistical Tests	104
Analysis For Research Question 2b	105
Overview.....	105
Force Concept Inventory Measures.....	106
Thornton Force and Motion Test Measures.....	106
Student Descriptions of Their Learning	
Activities	107
Student Description of Conceptual	
Understanding	108
Organization and Analysis of Data.....	109
Analysis For Research Question 2c.....	110
Data Sources.....	110
Comparisons Using the Force Concept	
Inventory.....	111
Analysis For Research Question 3a	112
Analysis For Research Question 3b	115
Reliability Of Ratings.....	115
CHAPTER 4	117
Results and Discussion.....	117
Overview.....	117
Confounding factors	117
Attendance.....	117
Small numbers and incomplete test results.....	117
Overtesting.....	117

Audio tape debriefing.....	118
Research Question 1a Results.....	119
Overview.....	119
Student 301.....	120
Student 302.....	122
Student 304.....	124
Student 305.....	126
Student 307.....	128
Student 308.....	130
Student 309.....	133
Student 310.....	135
Student 313.....	137
Student 314.....	139
Student 315.....	142
Student 316.....	144
Student 317.....	146
Summary: initial knowledge.....	148
Summary: immediate knowledge.....	148
Summary: final knowledge.....	150
Research Question 1b Results.....	152
Research Question 1c: Results	155
A) Comparison by day.	155
B) Comparison by Investigation.....	158
Research Question 1d: Results.....	160
Activities Identified by Students.....	160
Research Question 2a: Results.....	166

Pretest to Final Exam Comparisons.....	166
Pretest to Final Exam Commentary.....	167
Analysis of the 5 Question FCI Sub-test.....	167
Research Question 2b: Results.....	170
Success Rate Results.....	170
Success Rates Related to Learning Activities	
Score from 1b.....	172
Success Rates Related to Learning Activities	
Score from 1d.....	174
Success Rates Related to Conceptual	
Understanding	176
Summary.....	177
Research Question 2c: Results	178
Comparisons Using the Force Concept	
Inventory:.....	178
Comparison of Pretest scores:	180
Comparison of Posttest Scores:.....	182
Comparisons with 5 Question Sub-test of FCI.	184
Comparison of Gain Scores: Entire FCI Test.....	188
Comparison with Relative Gain (g) Scores.....	189
Comparisons Using the Thornton Motion Test.....	190
Velocity question comparisons.	191
Acceleration question comparisons.	192
Force on Sled Questions comparison:.....	193
Force graph questions comparison.....	195
Research Question 3a Results.....	198

MSLQ Correlations.....	198
Motivational and Cognitive Strategy	
Correlations	198
Motivation, Self-Regulated Learning and	
Performance Relations.....	200
Performance versus posttest scores.	201
Research Question 3b Results.....	203
CHAPTER 5	205
Conclusions	205
1. Effect of Instructional Design.....	206
Research Question 1a.....	206
Research Question 1b.....	208
Research Question 1c.....	210
Research Question 1d	211
Conclusions from Research Question 1	213
2. Test Measures of Changes in Conceptual	
Understanding.....	214
Research Question 2a.....	214
Research Question 2b.....	215
Research Question 2c.....	217
Conclusions from Research Question 2	220
3. Effect of Student Learning Beliefs.....	222
Research Question 3a.....	222
Research Question 3b.....	222
Conclusions from Research Question 3	225
Some Commentary from the Perspective of the	

Teacher-Researcher	227
Final Conclusions and the Importance of this Study.....	230
Delimitations of the Study	231
Directions for Future Research.....	232
Implications for Instruction.....	234
APPENDIX A: Experimental Teaching Unit.....	235
APPENDIX B: Force Concept Inventory.....	255
APPENDIX C: Thornton Force And Motion Test.....	265
Motivated Strategies for Learning Questionnaire.....	269
Questionnaire as given to students.....	270
Questionnaire items grouped by scales.....	273
Motivational beliefs.....	273
A. Self-Efficacy	273
B. Intrinsic Value.....	273
C. Test Anxiety	273
Self-Regulated Learning Strategies.....	274
D. Cognitive Strategy Use	274
E. Self-Regulation.....	274
APPENDIX E: Tape Interview Questions.....	275
Questions Day 1.....	275
Questions Day 2.....	276
Questions Day 3.....	277
Questions Day 4.....	278
Questions Day 5.....	279
Questions Day 6.....	280

LIST OF TABLES

<u>Table</u>	<u>Page</u>
Table 1 Misconceptions Taxonomy from Hestenes et al, 1992.....	32
Table 2: PSAT scores for study group students.....	73
Table 3: Initial conceptions and misconceptions.....	83
Table 4: Newtonian responses to selected FCI questions.....	83
Table 5: Active Force Misconceptions from selected FCI questions.....	84
Table 6: Force, acceleration and velocity relationship matrix.....	85
Table 7: Newtonian conception rating criteria for immediate posttest Thornton and FCI questions.....	87
Table 8: Sample table of student conceptions and changes in conceptions during experimental sequence.	88
Table 9: Force, acceleration and velocity relationship matrix.....	94
Table 10: Activities and objectives of the instructional unit.....	99
Table 11: Knowledge changes for student 301	120
Table 12: Knowledge changes for student 302	122
Table 13: Knowledge changes for student 304	124
Table 14: Knowledge changes for student 305	126
Table 15: Knowledge changes for student 307	128
Table 16: Knowledge changes for student 308	130
Table 17: Knowledge changes for student 309	133
Table 18: Knowledge changes for student 310	135
Table 19: Knowledge changes for student 313	137
Table 20: Knowledge changes for student 314	139

Table 21: Knowledge changes for student 315	142
Table 22: Knowledge changes for student 316	144
Table 23: Knowledge changes for student 317	146
Table 24: Newtonian score for day 5, day 6&7, and application questions.....	148
Table 25: Newtonian scoring for FCI final, and Thornton test questions for immediate posttest, final and delayed posttest.	150
Table 26: Summary of scores for RQ 1b.....	152
Table 27: Goal and Sub-goal percentages by day. Goal/Subgoal/Missing, Unclear, No data in %	155
Table 27: Identification and focus by investigation.....	158
Table 28: responses by day	162
Table 29 responses by category	163
Table 30: References to particular experiments.....	164
Table 31: FCI pretest and posttest comparisons.....	166
Table 32: 5 question FCI sub-test gains	168
Table 33: 5 question sub-test: pretest to final gains.....	168
Table 34: High and low ratings for research question 2b.....	171
Table 35: 1b Learning activities score correlated with success rates.....	172
Table 36: 1d Learning activities correlated with success rates.....	174
Table 37: Conceptual understanding correlated with success rates.....	176
Table 38: FCI comparison data	178
Table 39: FCI comparisons sorted by pretest score	180

Table 40: T-tests for differences-study and comparison groups....	181
Table 41: FCI comparisons sorted by posttest scores.....	182
Table 42: T-test for study group and Interactive Engagement posttest scores	184
Table 43: FCI sub-test comparisons	185
Table 44: FCI sub-test comparisons by question-immediate posttest.....	186
Table 45: FCI sub-test comparisons by question-final exam	187
Table 46: FCI comparison scores sorted by gain scores.....	188
Table 47: t-test for FCI gain score differences	189
Table 48: FCI comparisons sorted by g scores.....	189
Table 49: Pretest and posttest MSLQ correlations	198
Table 50: MSLQ and test performance correlations.....	200
Table 51: Pretest to posttest comparisons of MSLQ scores	203

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Figure 1: Graphical interpretation of average and instantaneous velocity	14
Figure 2: Information Processing Model.....	26
Figure 3: Motion detector.....	36
Figure 4: Force probe.....	37
Figure 5: Modified force probe.....	37
Figure 6: Set up for the iconographic force and motion experiment.....	67
Figure 7: Graphs from the force and motion experiment	68
Figure 8: Identification of goals by day	157
Figure 9: Focus on goals and sub-goals by day.....	157
Figure 10: Identification of goals and sub-goals by investigation.....	159
Figure 11: Focus on goals and sub-goals by investigation.....	159
Figure 12: High School Kinematics: velocity questions: Study38 students posttest compared with 8 Mass. High Schools pretest and posttest results. (Thornton, 1993)	191
Figure 13: High School Kinematics: Acceleration Questions. Study38 students posttest results compared with 8 Mass. high schools pretest and posttest results	192
Figure 14: Force Sled questions: Study38 students immediate posttest and final examination compared with U. of Oregon non-calculus physics course pretest and posttest results.....	194

Figure 15: Force Graph Questions: Study38 students

immediate posttest results compared with U. of Oregon
non-calculus physics pretest and posttest results. 195

Figure 16: Oregon non-calculus 89/90 force questions, pre-

lecture and post-lecture instruction results, with out MBL
use..... 197

CHAPTER ONE

Introduction

The purpose of this study was to investigate the effect on student understanding of the relationship between motion and force by instruction based on cognitive theory, using microcomputers interfaced with laboratory instruments as a primary instructional tool. The investigation of the effect of theory-based Microcomputer-Based Laboratory instruction on student learning and motivation was carried out in a high school physics class taught by the researcher. The instructional unit used for this study was a one-week unit on Newton's Second Law using a novel MBL experiment to relate force and motion. The experiment, described in detail in Chapter Two, uses the real time graphing capabilities of a microcomputer interfaced with laboratory equipment to allow students to create an immediate *iconographic* representation (defined below) of the relationship between force, acceleration and velocity for a moving cart. This experiment was described in an informal action research report by Morse (1993b), whose conclusions were based initially on a single posttest measure and on anecdotal descriptions of student performance. The present study replicates and extends the earlier work using a revised instructional unit in order to explore the effect of the instructional design on student knowledge, the conceptual changes that occur, and the interaction of instructional design, academic performance and students' motivational and cognitive beliefs.

The intent of this research was to extend and improve our understanding of the fine structure of conceptual change during Microcomputer Based Laboratory instruction in physics, to improve

understanding of the interplay of instructional design and conceptual change, to improve classroom practice, and to extend the research base of conceptual change in authentic classroom contexts.

Rationale

Several developments in science education over the last two decades have the potential to affect design of classroom instruction in physics. Constructivist models of learning (Shuell, 1985; von Glaserfeld, 1992) provide a theoretical base which can inform the design of instruction. Information processing models of cognitive function (Bransford, 1979; Simon, 1991) detail some of the abilities and limitations of human cognition, defining constraints on instructional design but pointing directions as well. Research into student difficulties in learning physics has described the nature and extent of the prior knowledge that students are likely to bring to the physics classroom, allowing instructional design to take this prior knowledge into account (Arons, 1990; diSessa, 1993; Dykstra, Boyle, & Monarch, 1992; Hestenes, et al., 1992; McDermott, 1984; Minstrell, 1992). Other research has demonstrated the failure of traditional lecture instruction to effect significant change in students' conceptual understanding (Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b). This has led several groups to propose and test new instructional strategies aimed at effecting conceptual change (Scott, Asoko, & Driver, 1992). Research by educational psychologists in effects on academic performance of self-regulated learning, metacognitive strategy use and the motivational beliefs of students (Pintrich & DeGroot, 1990) gives additional guidance to design of instruction, and specifies additional variables of concern.

The rapid development of powerful microcomputers and

hardware and software techniques for real time graphing of experimental data in classroom laboratories, referred to as Microcomputer Based Laboratory (MBL) tools has supplied a powerful tool for use in classroom physics instruction (Thornton, 1987; Tinker, 1991). Finally, re-examination of the epistemology of school physics from both theoretical and instructional viewpoints (Arons, 1990; Hestenes, 1992; Rothman, 1989) has led some workers (Laws, Thornton, Sokoloff, & Dykstra, 1991; Morse, 1992b) to propose a re-ordering of the sequence of experiences for learning Newtonian mechanics.

Thornton, Sokoloff and Laws (Laws, 1991; Sokoloff, Laws, & Thornton, 1992; Thornton & Sokoloff, 1990), Linn and Songer (1991) and Morse (1992a) among others, have developed and tested instructional units based on the theory and research described above which rely heavily on the use of MBL tools as an instructional tactic. The effect of such instruction has been described in a few studies for middle school students studying heat and temperature (Linn, Layman, & Nachmias, 1987) and for college and high school students studying kinematics (Thornton & Sokoloff, 1990). Another study examined the effect of delaying presentation of graphs of experimental data (Brasell, 1987). The recent addition of a force probe to the set of MBL tools has permitted the development of MBL based instructional strategies for teaching the relationship between forces and motion, (Laws, 1991; Morse, 1992a; Sokoloff, et al., 1992; Thornton & Sokoloff, 1990), a particularly difficult but important area of physics instruction (diSessa, 1993; Hestenes, et al., 1992). Researchers working with MBL instruction involving force and motion have described significant gains in student performance on conceptual tests (Morse, 1992a; Thornton

& Sokoloff, 1990), but there has been little published investigation of the character of student reasoning and learning during theory-based instruction using MBL tools. There is a need to investigate carefully the process of conceptual change brought about by experiments using real-time graphing. Research of this nature may allow us to develop more accurate and comprehensive models of the learning that occurs during MBL use and provide a detailed description of learning by a variety of students to enhance our present models of student learning using MBL tools.

An important consideration is the research setting. Significant criticisms of science education research include the observations that the research is poorly linked to the practice of science teaching and has little influence on classroom practice (Holliday, 1990).

Linn (1986, p 23), argues that "research conducted in real educational settings provides new insights into the nature of cognitive and instructional processes,...permits trial and refinement of innovations and is thus far more likely to influence science education practice." and again (1992) that "The recent advances in our understanding of learning and instruction are necessary but far from sufficient to yield science education reform. These ideas are best refined and elaborated in science classrooms."

Hurd (1991) suggests "we especially need a system for the transfer and implementation of research in the classroom, somewhat like the agriculture model. As yet we do not have a conduit between the researcher and the classroom."

This system for transfer and implementation may be particularly strengthened if research is done in the classroom, but only if this research is broadly distributed. There are in fact a few projects that have transferred

research responsibilities to practicing teachers. The collaborative efforts between teachers and researchers in the work of Linn (Friedler, Nachmias, & Linn, 1990; Linn & Songer, 1991) are one example. McDermott (1991) and the Physics Education Group at the University of Washington have incorporated teacher training as part of their cycle of research, curriculum development and revision. Members of the group have also solicited the collaboration of both college and high school teachers in their work. Formal research in classroom contexts by independent teacher-researchers is exemplified in physics education by the work of Minstrell (1982; 1992) . Action Research, (Feldman, 1992; Hopkins, 1993) in which teachers engage in less formal individual or group research in their own classrooms is another possibility.

The critiques by Holliday, Hurd and Linn point to a need for research conducted in the classroom. In addition, they all note the need to have research influence practice. A specific intent of the present study is to combine knowledge of educational research, knowledge of curriculum and knowledge of physics to carry out research in a classroom setting, and to communicate this work in the physics teaching community. Particularly in high school teaching, the teacher-researcher may be able to communicate the advantages of research-based instructional practices to the broader audience of teachers more effectively than researchers can.

Hurd (1991) specifically identifies curriculum as the area where research is most needed. "Cognitive scientists are interested in how knowledge is acquired, but they do not directly consider the curriculum or its context. Science educators have been restating the goal of science teaching, but have neglected to identify the supporting subject matter

changes and the curriculum organization essential for achieving the reformulated goals....Currently the most crucial and neglected issue in science education is a well-structured curriculum that recognizes the new instructional goals, is provocative for the student, and can be taught operationally. The researcher has the intriguing task of carrying on studies that consider jointly cognition, instruction and curriculum, so that the quality of learning and achievement can be raised to new heights."

Although the present study uses a curriculum segment which covers the same subject matter as the standard curriculum, the emphasis and structure of the unit has been significantly changed, specifically taking account of the interplay of "cognition, instruction and curriculum", and thus addressing part of Hurd's concern.

Hurd may overstate the lack of transfer of knowledge between research and teaching in physics education, but he correctly suggests a need for classroom based research that speaks to the concerns of both researchers and teachers. Classroom research drawing on multiple sources of data to provide a rich description of conceptual change brought about by theory-based instructional design offers one method of meeting this need, providing information that can simultaneously advance our knowledge of learning, the process of instructional design and the practice of teaching.

Goals

To accomplish the purposes of this study, five goals were selected:

- 1) to generate a rich description of the process of conceptual change during a week of MBL instruction on Newton's Second Law for an entire class of students using pretest and posttest measures and self-report surveys, 2) to describe the relationship of the instructional design to the process of

conceptual growth and change in order to improve understanding of how the elements of the instructional unit affect student learning, 3) to relate the changes in conceptual understanding as seen with pretest and posttest questions to changes seen in student self-report interviews, 4) to use the pretest and posttest measures to compare the conceptual change and/or final conceptual state of students in this study with data obtained on the same measures for students experiencing other forms of instruction, 5) to examine and describe the interaction of students' cognitive beliefs, motivational beliefs, conceptual change and the instructional design.

The research questions for this study were selected to study the effect of the instructional design on students' conceptual understanding, to detail the changes in their conceptual understanding, and to investigate the effects of students' beliefs about learning on their learning and the possible effect of MBL instruction on students' learning beliefs.

Research Questions

The research questions for this study were:

1. Effect of instructional design

a) What is the nature of student reasoning activities and cognitive change during classroom MBL instruction, in particular the understanding derived from real-time graphs of experimental data?

b) What evidence is there that the nature of the conceptual change is consistent with the mechanisms posited in the instructional design, in particular that the “iconographic” experiment (described in chapter 2) relating force and motion is an effective learning activity?

c) What evidence is there that this instructional design allows students to identify and focus on important conceptual goals of experiments rather than subgoals?

d) Which instructional activities and what aspects of the instructional design do students identify as effective for their learning?

2. Changes in conceptual understanding

a) What are the changes in student success rates on measures of conceptual understanding applied before and after instruction specifically in regard to Newton’s Second Law?

b) Do changes in student success rates on conceptual measures relate to students’ descriptions of their learning activities and conceptual understanding?

c) What is the comparison between student success rates on conceptual measures of students in this study and the student success rates reported for students in traditional instructional settings and in other

theory based instructional settings?

3. Effect of student learning beliefs

a) How are motivational and self-regulated learning beliefs of students related to success rates on conceptual measures in the MBL classroom?

b) What effect does theory based MBL instruction have on the motivational and self-regulated learning beliefs of students.

CHAPTER TWO

Background, Definitions and Review of the Literature

Overview

This chapter describes the background of the study, defining the terminology of the physics, the pedagogy and the theory and placing the study in the context of other research. The terminology for Newton's second law, for the kinematics and for the dynamics of a moving object are defined, and the importance of this material for understanding physics is described first. Then the interplay of cognition, learning and physics is described, including the kinds of knowledge, the construction of knowledge, goals for student knowledge outcomes, the difficulties students have in learning physics, the nature of students' prior knowledge in general, and the specifics of prior knowledge in the realm of force and motion. Microcomputer Based Laboratory instruction is reviewed, with a description of the equipment used, discussion of the arguments for MBL instruction and research on MBL effectiveness, and the implications of cognitive theory for the design of MBL instruction. Conceptual change teaching strategies are reviewed, and three teaching sequences, a traditional lecture sequence, an inquiry based sequence, and the theory-based MBL sequence used in this study are described and contrasted. Finally, the relations between motivation, self-regulated learning and performance are considered.

Newton's Second Law: Definition of Terms

Newton's second law of motion is the central relationship in the set of laws which describe the Newtonian conception of cause and effect in

the interactions of moving and stationary objects (Arons, 1990, ch 3; Hestenes, et al., 1992). In the Newtonian view, the combination of interactions of a given object with other objects (the *net force*) causes a change in the state of motion of the object (an *acceleration*). The amount of net force required to cause a unit acceleration is described by a property of the object called the *inertial mass*.

Arons (1990) notes that the presentation of Newton's laws in most textbooks pays insufficient attention to operational definitions of the terms and concepts. Before proceeding further, it is necessary to define the technical terms from physics that will be employed in this study and at the same time to give some indication of the sequence in which the concepts described here will be presented to students.

The instructional unit that is the focus of this study is concerned with the dynamics or causes of motion of an object. A pre-requisite to developing this understanding is a knowledge of the kinematics or the description of motion of an object. Thus the sequence of definitions presented here begins with kinematics, defining and distinguishing the concepts of position, velocity and acceleration of an object moving along a straight line path. It continues by defining force from a primitive, kinesthetic idea of force and proceeds to determine the relationship between force and motion by experiment. The order of presentation of ideas is consistent with a sequence that Arons (1990) refers to as the "Newtonian" sequence, and with the New Mechanics sequence advocated by Laws and others (Laws, et al., 1991; Morse, 1992b).

Terms Describing the Motion or Kinematics of an Object

The general term *motion* is used to refer to the undifferentiated,

qualitative description of the position of an object as a function of time, or when reference is made collectively to more than one of the motion variables.

Kinematics is the formal term meaning the description of the position, velocity and acceleration of an object as a function of time, without reference to the causes of the motion.

Dynamics refers to the study of the causes of motion and changes in motion of objects relating the observed motion of objects to the external influences or forces acting on objects and to the intrinsic properties or masses that determine how much response objects have to the forces.

The following definitions refer to one-dimensional descriptions of the kinematics of an object.

The *position* of a moving object is operationally defined by reading the number on a scale that is next to the object. (A zero or reference position must be chosen, scales set up leading away from the reference and a direction chosen as positive.) Any process that gives a result consistent with this primitive definition of position is acceptable to measure the position. The algebraic symbol x is used to represent the position of the object.

The *time instant* at which an event occurs is defined as the clock reading or number shown on a clock located at the position where the event occurs. (A zero or reference time must be chosen and an array of synchronized clocks provided. It is explicitly assumed that clocks which are synchronized at one time position and time instant will remain synchronized regardless of change in position or speed of the moving object.) Any process that will give a result consistent with this primitive

definition of time instant is acceptable to measure the time instant. The algebraic symbol t is used to represent the time instant.

The *displacement* or *change in position* of a moving object between two positions is defined as the algebraic difference subtracting the value of the earlier position of the object from the value of the later position of the object. The algebraic symbol Δx is used to represent the displacement of the object.

The *distance travelled* by a moving object is defined as the sum of absolute values of displacements, each of which is made while travelling only in one direction. For example, a student who walks from one end of a 100 meter track to the other and back again would have a displacement of zero meters, but a distance travelled of 200 meters.

The *time interval* between two time instants is defined as the algebraic difference obtained by subtracting the value of the earlier time instant of the object from the value of the later time instant. The algebraic symbol Δt is used to represent the time interval.

The *average velocity* of a moving object is defined as the ratio of the displacement of an object to the time interval during which the displacement occurs. It can also be calculated as the slope of the secant line joining the points representing the two positions on a position-time graph (See Figure 1). The algebraic symbol v_{av} is used to represent the average velocity.

The *instantaneous velocity* of a moving object is defined as the limit of the average velocity as the time interval is reduced towards zero. It can also be calculated as the slope of the tangent line to a position-time graph representing the motion of the object (See Figure 1). The algebraic

symbol $\underline{v}$ is used to represent the instantaneous velocity.

The *average speed* of a moving object is defined as the absolute value of the average velocity, and the *instantaneous speed* of a moving object is defined as the absolute value of the instantaneous velocity. Thus the concept of speed considers the magnitude of the velocity, but does not consider the direction of motion.

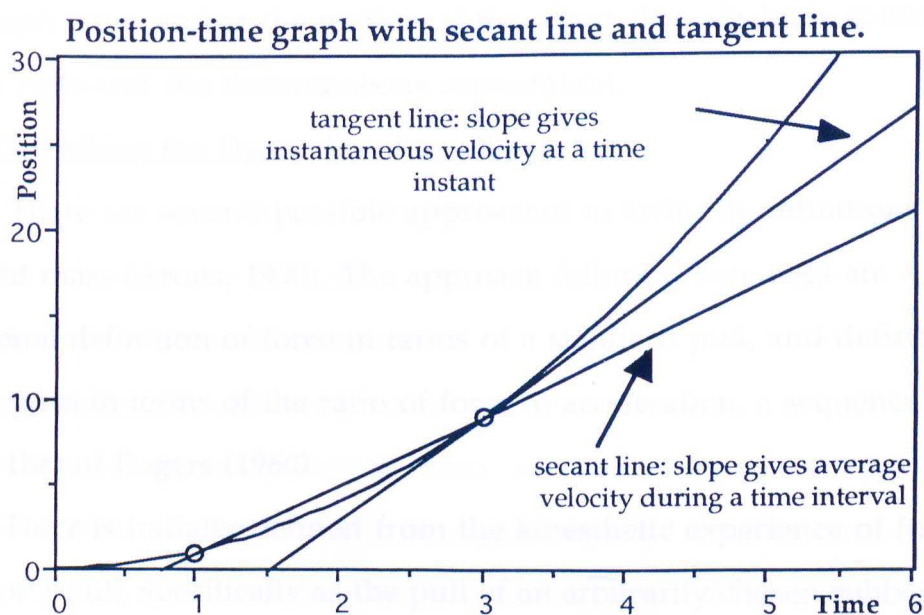


Figure 1: Graphical interpretation of average and instantaneous velocity

The *change in velocity* of a moving object is defined as the algebraic difference subtracting the value of the earlier *instantaneous velocity* of the object from the value of the later *instantaneous velocity* of the object. The algebraic symbol Δv is used to represent the change in velocity of the object.

The *average acceleration* of a moving object is defined as the ratio of the change in instantaneous velocity of an object to the time interval

during which the change of instantaneous velocity occurs. It can also be calculated as the slope of the secant line joining the points representing the two instantaneous velocities on a velocity-time graph. The algebraic symbol $\underline{a}_v$ is used to represent the average acceleration.

The *instantaneous acceleration* of a moving object is defined as the limit of the average acceleration as the time interval is reduced towards zero. It can also be calculated as the slope of the tangent line to a velocity-time graph representing the motion of the object. The algebraic symbol $\underline{a}$ is used to represent the instantaneous acceleration.

Terms Describing the Dynamics of an Object

There are several possible approaches to arrive at definitions of force and mass (Arons, 1990). The approach followed here uses an operational definition of force in terms of a standard pull, and defines the inertial mass in terms of the ratio of force to acceleration, a sequence which follows that of Rogers (1960).

Force is initially defined from the kinesthetic experience of force as a push or a pull, specifically as the pull of an arbitrarily chosen rubber band stretched to a given length. A discrete force scale is then established using the pull of multiple identical rubber bands arranged side by side and stretched to the specified length to give multiples of the original force. A *continuous force scale* is established by observing a linear relationship between the force applied to a spring by different numbers of stretched rubber bands and the consequent extension of the spring from its length with no force applied. This leads to a re-definition of force as the pull measured by the extension of a standard spring, in particular a calibrated spring scale. Any process that will give a result consistent with this

primitive definition of force is acceptable to measure the force (Rogers, 1960). The algebraic symbol $\underline{F}$ is used to represent force. Subscripts may be added to label different forces according to the kind of interaction. Thus $\underline{F}_g$ could indicate a gravitational force, $\underline{F}_f$ a frictional force, etc.

The *combination of forces, combined force or net force* is defined as the combined effect of two or more forces in either the positive or the negative direction as measured by the extension of a single standard spring or any equivalent process. Net force is the usual textbook terminology for this quantity, but in this study the preferred term is combination of forces. The algebraic symbol $\Sigma \underline{F}$ is used to represent the combination of forces.

An experiment or sequence of experiments is used to establish the causal link between the combination of forces acting on a single object and the motion of that object, namely that the combination of forces acting on the object causes an acceleration of the object in direct proportion to the combination of forces. This result forms one part of the relationship which is called Newton's second law.

Experimentally, we find that the same combination of forces causes different values of acceleration in different objects. The *inertial mass* of an object is defined as the ratio of the combination of forces acting on the object to the consequent acceleration of the object, or as the amount of combined force needed to produce a unit acceleration of the object. This quantity can also be calculated as the slope of the graph of the combination of forces as a function of acceleration of the object. The algebraic symbol $\underline{m}_i$ or simply $\underline{m}$ is used to represent the inertial mass. This experimental observation and consequent definition of inertial mass forms the second part of Newton's second law.

The Importance of Newton's Second Law in Classical Mechanics

The sequential development of definitions and experimental results just described leads logically to the expression of the cause and effect relationship between dynamics and kinematics, with the combination of forces acting on the inertial mass of the object as causes and the observed acceleration of the object as the effect. This is the relationship called Newton's second law. An understanding of the specific nature of this cause and effect relationship is considered essential to an understanding of the Newtonian world view that all motions and changes of motion of objects under all conditions can be understood, at least in principle, as the effect of the combined interactions of the objects; that the apparent complexity of motions and causes can be understood by the application of a small number of universal principles or laws.

The Importance of Understanding Newton's Second Law

The development of a rich understanding of Newton's second law marks a transition for students from explaining the behavior of the physical world with a large set of disconnected, situation specific rules (diSessa, 1993; Minstrell, 1992) to explaining the behavior of the physical world with a smaller set of pervasive organizing principles. Extension of this notion of explainability to other areas of physics and transfer of this notion to other sciences are hallmarks of understanding the fundamental nature of scientific knowledge, a goal of scientific literacy (Project 2061, 1990).

Cognition, Learning and Physics

Physics has been a favorite field for cognitive research since the work of Piaget (Ginsburg & Oppen, 1969) and of Newell and Simon (1972). Studies have examined the process of problem solving in physics (Newell & Simon, 1972; Reif, Larkin, & Brackett, 1976), the differences between successful and unsuccessful problem solvers and novice and expert problem solvers (Chi, Feltovich, & Glaser, 1982), the representation of information and its relationship to problem solving (Reif & Heller, 1982), the conceptual difficulties students have with physics and techniques for doing physics, for learning physics and for teaching physics (Champagne, Klopfer, & Anderson, 1980; diSessa, 1982; diSessa, 1993; Reif & Heller, 1984). These studies have been connected with research on cognition in other content areas and with cognitive theories of learning in general. This base of theory and research will be drawn on to define the terms relating to cognition used in this study.

Bransford (1979, p 7) suggests that four basic factors must be considered in studying learning. 1) "The nature of the materials to be learned" including their presentation (visual, verbal, etc.), the difficulty, the sequence of presentation, etc., 2) "the characteristics of the learner," including the prior knowledge, skills, attitudes, etc., 3) "the learning activities" that learners engage in, such as attention, rehearsal, elaboration, etc. and 4) "the criterial tasks" used to evaluate learning, such as recognition, recall, problem-solving, transfer, etc.

McDermott (1991) argues for an interplay of research, curriculum development and instruction in a continuous process of redesigning curriculum taking into account specific student difficulties.

Theory-Based Instruction

Following this framework, for this study, *theory-based instruction* will be defined as instruction designed using knowledge from theory and research. Specifically, knowledge about *characteristics of the learner*, is combined with *content knowledge* of the subject to be learned, *pedagogical content knowledge* of the subject (Shulman, 1987), and *knowledge of pedagogical tools*. The combination is used to guide the selection of *materials to be learned* so that the modes of presentation, the sequencing and the difficulty of the materials are appropriate to stimulate *learning activities* which will lead to acceptable performance on the *criteria tasks* chosen as specific goals of instruction.

The goal of instruction is to have *learning* occur. Following Shuell (1986), learning occurs when as a result of engaging in cognitive activities there is a relatively permanent change in a person's *state of knowledge*, changing the person's ability to perform successfully on criteria tasks. The process of learning is "active, constructive and goal-oriented" (Shuell, 1986 p. 415), requiring that students engage in mental activities including planning, selecting goals and subgoals, choosing stimuli to attend to, organizing information into patterns, making responses and choosing and using learning strategies. The emphasis is on learning as an active process rather than a passive process.

This *active learning* view from cognitive theory implies a change in the roles of the curriculum designer and the teacher. In what will be called *traditional instruction*, the emphasis is on transmission of information to a passive receiver, the role of the curriculum designer is to organize the information into an optimal form for efficient transmission,

and the role of the teacher is to present the information. The student is a passive receiver of information, and good learning depends on accurate reception. Thus the primary attention of the curriculum designer is focussed on the nature of the information, i. e., the nature of the materials to be learned.

By contrast, in theory-based instruction, where learning is viewed as an active process, the role of the curriculum designer is expanded beyond the organization of information. Now the curriculum designer must in addition select the learning activities that will enable students to change their knowledge state. This requires a description of the *initial knowledge state* or *prior knowledge* of the learner and the specification of the desired *final knowledge state*, by specification of the criterial tasks that learners should be able to carry out as a result of instruction. The role of the teacher is now to facilitate the students' cognitive engagement in the learning activities. The attention of the curriculum designer is on the nature of the learner, as well as the nature of the materials to be learned. The teacher is not primarily a presenter of information, but must orchestrate the engagement of students in the learning activities.

Theory-based MBL instruction will be described below, but may be briefly contrasted with routine MBL instruction. In routine MBL instruction, the MBL tools are simply used to replace standard measuring devices, but no changes are made in the design of instructional activities. By contrast, in theory-based MBL instruction, activities are specifically designed to take advantage of the real-time graphing capability of MBL tools. The "iconographic" force and motion experiment developed by Morse (1992a) exemplifies this difference.

Knowledge

Cognitive theory holds that *knowledge* is represented in the mind in *knowledge structures* or complex networks of interrelated and associated information (Shuell, 1986). These organized knowledge structures are also referred to as *schemata*, *frames* or *scripts* (Bransford, 1979, p. 181ff). A knowledge structure contains and interrelates many pieces of knowledge including *factual* and *procedural* knowledge. The particular knowledge structures that are activated determine how a person understands and interacts with the person's environment in a particular situation. Learning involves activating and modifying existing knowledge structures, by adding new concepts, and by changing, replacing, developing and refining existing concepts (diSessa, 1993).

Knowledge is of different kinds, and may be represented in different ways in memory. A set of terms differentiating kinds of knowledge has been developed in the literature on cognition. Broadly, *procedural knowledge* of how to carry out processes or skills is distinguished from *declarative knowledge* or knowledge about things or factual knowledge (Shuell, 1986). Alexander, Schallert and Hare (1991 p. 333) have collected a list of terms about knowledge relating to research in learning and literacy. The quotations in the following four paragraphs are from the table in that article.

Declarative, procedural and conditional knowledge.

From the point of view of instructional design, we must start with a model of the *prior knowledge*, "the sum of what an individual knows." This knowledge can be considered in various ways. In general, we may divide all prior knowledge into *declarative knowledge*, *procedural*

knowledge, and *conditional knowledge* “of when and where knowledge should be applied” (Alexander, et al., 1991 p. 333).

Conceptual knowledge.

Alexander, Schallert and Hare go on to consider a hierarchical arrangement of knowledge, considering specific *discipline knowledge*, “a highly formal ... knowledge of an academic subject” or “branch of learning,” to be a subset of *domain knowledge*, “a realm of knowledge that broadly encompasses a field of study or thought.” Domain knowledge is in turn a subset of *content knowledge*, which “includes formal and informal knowledge of some aspect of one’s physical, social, or mental world,” and content knowledge is a type of *conceptual knowledge*. The hierarchical breakdown of conceptual knowledge into subsets reflects research showing that expertise in a particular domain or discipline does not necessarily transfer to other domains or disciplines (Bransford, 1979; Shuell, 1986).

Metacognitive knowledge.

Conceptual knowledge interacts with *metacognitive knowledge*, “knowledge about one’s cognition and the regulation of that cognition.” This includes *task knowledge* or “understanding of the cognitive demands of a task,” *self knowledge* of oneself “as a thinker and learner,” and *knowledge of plans and goals*. Knowledge of plans and goals includes *strategic knowledge* “of processes that are effortful, planful and consciously invoked to facilitate the acquisition and utilization of knowledge,” which in turn includes specific *metacognitive strategy knowledge*, “of strategies that allow one to monitor task completion.” (Alexander, et al., 1991 p. 333).

Tacit and explicit knowledge.

Knowledge may be also be divided into *tacit knowledge*, “of which

we are normally or currently not aware; unanalyzed knowledge,” and *explicit knowledge*, “that is directly guiding on-going interaction with the world; analyzed knowledge; knowledge that is currently or usually the object of thought.” Some tacit knowledge can be made explicit by conscious analysis, and some explicit knowledge can become tacit through loss of importance or attention (Alexander, et al., 1991) or through extensive practice until the process becomes automatic (Bransford, 1979, pp 24ff) and no longer the object of explicit thought.

Forms of knowledge representation.

Knowledge can exist in several forms. Paivio’s dual coding theory (Bransford, 1979; Paivio, 1990), suggests that people store information in both verbalized and visualized forms and Bransford (p. 191ff) mentions tactual or kinesthetic knowledge as another form. Dual coding theory holds that information that is learned in more than one form may be acquired more readily and better remembered than information acquired in only one form. Some experimental tests (e.g. (Mayer & Anderson, 1991)) are consistent with this theory. Baddeley (1992) describes recent models of working memory which have a central executive function controlling a visuospatial sketch pad and a phonological loop, which can engage in simultaneous processing and storage of information. One subsystem of the visuospatial sketch pad is primarily responsible for representing pattern information and a second subsystem deals with more spatial information. Anderson (1992) in a survey of the applications of neurobiological theory to learning suggests that simultaneous input from several sensory paths may increase synaptic activity associated with learning, and that changing prior conceptual understanding will be most effective if multiple modes of

perception and learning are involved.

Constructing Knowledge

As defined above, the process of learning consists of activating and changing existing knowledge structures by extension and modification of the knowledge structures (Shuell, 1986). This *construction* of knowledge occurs when a student's metacognitive and conceptual knowledge interact in a context that is partly determined by the instructional design, and partly by the world view of the student; the world view encompassing the ways in which the student talks about, thinks about and conceptualizes the world (Alexander, et al., 1991) and the motives and goals that the student brings to the class (Pintrich & DeGroot, 1990).

In the view of learning theorists, knowledge construction proceeds by several processes. Piaget views learning as the intellectual adaptation of an individual through interaction with the environment (Ginsburg & Oppen, 1969). This adaptation proceeds by two processes, *assimilation* and *accommodation*. Assimilation involves the addition of new information to existing knowledge structures, where there is a fundamental consistency between the new knowledge and the old knowledge. Accommodation occurs where there is a conflict between the new knowledge and the existing knowledge structures. The new knowledge cannot be assimilated into the existing structure, and consequently the knowledge structure must be modified to accommodate the new knowledge. Piaget suggests that optimal learning occurs in situations with moderate novelty (Ginsburg & Oppen, 1969, p. 223), that is where new knowledge has sufficient novelty to be interesting, but is not entirely in conflict with existing knowledge. Other theories of learning have modified and extended these ideas of the

learning process, but have not replaced them. Thus Rumelhart and Norman (1978 cited in Shuell, 1986). propose three learning mechanisms: accretion, restructuring, and tuning. Accretion is essentially the same as assimilation, as new information is added to existing knowledge structures. Restructuring is similar to accommodation, and involves the construction of new knowledge structures. Tuning refers to the refinement of a knowledge structure over time, and has aspects of both assimilation and accommodation.

Self-regulation refers to the control of the learning process by the learner (Pintrich & DeGroot, 1990), and includes students' use of metacognitive strategies for control of their learning, management of effort and the cognitive strategies employed by students. It refers to the conception of learning as an active process under the control of the learner.

Research on the differences between short-term and long-term memory, combined with computer models of cognition have led to the development of *information processing models* of memory and learning (Bransford, 1979). In these models, sensory registers respond to stimuli and information from the sensory registers can be selected and transferred to short term memory (STM) or conscious memory. Information can be transferred from STM to long term memory (LTM) and information can also be transferred from LTM back to STM. An important result of the research on the differences between STM and LTM is that STM can store only limited amounts of information, namely about 5 to 9 *chunks* of information, while LTM storage is essentially unlimited (Bransford, 1979) . A chunk is a piece of meaningful information, such as a word or concept, and can have a fairly complex substructure.

In these models, learning occurs as modifications to the information take place. Mayer (1992), for example, illustrates a model in which three learning processes, selecting, organizing and integrating occur in the conjunction with the transfer of information among sensory memory, short-term memory and long-term memory. (Figure 2)

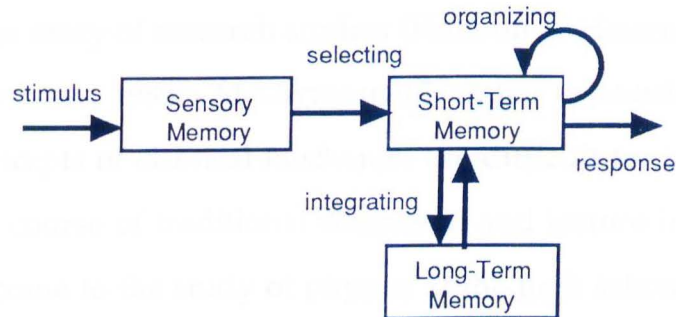


Figure 2: Information Processing Model

Selection of information occurs when the student attends to the information, and sorts out relevant from irrelevant stimuli. Organization involves establishing relationships between the various pieces of information in STM selected both from sensory memory and activated from LTM. Integration occurs as the organized information is related to existing knowledge structures. These processes are regulated by the learner to make sense of the information and construct knowledge. The organization process described above is part of the process of chunking information into single concepts.

Goals for Student Knowledge Outcomes

In designing instruction, it is important to specify the characteristics as well as the content of the knowledge we would like students to construct during instruction. It is suggested here that desirable characteristics of knowledge of physics are that it be accurate, extendable,

integrated with other knowledge, recognized as knowledge, related to experience and experiment, strategic, and available in multiple representations such as verbal, graphical, algebraic, pictorial, and story representations.

Student Difficulties in Learning Physics: Prior Knowledge

A large array of research studies (Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b; McDermott, 1984), has established that many of the central concepts of classical mechanics are difficult for students to acquire in the course of traditional classroom and lecture instruction and that students come to the study of physics at the high school and college level with a significant body of previously acquired conceptual knowledge which is at variance with the accepted understanding of classical mechanics. Constructivist theory (Bransford, 1979) suggests that cognitive growth and cognitive change depend not only on the nature of the learning activities, but also on the nature, extent and activation of prior knowledge. Thus the curriculum designer must have a description of students' initial knowledge state relating to the area of instruction in order to select activities to bring about conceptual change (Scott, et al., 1992).

Nature of Prior Conceptual Knowledge

The literature describing students' conceptual knowledge in physics suggests several categories of prior knowledge concerns which may have slightly differing implications for instructional design (Arons, 1990; diSessa, 1988; diSessa, 1993; Minstrell, 1992). It is suggested here that students may have 1) incomplete knowledge, 2) undifferentiated knowledge, 3) incorrect knowledge, 4) simplistic knowledge and 5) non-scientific cognitive and epistemological beliefs.

1) Incomplete knowledge.

Students have conceptual knowledge and procedural knowledge which is consistent with accepted knowledge, but is incomplete, unelaborated, and not robustly interconnected, thus providing an insufficient knowledge base for further learning. For example, students at the 11th and 12th grade have studied area, volume, ratios, equations and graphs in mathematics courses, but have little practice at inter-relating the concepts they have acquired and consequently cannot verbally interpret the meaning of a ratio, relate a ratio to the slope of a graph, relate the shape of a graph to a verbal description or an observed sequence of events, translate between mathematical expressions and verbal statements or use technical language with accuracy (Arons, 1990).

2) Undifferentiated knowledge.

Students have conceptual knowledge which is not consistent with accepted knowledge because the concepts involved are not sufficiently differentiated and elaborated. A well documented example is in the study of kinematics, (Arons, 1990; McDermott, Rosenquist, & van Zee, 1987; Trowbridge & McDermott, 1980; Trowbridge & McDermott, 1981) where students arriving in a physics course have only a partially differentiated concept of motion. They fail to reliably distinguish the concepts of position, change of position or displacement and distance travelled, they do not have a well-differentiated understanding of the distinction between speed and velocity, or between average and instantaneous velocity and have only a vague concept of acceleration as "speeding up." Thus they use the vocabulary of physics but without the carefully limited and well-defined meanings of the physicist.

3) Incorrect knowledge.

Students have specific conceptual knowledge which conflicts or contradicts accepted knowledge in the domain. The nature and extent of this conceptual knowledge, variously referred to as misconceptions, naive conceptions or pre-conceptions, has been studied and reported on extensively in the literature (Arons, 1990; Halloun & Hestenes, 1985a; Halloun & Hestenes, 1985b). The origins of this knowledge lie variously in linguistic usage (Arons, 1990; Talmy, 1988), prior experience (Anderson, 1992) and to some extent in prior formal and informal instruction (Dykstra, Boyle, & Monarch, 1993). For example, a significant fraction of students believe that a force must be continually applied for an object to move steadily along a horizontal surface (Clement, 1982) and that only "active" objects can exert forces on other objects (McDermott, 1984).

4) Simplistic knowledge.

Students have a set of general principles abstracted from common experience called *phenomenological primitives* by diSessa (1988; 1993) which they apply to specific situations which seem to match prototypical experiences. For example, diSessa describes an *Ohm's Law p-prim* abstracted from situations where an agent exerts effort against a resistance. In such circumstances, more effort gives more result, while more resistance gives less result. This piece of knowledge is then applied by students indiscriminately to situations where it is a correct description and to situations where it is an incorrect description, with little evaluation of the logical consequences of such a description beyond the situation at hand. DiSessa holds that these p-prims arise from small abstractions made from experience. They are useful within the particular contexts in which they

arise, but may be later over-generalized in response to demands for explanation of other phenomena.

5) Cognitive and epistemological beliefs.

Students have prior beliefs about the process of learning science and the nature of knowledge in physics. Hestenes (1992) notes that beginning physics students view learning as the “collection of facts and the memorization of procedures,” instead of as the process of building conceptual models that explain the observed behavior of objects. Schauble, Klopfer and Raghavan (1991) observe that students typically treat experiments at least initially from an engineering perspective, with the object of trying to produce a particular outcome rather than from a scientific perspective of trying to connect cause and effect. Hammer (1994) notes that students with certain beliefs about learning physics displayed fundamental misconceptions in response to questions probing their understanding of mechanics. These students typically believed that physics knowledge was a collection of isolated facts, consisting of formulas, which are to be learned by memorizing.

This study takes the view that different kinds of prior knowledge may call for different tactics in instructional design. For example, to build on incomplete knowledge, activities may simply provide practice in using and extending existing knowledge. Learning in areas with undifferentiated knowledge requires activities which cause students to observe differences between related concepts and refine their conceptual structure. The most difficult category to deal with is incorrect knowledge, where instructional strategies must cause students to re-examine and modify established knowledge structures.

Details of Students Prior Conceptual Knowledge Related to Concepts of Force, and the Relationship Between Force and Motion

As this study is primarily concerned with students learning Newton's second law, it is useful to look at some specifics of student prior knowledge which show up as misconceptions on tests and interview tasks. Hestenes, Wells and Swackhamer (1992) provide a concise taxonomy of conceptual misunderstandings which are probed by their Force Concept Inventory. Table 1 reproduces this taxonomy, which can serve as an initial guide to organize a description of students' prior knowledge of classical mechanics. A more detailed taxonomy drawing on the work of several other groups has been developed by Dykstra, Boyle and Monarch (1993). For the purposes of this study, the Hestenes classification will be used in conjunction with the Force Concept Inventory.

For instruction concerned with the portion of the mechanics curriculum involved in building an initial understanding of the concept of force and the relationship between force and motion, the items on the taxonomy that are most relevant are items I1 through I4 under Impetus, all the items under Active Force, and the items under the heading of Resistance and Gravity.

A Taxonomy of Misconceptions

- 0. Kinematics
 - K1. position-velocity indiscriminated
 - K2. velocity-acceleration indiscriminated
 - K3. nonvectorial velocity composition
- 1. Impetus
 - I1. impetus supplied by "hit"
 - I2. loss/recovery of original impetus
 - I3. impetus dissipation
 - I4. gradual/delayed impetus build up
 - I5. circular impetus
- 2. Active Force
 - AF1. only active agents exert force
 - AF2. motion implies active force
 - AF3. no motion implies no force
 - AF4. velocity proportional to applied force
 - AF5. acceleration implies increasing force
 - AF6. force causes acceleration to terminal velocity
 - AF7. active force wears out
- 3. Action/Reaction Pairs
 - AR1. greater mass implies greater force
 - AR2. most active agent produces greatest force
- 4. Concatenation of Influences
 - CI1. largest force determines motion
 - CI2. force compromise determines motion
 - CI3. last force to act determines motion
- 5. Other Influences on Motion
 - CF. centrifugal force
 - Ob. obstacles exert no force
 - Resistance
 - R1. mass makes things stop
 - R2. motion when force overcomes resistance
 - R3. resistance opposes force/impetus
 - Gravity
 - G1. air pressure assisted gravity
 - G2. gravity intrinsic to mass
 - G3. heavier objects fall faster
 - G4. gravity increases as objects fall
 - G5. gravity acts after impetus wears down

Table 1 Misconceptions Taxonomy from Hestenes et al, 1992

One choice that must be made in the study of force and motion is which kind of force to study first. Most physics textbooks place gravitational force and the motion caused by gravitational force early in the sequence of study. The complex nature of the incorrect prior

knowledge students have about gravity has been documented by many researchers (Dykstra, et al., 1993; Gunstone & White, 1981; Halloun & Hestenes, 1985a; Watts, 1982). This knowledge and the nature of the gravitational force and its interaction with matter (Morse, 1993b) argues strongly that the study of gravitational forces should be deferred until after students have developed an understanding of the relationship between force and motion. This was the choice made for the instructional design used in this research.

The Active Force heading gathers several student ideas that conflict with the understanding of Newton's second law. In particular, typical student alternate conceptions are that a constant external force on an object is required to maintain a constant velocity (Clement, 1982; diSessa, 1993) and that objects naturally come to rest in the absence of any force (Halloun & Hestenes, 1985a). This contrasts with the Newtonian understanding that a constant net force acting on an object causes a constant acceleration of the object, and that in the absence of a net force, an object continues to move at constant speed in a straight line. This is termed the "motion implies force" preconception by Clement, and has proved to be a difficult concept to change by conventional instruction (diSessa, 1993). Part of student difficulty with understanding the relationship of force and motion is the failure to consider the effect of "passive" forces (McDermott, 1984) such as friction, tension and normal force. Frictional and drag forces, as "invisible" forces, seem to be particularly difficult for students to deal with (Bliss, Morrison, & Ogborn, 1988), and many students feel that only obviously active agents can exert force. The instructional design for this study deliberately uses rubber bands, springs and motor driven fan units to

provide forces for the initial study of force and motion relationships. The kinesthetic experience of pulling on rubber bands and springs correlated with the visible change in the length of these objects makes them good models of forces that do not conflict with students' notions of active agents. Clement (1989) and Minstrell (1982) have found spring forces to be fruitful tools to develop and extend students conceptual understanding. Morse (1993b) has used a motor driven fan unit, derived from the Harvard Project Physics materials to provide a reasonably convenient, obviously active constant force for study (Holton & Rutherford, 1975).

The Impetus heading refers to a group of related ideas similar in some ways to theories of motion proposed in medieval times, prior to the theories of Galileo and Newton (Halloun & Hestenes, 1985a). These concepts express the notion that motion as a process requires a cause, and that there must be a force of motion or impetus to conserve motion (Dykstra, et al., 1993; Halloun & Hestenes, 1985a) when there is no other active agent visible. The idea that impetus dissipates or is used up occurs in students' explanations of motions such as throwing a ball up in the air and having it slow to a halt and fall, or watching a moving object slide along a surface and come to rest. The impetus explanation here is related to the failure to recognize the role played by the invisible forces of gravity and friction. The use of low-friction carts in the instructional design and the choice to initially study only horizontal motion are decisions made to avoid an early confrontation with impetus notions.

The prior conceptions of students under the heading of Resistance include the idea that mass makes things stop moving, and that motion begins when force overcomes resistance caused by the "hold-back"

tendency of mass (Dykstra, et al., 1993). These ideas relate to the failure to recognize frictional forces and to the experience of trying to move massive objects under circumstances when a large gravitational force pressing surfaces together causes a large frictional force between the surfaces. The presence of these concepts motivates the decision to use low friction carts in the early study of force and motion and to develop the concept of inertial mass before studying the relationship of weight and gravitational force to mass.

The ultrasonic range detector is a device designed by Thomas (1992).

The range detector (Figure 2) consists of an ultrasonic transducer which can determine the position of an object relative to the detector by sending an ultrasonic pulse and determining the time it takes for the echo to return. It is capable of measuring distances from about 0.5 meters to more than 4.0 meters from the detector at rates of about 40 measurements per second.



Figure 2. The range detector.

The force probe (Figure 3) has a hook connected to a springy brass

strip with a magnet mounted on the strip. Small deflections of the magnet cause changes in voltage in a Hall effect chip. The signals from the Hall effect chip can then be used to give a measure of the force applied to the strip.

Microcomputer Based Laboratory Tools

Microcomputer Based Laboratory tools consist of both hardware and software tools that allow a computer to be connected to laboratory instruments. Typically the MBL system allows the display of information in graphical form as the information is being collected. This real-time graphing property of MBL tools seems to be an important feature to facilitate learning (Brasell, 1987). The MBL system that will be used in this research uses a motion detector, a force probe, and a Universal Laboratory Interface (ULI) controlled by the MacMotion 4.0 software developed by Thornton (1992).

The motion detector (Figure 3) contains an ultrasonic transducer which can determine the position of an object relative to the detector by sending an ultrasonic pulse and determining the time it takes for the echo to return. It is capable of measuring distances from about 0.5 meters to more than 4.0 meters from the detector at rates of about 40 measurements each second.

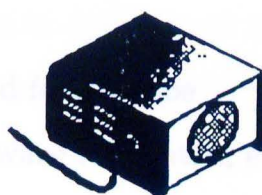


Figure 3: the motion detector

The force probe (Figure 4) has a hook connected to a springy brass strip with a magnet mounted on the strip. Small deflections of the magnet cause changes in voltage in a Hall effect chip. The signals from the Hall effect chip can then be used to give a measure of the force applied to the probe.

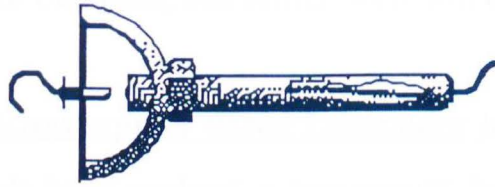


Figure 4: Force probe

The modified force probe (Figure 5) devised by Morse (1992a) has a bracket which supports a hook shaped rod permitting forces to be simultaneously applied to both ends of the probe, thus allowing a measurement of the combination of forces acting on the probe.

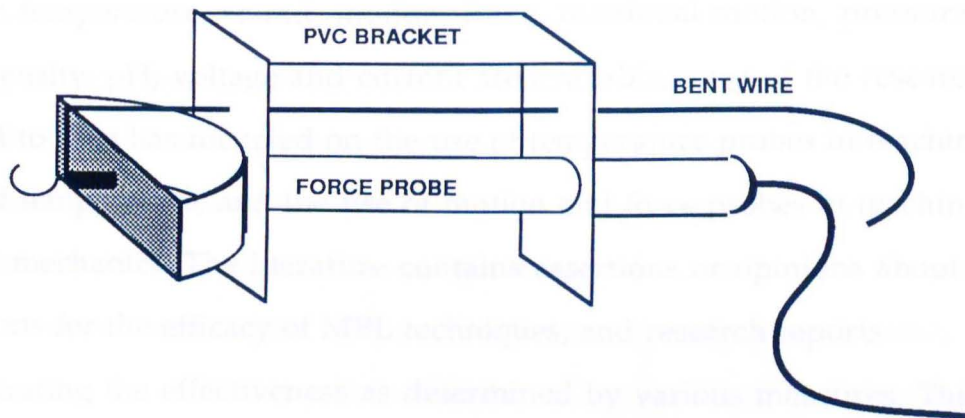


Figure 5: the modified force probe

The MacMotion™ software (Thornton, et al., 1992) rapidly computes the velocity and acceleration from the position information provided by the motion detector, computes the force from the force probe information and permits the simultaneous display of several graphs. In particular, graphs can be made in nearly real time of the position, velocity, acceleration and force as a function of time or as a function of each other. If desired, several graphs can be simultaneously displayed in near real time. The software has a number of other features which allow analysis of the

data once it has been obtained, but which were not employed extensively in this study.

Microcomputer Based Laboratory Instruction

As MBL tools have evolved, a few groups have incorporated the use of MBL tools in instructional design based on cognitive theory. In this study the phrases MBL instruction, MBL curriculum, theory-based MBL instruction and simply MBL refer to theory-based instructional designs which use MBL tools. Note that the claims for effectiveness of MBL instruction are actually based on the combination of MBL tool use with instructional design (Thornton & Sokoloff, 1990). Although MBL tools to measure temperature, sound, motion, force, rotational motion, pressure, light intensity, pH, voltage and current are available, most of the research reported to date has focussed on the use of temperature probes in teaching heat and temperature, and the use of motion and force probes in teaching classical mechanics. The literature contains assertions or opinions about the reasons for the efficacy of MBL techniques, and research reports demonstrating the effectiveness as determined by various measures. This section describes those assertions and research results.

MBL-Assertions by Proponents

Proponents of MBL use have made a number of assertions in support of the use of MBL tools in instructional design (Linn & Songer, 1991; Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). Although some of these assertions are untested and perhaps untestable, a number can be tied to cognitive theory. Five principal assertions made by proponents are discussed below.

1) Reduced drudgery.

MBL tools reduce the drudgery associated with translating experimental data into a graphical representation (Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). The almost automatic production of graphs reduces the memory load on students. Information processing theory suggests this should reduce the situation to a more manageable complexity, and free short term memory for meaningful processing of the information (Bransford, 1979, p 257). It also reduces the number of steps students need to take between making and analyzing a graph, and thus reduces the number of intermediate sub-goals (Simon, 1991, p. 88) which can interfere with students' focus on the main goals of the experiment.

2) Immediate representation.

Since MBL tools produce the graph at the same time as the experiment is performed, the abstract, symbolic representation given by the graph is linked to the observed events in the experiment (Linn & Songer, 1991; Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). Brasell (1987) found that even a short delay in the display of a graph inhibited the impact of MBL on learning graphing skills. In his dual coding theory, Paivio (1990) argues that there are two distinct memory system, one for visual and one for verbal representations, and that learners will learn and remember information better when information is encoded both ways simultaneously. Mayer and Anderson (1991) found support for this hypothesis in experiments with animations and narration, comparing simultaneous presentation with separate presentation. If the argument is extended, separate but linked graphical and visual representations may stimulate more powerful learning than separate presentations of this

information. Regardless of the truth of the dual-coding hypothesis, multiple cues may be helpful for learning and remembering information. Recent models of working memory supported by experimental work (Baddeley, 1992) suggest that there are independent, simultaneously operating modules specialized for visuospatial information and for verbal or phonological information. All of this work supports the idea that the immediate feedback of graphical information as a student observes a change or causes a change in an experiment is important to make graphs make sense.

3) Simultaneous kinesthetic and abstract representation.

Not only are MBL graphs presented in real time, but in experiments in which the student is part of the experiment, or is manipulating the experiment as the graph is being made, there is the immediate feedback connecting changes in the symbolic representation with experimental changes made by the student. The graphical changes are also connected with the kinesthetic sensations as such changes are made (Mokros & Tinker, 1987; Thornton & Sokoloff, 1990). This reinforces the active engagement of the learner in relating the abstract representations of information to physical events and the learner's own actions. It also engages the student in planning future actions and in predicting consequences of changes, activities that are consistent with the constructivist view that the learning process requires the active mental engagement of students in building and modifying their conceptual structure (Shuell, 1986). DiSessa suggests that phenomenological primitives are likely to arise in abstractions from kinesthetic experience, which he calls the principle of the body (1993). If this is the case, then

situations which allow students to couple kinesthetic experience with analytical thinking may help in the evolution and restructuring of ideas derived from p-prims.

4) Rapid repetition of results.

MBL tools allow graphs to be produced in the same time it takes to perform an experiment, providing immediate and immediately repeatable feedback, and information that can be quickly recalled from past experiments (Linn & Songer, 1991; Mokros & Tinker, 1987). Real time response allows students to easily repeat experiments whose results do not agree with their expectations, allowing them to eliminate mistakes in procedures until they get clean data, a process that involves the student in evaluating results and comparing them with expectations. It also allows students to repeat experiments that have unexpected results, allowing them to convince themselves that the results are not mistakes. Repetition in an analytic context may serve to promote restructuring of concepts. Here again, students are actively involved in the learning process, evaluating their work and planning their activities on the basis of their judgements, all of which are aspects of active learning. Classroom time is also efficiently used in that students spend less time in lower level process skills such as plotting points one by one on graphs and spend more time engaged in higher order processes (Linn & Songer, 1991).

5) Encourages exploration.

MBL tools allow students to do real science (Mokros & Tinker, 1987; Thornton & Sokoloff, 1990), building and testing mental models as they work initially with familiar materials and experiences and extend their understanding to more general conclusions. Students have control of the

processes of prediction and testing of ideas, and the responsibility for development and mastery of knowledge is in their hands. This learning atmosphere is consistent with the mastery-goal orientation of goal theory, which Blumenfeld (1992) suggests may promote the active learning engagement needed for learning in constructivist theory.

Research on MBL Effectiveness

The body of published research available on MBL effectiveness is relatively small. This section describes some of the most frequently cited works.

Brasell (1987) studied the effect of a delay in the display of a kinematics graph on student performance using a pretest, treatment, posttest design comparing standard MBL, delayed display MBL and test-only groups. She found greater gains in student understanding of position and velocity graphs with real-time graphing compared with the condition that the display of the graph was delayed, even when the delays were as small as 20-30 seconds. Brasell suggests that the delay places an additional information processing load on students, requiring them to hold in memory the sequence of events which they saw occur and to relate them to the graph after the fact.

Mokros and Tinker (1987) report that middle school students studying motion using an MBL unit developed good graph interpretation skills in a five day study unit. A quasi-experimental study with seventh and eighth graders over a three month period using MBL to study visual illusions, heat and temperature, sound and motion resulted in significant change between pretest and posttest scores on a test of graphing interpretation.

Nachmias and Linn (1987) studied the change in students' ability to interpret graphs and to understand some of the complexity associated with graphs of experimental results in eighth grade physical science classes using MBL instruction on heat and temperature. Students showed improvement in many parts of a Critical Evaluation of Graphs test given as a pretest and posttest. This is also reported in Linn, Layman and Nachmias (1987).

Nakhleh and Krajcik (1993) looked at high school chemistry students' verbal commentary during acid-base titration experiments for students using different technologies. One group used chemical indicators, a second used pH meters and a third used MBL. Analysis of student commentary supported the notion that students with access to more information, i.e. those using MBL, would reflect more analytical thought processes, consistent with the hypothesis that the real-time graphical displays obtained using MBL serve to free students' working memory and attention for more analytical tasks. An analysis of concept maps constructed from the same data (Nakhleh & Krajcik, 1994) found a greater positive shift in concept map scores for students using the MBL method, although MBL students also generated more inappropriate links, suggesting that effective MBL instruction requires more changes in curriculum design than the mere substitution of one technology for another. Nakhleh and Krajcik argue that more research is needed on the role of immediate graphical representations in developing students' understanding.

Most research on MBL instruction in classical mechanics has been carried out by Thornton, Sokoloff and Laws (Laws, Thornton, & Sokoloff,

1989; Sokoloff, 1991; Sokoloff, 1992; Sokoloff, 1994; Thornton, 1987; Thornton & Sokoloff, 1990; Thornton, 1991; Thornton, 1992b; Thornton, 1994). Other work has been reported by Dykstra (1992) and Morse (1992a).

Thornton and Sokoloff (1990) report significant gains in student understanding of the concepts of kinematics using MBL motion detectors with real time display of position, velocity and acceleration graphs compared with students in traditional lecture instruction for college students. More recently (1994) they have demonstrated gains in understanding force concepts using MBL force probes in conjunction with motion detectors to display both force and motion graphs. This research has relied primarily on pretest and posttest results to demonstrate conceptual change in students.

Dykstra (1992) includes MBL instruction among the strategies used to foster conceptual change in students taking introductory physics.

Morse (1992a; 1993a), describing classroom research following an Action Research model, gives anecdotal evidence for the effectiveness in his classes of a novel experiment using the modified force probe in a theory-based MBL sequence for teaching Newton's second law. He gives results of an end-of-course administration of the Force Concept Inventory (Hestenes, et al., 1992) indicating significantly better performance than classes taught using standard instruction, although gains cannot be confirmed as no pretest was given.

There is relatively little in the way of classical controlled experimental studies in the published results on MBL research, partly reflecting the logistical difficulties in doing large educational studies involving lots of students and necessarily lots of computers. The largely

unpublished data of Thornton (1995) suggests that results for theory-based MBL instruction in kinematics are robust and reproducible in a variety of settings, but there is certainly the opportunity for a large controlled study on this question.

The nature of the research reported in classical mechanics suggests the need to take a more detailed look at student learning during MBL instruction to refine the description of how students learn in a theory based MBL curriculum.

Implications of Cognitive Theory for Theory-Based MBL Instruction

Students conducting experiments using traditional laboratory tools must first collect and tabulate numerical data from their instruments and then turn that data into a graphical representation. Students using MBL tools have the graphs produced dynamically as the phenomena under study unfold. They may then, if they wish, examine the tabulation of data that underlies the graph. The salient differences between these methods are the reduction in the number of steps required to take a measurement and turn it into a graph and the immediate presentation of the data. These differences reduce the number of steps students need to carry out during an experiment, consequently reducing the load on short term memory, and change the nature of the representation of information to the senses, presenting the information in graphic terms.

Champagne, Klopfer, and Anderson (1980) note that traditional instruction in classical mechanics is heavily based on mathematics as “the medium of analysis and communication.” Given the finite attention capacities (limited short term memory) and the limited mathematical fluency of students, instruction that relies on high mathematical fluency is less likely to be successful in developing initial conceptual understanding of physical concepts. MBL tools offer the opportunity to design experimental sequences which do not initially require high mathematical fluency by using the ability of the computer to translate the force and acceleration information directly into graphs. Additionally, the graphs are related to simultaneous visual and kinesthetic perception of the motion as they are made.

What is the effect of this change in the kind of representations used

to present information on learning? Larkin and Simon (1987 p. 69) discuss the efficiency of sentential versus diagrammatic representations of information. They note that "human abilities to recognize information are highly sensitive to the exact form (representation) in which information is presented to the senses." Dual coding theory and experiments (Mayer & Anderson, 1991) suggest that a simultaneous combination of representations makes a more powerful impression than a single representation. There is some suggestion from neurobiology (Anderson, 1992) that simultaneous input from several sensory systems may cause enhanced efficiency in encoding information, with long-term changes facilitated by a sufficiently intensive experience. Larkin and Simon (1987 p. 71) also suggest that efficiency in learning and understanding information "might arise from low search and recognition costs, or from very powerful inference rules or from both." As many high school students may not have developed powerful inference rules, instructional designs in which the introduction of major concepts does not depend on sequences that require powerful inference skills but on sequences that have low search and recognition costs may be more effective. This criterion can be met by MBL activities in which the experimental question can be put in terms of a simple match/mismatch comparison of real time graphs.

Reduction in the number of steps in an experiment is also important in designing efficient experiments using MBL. Simon (1991, p. 88) notes that "human beings are able to achieve only a very bounded rationality, and as one consequence of their cognitive limitations, they are prone to identify with subgoals." One reason students may fail to learn what we intend them to learn from a logical sequence of experiments is

that they focus on the subgoals in a complex series of experiments rather than on the final goal, and are satisfied with achievement of sub-goals and thus do not fully perceive or reach the final goal. This is consistent with the engineering view of experimentation taken by students described by Schauble (1991). Their view of such a sequence is a “worm’s eye” view, as contrasted with the “eagle’s eye” view of the teacher. In designing lessons, we can reduce the disparity between these views by reducing the complexity of the logical sequence needed to arrive at a conclusion. In the case of the Newton’s second law experiment described by Morse (1993a), the apparent success of the technique may be due to reduction in the number of subgoals relative to other curricular designs. Simon (1991, p. 368), suggests that “the ‘insight’ required for such work as discovery turns out to be synonymous with the familiar process of recognition.” Thus for a student to discover the relation between the net force and the acceleration requires only that he or she recognize that they are directly related. This recognition test of an experimental question is consistent with beliefs many students hold about the nature of scientific discovery (Ryan & Aikenhead, 1992). By *discovery*, we mean the conscious recognition of a relationship between two physical quantities. The simpler and more powerful we can make that act of recognition, the more powerful will be the sense of discovery, given that the student is properly prepared for the experiment.

To summarize the arguments above, students at the introductory level have a low level concept of the process and purpose of experiment. Experiments with multi-step procedures of significant length may overload students’ short-term memory capacity to attend to the ideas. This

can lead students to focus on sub-goals. MBL tools both reduce the number of steps to turn measurements into graphical representations, and allow the design of new experiments which require fewer steps and more closely match students' limited concepts of the nature of scientific experiments. This implies that to take full advantage of MBL tools, important conceptual experiments should be designed to have relatively few steps.

Conceptual Change Teaching Strategies in Instructional Design

The constructivist theories of learning describe a model of the learner which can give guidance to the development of specific teaching strategies. Such strategies are also guided by knowledge of the prior knowledge state of the learner, by the nature of the intended learning outcomes, and by the available resources for constructing learning activities. This section will review some model strategies.

During the last twenty years, researchers have recognized the importance of students' prior knowledge and documented the nature and extent of that knowledge. Based on this research they have developed instructional models which aim to effect conceptual change by taking cognizance of students' existing conceptual understanding or prior knowledge. These instructional approaches or *conceptual change strategies* have been recently described in a review by Scott, Asoko and Driver, (1992) and the rest of this discussion follows that review. The strategies are broadly based on constructivist theory, have usually been tested in limited circumstances, have strong implications for classroom practice, but have had a small (although perhaps growing) effect on classroom practice.

One group of these strategies is based on the idea of cognitive conflict, and seeks to promote conceptual change by establishing situations which bring a student's existing ideas into explicit conflict with either another set of ideas or with an experimental result. Learning is assumed to take place by accommodation to yield a new knowledge structure. (Note that this approach usually interprets students' misconceptions as constituting a theory or at least a reasonably systematic set of beliefs, an interpretation which is argued against by diSessa's concept of p-prims (1993).) Examples of

this approach are the *discrepant event* strategy of Nussbaum and Novick (1982), where conflict occurs between students' preconceived ideas and an experiment which clearly conflicts with their prediction, and *discrepant ideas* strategies where a cognitive conflict is established between two inconsistent preconceptions about the same physical situation. Variations of this strategy have been used by Stavy and Berkovitz (1980), Cosgrove and Osborne (1985), and Champagne, Gunstone and Klopfer (1985) among others.

A second set of conceptual change strategies relies instead on building and extending those aspects of students' conceptions that are consistent with the scientific view by discussions and experiments that encourage students to extend the range of application of correct conceptions. (This view of students' prior knowledge would be consistent with diSessa's p-prims theory (1993).) Thus Clement, Brown and Zietsman (1989) use a bridging strategy in which students' intuitive ideas about an anchoring situation are extended by a careful discussion to an analogous, but misunderstood situation. Niedderer (1987) proposes a process in which students first learn a set of concepts in the class, then the teacher proposes an open-ended problem which students explore, followed by a class discussion of results. Finally, students' ideas are compared with scientific ideas and differences are discussed.

One variant suggested by Rowell and Dawson (1985) combines aspects of the two approaches based on the premises that contradictory preconceptions must be replaced by better conceptions but development of better conceptions need not involve immediate confrontation. Student preconceptions about a problem situation are elicited and recorded, but are

not discussed until after the class has developed a new theory from experiments or discussions linked to students' prior knowledge. The new theory is then applied to the problem situation and the ideas are compared with the original ideas recorded earlier.

A possible teaching concern with cognitive conflict methods is the problem of ownership of ideas (Scott, et al., 1992). Stavy (1991) suggests that if students feel their prestige is connected with the success of their ideas, rejection of these ideas may lead to a loss of confidence. The present author's classroom experience suggests that even carefully run discussions may on occasion degenerate from discussions of the proposed ideas to ad hominem attacks on the proposers of the ideas. In addition, the process of discussion may lead some students to strongly defend what were initially weak conceptual positions in order to save face. Dreyfus, Jungwirth and Elovitch (1990) observed that unsuccessful students often developed negative attitudes towards this process of conceptual conflict and tended to avoid the conflicts. Scott, Asoko and Driver (1992) note that successful use of these techniques places significant demands on the skills and knowledge of the teacher.

Several groups report success in modifying student conceptions of force through extensive classroom discussion (Minstrell, 1982), the use of written qualitative questions (Clement, 1982), and laboratory tasks ((Lawson, 1984) in (McDermott, 1984)). The Physics Education Group at the University of Washington has been a leader in studying students' prior knowledge, designing instruction to foster conceptual change and modifying the instructional designs based on continued research (McDermott, 1984; McDermott, 1991; McDermott, et al., 1987). Dykstra,

Boyle and Franklin (1992) discuss the design of experiences intended to facilitate conceptual change in teaching Newton's laws through discussion and experiment, including the use of MBL techniques. White (1984; 1993) has used computer simulation games to develop student understanding of motion in a simulated environment. Students are led to construct conceptual causal models that are based on simulated experience but consistent with Newtonian physics.

In the instructional design chosen for this study, the author (Morse) has chosen for the most part to accept the premises of Rowell and Dawson (1985), concentrating first on building a well articulated conceptual theory based on experiments, and only bringing that theory into conflict with students' intuitive notions when the structure of the theory is sufficiently robust. The choice of experimental situations for study is made to avoid situations which evoke strong pre-conceptions. In particular, the study of Newton's second law takes place before the study of situations which would involve conflict, and the understanding of this relationship forms the theoretical basis for resolving the conflicts that will occur in the later portions of the curriculum.

In sum, the argument of this study is that given the power of MBL methods, it is desirable to first develop a reasonable base of belief in a central tenet of the Newtonian paradigm, namely the direct relation of acceleration to the combination of forces acting on an object, and then to extend the coverage of this idea over a wide range of experience by designing instructional activities that lead students to predict consequences, to contrast their predictions with their intuitions, and then to test these by experiments with a short chain of reasoning.

Relating Motivation, Self-Regulated Learning and Performance to Theory-Based MBL Instruction

Some assertions regarding the success of theory based instruction using MBL tools can be related to student motivation. Mokros and Tinker (1987 p. 381) suggest that MBL is effective in part because "it provides genuine scientific experiences," Thornton and Sokoloff (1990) assert that MBL tools give students opportunity to do real science, to experience excitement, to build and test models, and Thornton has noted that MBL instruction may aid those with science anxiety. These assertions suggest that students' success may be due to an interaction between the nature of the cognitive tasks in the MBL classroom and motivational aspects of students' academic performance. Blumenfeld (1992) has suggested that blending the views of constructivism and goal theory might add to research in learning as well as in motivation. She notes that constructivist theory assumes that emphasizing meaningful learning combined with constructivist teaching strategies will motivate students to pursue the work of conceptual change, while goal theory assumes that classroom structures that minimize the focus on ability will motivate students to be cognitively engaged, active learners. By reducing the drudgery associated with graphical production and manipulation, MBL tools may not only reduce the cognitive load on students to one of manageable complexity (Bransford, 1979, p 257), but may also be perceived by students as requiring less mathematical ability to use. In addition, the increased emphasis on conceptual understanding and verbal and graphical explanation in theory-based instruction relative to that on formula manipulation and algebraic representation in the traditional physics curriculum reduces the perceived

need for fluency in mathematics and the focus on the importance of mathematical ability.

Goal theory (Ames, 1992), (Blumenfeld, 1992), suggests that the nature of students approach to academic tasks is related to their orientation towards *mastery goals* or *performance goals*, which have different criteria for success and different approaches to achievement. Students with a mastery goal orientation believe that effort is the prime contributor to successful academic outcomes. These students focus on the intrinsic value of learning, and are motivated to understand new ideas by the sense of mastery they get from improving their competence. Their standard of performance is related primarily to their private recognition of efforts. Students with a performance goal orientation derive perceptions of self-worth from a comparison of their ability with that of others. The evidence for ability is public recognition such as doing better than others on test scores and grades, or by achieving success with little effort. Learning is not of intrinsic value, but is merely a way of achieving the goal of recognition. As a consequence, poor performance or expenditure of significant effort in learning diminish self-concept and students with a performance goal orientation may avoid tasks which might require effort.

Thus, the goal orientation of students may be a significant factor in contributing to academic success depending on the criteria for success. In particular, the constructivist criteria of success through effortful construction and modification of one's own knowledge structures through cognitive involvement may be facilitated by a mastery goal orientation, and thus the motivational beliefs of students may be a factor in student performance in an MBL curriculum. If student motivational beliefs are an

important factor, they should affect performance, and there should be a correlation between the nature of these beliefs and their academic performance (Pintrich & DeGroot, 1990; Zimmerman, Bandura, & Martinez-Pons, 1992).

Blumenfeld (1992) also argues that researchers should investigate the effect of constructivist classrooms on students' motivational beliefs. This suggests that if the motivational assertions about theory-based MBL instruction are correct, then this instruction may have an effect on students' motivational beliefs over the course of instruction. Thus it may be possible to detect a change in motivational beliefs in the context of the MBL classroom. In addition, if such a change occurs, there should be less correlation between students' motivational beliefs at the beginning of the course and their performance.

Instruments for measuring aspects of students motivational beliefs have been developed and used by several groups. Pintrich and DeGroot (1990) have developed a survey instrument which examines both motivational and cognitive beliefs of students and studied the correlations between these beliefs and the classroom academic performance of students. This study examines three dimensions of students motivational beliefs, namely belief in their ability to perform a task or *self-efficacy*, their beliefs about goals and the importance and interest of tasks or *intrinsic value*, and their emotional reactions to tasks, in particular, their *test anxiety*. They studied two dimensions of students cognitive orientation, namely their techniques for learning such as rehearsal, elaboration and organization of information or *cognitive strategy use*, and their use of metacognitive strategies for planning and monitoring their learning, for managing and

controlling their effort and for modifying their cognition referred to as *self-regulation*. Their research examined the correlations between these motivational and cognitive measures and the academic performance of students on a number of classroom tasks. The instrument was administered in junior high science and English classes, and self-regulation, self-efficacy and test anxiety were found to be the best predictors of academic performance. The availability of this instrument, the Motivated Strategies for Learning Questionnaire (Pintrich & DeGroot, 1990) (See Appendix D), and its combined focus on motivational and cognitive variables suggest its use to investigate these dimensions of motivation and cognitive performance in the context of theory based MBL instruction.

Three Alternative Teaching Sequences for Newton's Second Law

This section contrasts descriptions of three teaching sequences for Newton's Second law. The first sequence is an example of a traditional presentation, in which a lecture and text reading is followed by an experiment which involves application of the ideas presented by the teacher. The experiment is intended to confirm the ideas by using them to measure a physical quantity which can be compared with an established value.

The second sequence is an inquiry-based sequence using non-computer experimental tools. It is essentially the sequence followed by the PSSC texts (Haber-Schaim & et al., 1960ff) and described also by Rogers (1960). Arons (1990 p. 57) regards it as "simple, correct and consistent." It is intended to be used to introduce the study of Newton's second law by leading students to arrive at the conclusions that a) a constant force causes a constant acceleration b) that there is a linear relationship between the amount of force and the value of the acceleration, and c) that there is an inverse relationship between the amount of acceleration and the mass of the moving object.

The third sequence is the MBL based instructional unit which was used in this study, a modified version of a Real-Time Physics module originally written by Sokoloff, Thornton and Laws (1992). The basic instructional design has been described by Morse (1992a) and has as its centerpiece a novel experiment which is only practical using MBL techniques. After an introduction to the concept of force using rubber bands and springs, the modified version of the force probe is introduced and established as a force measuring tool, the notion of the combined force

is introduced, and students are led by the teacher to design an experiment to simultaneously measure the combined force, the velocity and the acceleration of a low friction cart moving under the influence of non-linear springs. The resulting graphs, made in real time, allow students to compare the force, acceleration and velocity simply by looking at the shapes of the graphs as they are being made, and serves as an iconographic experiment for the relationship of force and acceleration. (See Appendix A for the student guidebook for this unit.)

A traditional teaching Sequence for Newton's Second Law

Lecture and problem assignments on Newton's Laws of Motion would be followed by an Atwood's machine experiment in laboratory. The Atwood's machine consists of a low friction pulley, with mass hangers suspended from two ends of a string which runs over the pulley, so that when one mass is on the floor, the other hangs just below the pulley.

1) Students are instructed to load each mass hanger with 500 grams, then to add enough mass to hanger #1 so that the gravitational force on this mass will be sufficient to compensate for the frictional drag in the pulley bearings. This is tested by observing that the slightly heavier mass will move down at a constant speed when given a slight push. (This assumes an understanding of Newton's first law.)

2) Students are now instructed to add a small amount of mass to hanger #1. They calculate the gravitational force applied to the system by this mass using the equation $F = mg$, which has been given in lecture, and record the result, as well as recording the total mass on both hangers.

3) The students now release hanger #1 at the highest point and use a stopwatch to measure the time for it to travel a known distance from rest

as measured by a meter stick, and record the time and distance.

4) Using the formula for motion with constant acceleration, the students compute the acceleration of the mass, assuming that it was constant. Using the formula for Newton's second law, they calculate the acceleration the system should have using the total mass on the two hangers and the excess gravitational force calculated earlier.

5) Students compare the acceleration calculated from the distance and time measurement with that from the force and mass measurements. The agreement of the two numbers confirms that Newton's second law works.

Note that this experiment fundamentally requires only some manual and arithmetical dexterity. No conceptual understanding of mechanics is required to follow the recipe given. Understanding this experiment in detail is conceptually complex, requiring an understanding of gravitational forces, the different role of mass in gravitational and inertial contexts, the nature of tension forces in a string, recognition of the role of friction, and recognition that the experiment is limited by the assumption that the acceleration is in fact constant. However, no conceptual explanation is required as the experiment is designed. Students following the engineering model of experimentation will see the goal as getting two calculated numbers to match within the limits of "human error". There is no particular incentive to dig any deeper.

An Inquiry Based Teaching Sequence for Newton's Second Law

There are a variety of approaches to teaching Newton's second law, discussed for example in Arons (1990). The sequence described here is taken from the PSSC course (Haber-Schaim & et al., 1960ff). To a physicist,

the sequence of experiments and measurements yields a nice, clear result. Unfortunately, many students tend to focus on the sub-goals of making measurements (Séré, 1993) and lose sight of the overall goals of the sequence, as they concentrate on carrying out tasks rather than analyzing them. Thus the logical significance of the result is not clear to the students, and typically does not make a significant impact on their conceptual understanding. Nonetheless, with the tools available at the time, this is a reasonably well-conceived sequence of experiments.

The sequence of steps in the PSSC experiment as originally written is described below with rough estimates of the time required for different steps in the sequence. The equipment used in this experiment is a wooden or plastic cart equipped with roller-skate wheels, bricks which are used to vary the mass of the cart, long rubber bands which are attached to the carts, meter sticks which are used to hold the rubber band stretched a constant length as the cart is pulled across the floor, and an electric buzzer timing unit which has been modified to mark dots on a long thin strip of paper which can be fastened to the cart and pulled through the stationary timer. The dots are laid down at regular time intervals of about $1/30$ to $1/60$ second depending on the design of the timer, so the marks on the paper constitute a position-time record of the motion. Velocity graphs are then constructed by dividing the changes in position by the time intervals, and plotting the results on graph paper.

1) Establish a "primitive standard" for the concept of force from the kinesthetic experience of force as the pull of a specific type of rubber band when stretched a particular distance, i.e. one force unit = the pull of a #30 rubber band stretched to a length of 40 cm. (10 min class discussion.)

2) Take an object with low friction, in this case a roller skate cart with some bricks on it, and pull it across the floor with a constant force of one unit. Make a position-time record with a ticker-tape timer which puts dots on a strip of paper at even time intervals. (10 - 15 min to get first good tape.)

3) Measure position as a function of time and then construct a velocity-time graph of the motion. (10-15 min)

4) From the graph:

- a) observe the slope and recognize that it is constant which implies that the acceleration is constant,
- b) measure the slope and record the value of the (constant) acceleration with one force unit. (10 min.)

5) Pull the skate cart across the floor with two identical rubber bands side by side, stretched the same amount as the single rubber band in the first measurement, again recording the motion on paper tape. (10 min to get good tape.)

6) From the graph:

- a) observe that the slope is constant which implies the acceleration is constant,
- b) measure the slope and record the value of the (constant) acceleration with two units of force. (10 min.)

7) Pull the skate cart across the floor with three identical rubber bands side by side, stretched the same amount as the single rubber band in the first measurement, again recording the motion on paper tape. (10 min to get a good tape.)

8) From the velocity-time graph:

- a) observe that the slope is constant which implies the acceleration is constant,
 - b) measure the slope and record the value of the (constant) acceleration with three force units. (10 min.)
- 9) Plot a final graph of acceleration as a function of the force. (10 min.)
- 10) Observe that the graph is (more or less) a straight line with positive slope indicating a linear relationship between force and acceleration.
- 11) Conclude that acceleration is directly proportional to applied force. (10 min discussion.)
- 12) Repeat the sequence of measuring acceleration with a single value of force while varying the mass on the cart, finding acceleration values, plotting graph of acceleration as a function of mass and interpreting results. (60 min lab and analysis.)

This process can take 100 or more minutes (2 to 3 periods) of class time over several days to reach the conclusion that acceleration of an object is proportional to the applied force, and another 60 minutes (2 periods) to reach the conclusion that the acceleration is inversely proportional to the mass. Each of the tasks requires manual dexterity. The present author's experience suggests that students who see labs as a set of tasks to be accomplished feel after doing the lab work that they have completed each task, but the final assembly of data and conclusion may be so far removed in time and effort from the original question that they have no sense of having answered any overriding questions or made a discovery. The sequence of procedures described is too tedious to be readily "invented" by

students in a class discussion. Sub-goal directed students understand the final graph as a “get the right answer” exercise, since they have been trained to do this in other courses, particularly in mathematics where graphing almost invariably requires the creation of a picture from a given functional relationship rather than inducing a functional relationship from a picture. The goal is understood by students to be the visible construction—the graph as the end in itself, rather than the means to the invisible conclusion. The profusion of sub-goals and the task orientation of students confound the elegance of the “proof,” and so minimize the number of students who have an experience of discovery, or of mind-changing re-cognition, or of conceptual change. With all this said, this sequence is still a good, clear, logical sequence, and with care and effort can be taught fairly well, at least to a subset of students.

A Theory-Based MBL Sequence for Teaching Newton’s Second Law

The curriculum to be used in this study (See Appendix A) makes a radical change in the design of the central experiment to take full advantage of the real-time graphing ability of the computer. In the inquiry-based experimental sequence it was essential to keep the force constant while towing the cart because there was no other way to establish a force-time record to compare with the position, velocity and acceleration records that can be constructed from the marked timing tape. The development of MBL force probes removes this limitation and makes possible the instant by instant comparison of force-time, acceleration-time and velocity-time records, and the direct construction of force-acceleration and force-velocity records as well. The novel feature of the experimental sequence described by Morse (1992a) is the direct visual comparison of the shapes of the force,

velocity and acceleration histories of a motion with a complex force-time variation.

An earlier version of an MBL experiment on Newton's second law (Laws, et al., 1991) retained the logical structure of the PSSC sequence, but used the motion detector and force probe to measure the acceleration and to show that the force applied to the cart was constant. Average values of the acceleration and force were obtained and a separate graph of acceleration as a function of force was plotted as in the PSSC experiment. The inverse relation between acceleration and mass was established in the same fashion as the PSSC experiment, using data collected with the motion detector and the force probe. Although this procedure is much faster and involves less drudgery for students, the process of reaching a conclusion about the relationship of force and acceleration is still a step removed from the experiments. It does have the advantage of allowing students to study motion with constant force, a good preparation for later studies of motion caused by gravitational force for example, although it can be argued that we should have students predict such behavior from the general case of motion with a non-constant force, thus having them extend their understanding by applying the theory to special cases.

The sequence of steps in the experimental MBL sequence is:

- 1) Establish a "primitive standard" for the concept of force from the kinesthetic experience of force as the pull of a specific type of rubber band when stretched a particular distance, i.e. one force unit = the pull of a #30 rubber band stretched to a length of 40 cm. (10 min class discussion) This step is the same as the first step in the PSSC sequence and does not use MBL tools.

2) Further investigate and develop the concept of force by static pulls with rubber bands, springs, spring scales, and the modified force probe, establishing standard force units as defined by the pull of a standard spring. (40 min lab work.) This step allows more time for students to develop the idea of force and to become familiar with translating the kinesthetic experience into verbal, graphical and numerical terms. It also establishes the force probe as a force measuring tool.

3) Establish in static experiments with the modified force probe that the force probe can indicate the combination of forces acting on it by pulls in two directions. This is done by applying forces both to the head hook and to the tail hook of the modified force probe. (20 min lab work and discussion) This step builds familiarity with the force probe and calibration procedures, and develops the idea of the one-dimensional *combination of forces*, a precursor to the concept of the “net force” needed to fully understand Newton’s second law.

4) The teacher proposes the question (which has usually come up earlier but been deferred) of the effect of forces on the motion of objects. In questions and discussion, lead students to suggest using force probe and low-friction carts to investigate this. (15 min discussion)

5) Using a modified force probe attached to a cart with springs modified to have a non-linear behavior attached to each end, students make simultaneous graphs of force, acceleration and velocity as function of time. (10 min lab) Students observe the relative shapes of the force, velocity and acceleration graphs, and draw their conclusions about the relationship between combined force and motion. The teacher then poses the question “what motion variable does combined force most directly

affect?" (5 min discussion) (This is the crucial step-the recognition of the identity of the force and acceleration graphs, an event that takes place during the space of the 20 seconds or so while the motion takes place.) The visual picture of the three graphs serves as an iconographic representation of the experimental result, that the combined force is proportionally related to the acceleration at every instant, and has a more complex relationship with the velocity (See Figure 7). The intent of this experiment is to establish the general relationship of the combined force and acceleration in a single one-step experiment, and later to develop the application of this idea to particular instances of more restricted force behaviors. The fact that the result of the experiment is summarized by a single visual picture (Figure 7) makes it an iconographic experiment.

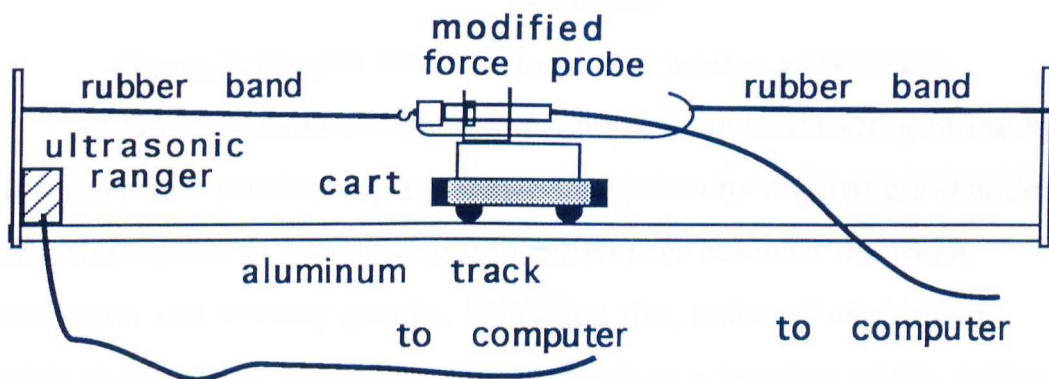


Figure 6: Set up for the iconographic force and motion experiment

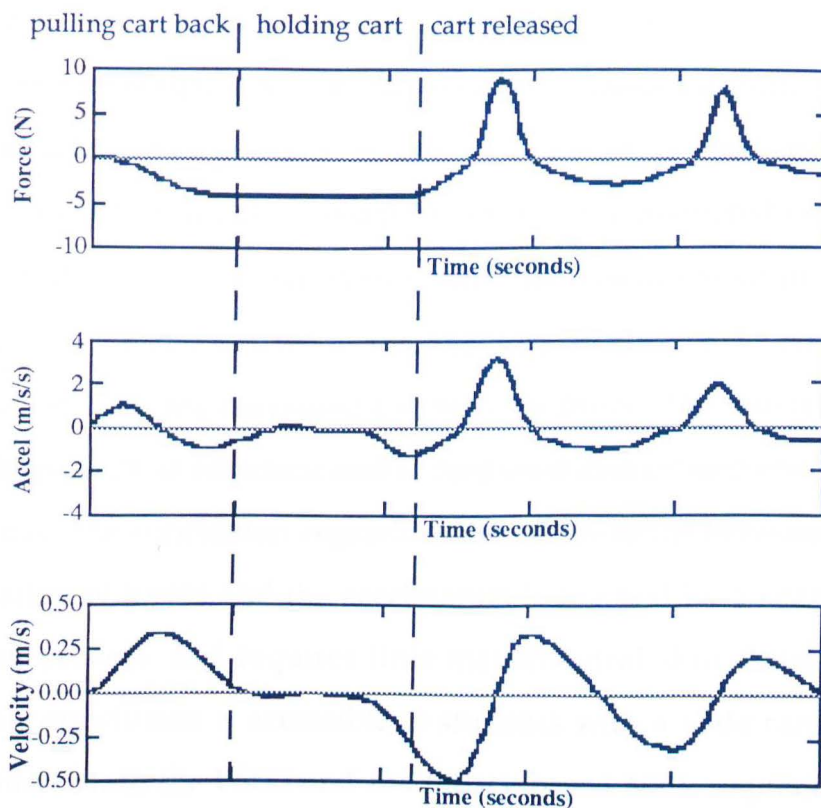


Figure 7: Graphs from the force and motion experiment

6) Now students extend and develop the understanding of the force and acceleration relationship by answering questions requiring a detailed verbal description of correlations and differences between the force, acceleration and velocity graphs. Following this, students explore and explain the shape of the graph of acceleration as a function of the combined force and the graph of velocity as a function of the combined force. (20 min lab.) The time spent on this process gives students practice in developing verbal explanations of the experiments and the graphical results of the experiments.

7) Finally, the teacher proposes the question of the effect of “the amount of stuff” on the motion, leads discussion to design of a qualitative experiment and has students carry out the experiment and discuss their

results and conclusions. (20 min discussion and lab.)

The total time spent in this sequence (about 140 min) is comparable to that in the standard sequence, but with important differences. More time is spent in establishing the concept of force in the restricted context of physics and in building familiarity with the measurement of force. The modified force probe is used to establish the concept of the combination of forces as the quantity measured by the force probe. The crucial experiment has a simple logical structure and is proposed and carried out in a very short time. The conclusion regarding the relationship between the combination of forces and the acceleration is reached by a simple pattern matching process, and requires little mathematical skill. Thus the important conclusion is accessible to students with a wide range of preparation. Both the PSSC and the theory-based MBL sequences provide practice with linear graphing and the interpretation of slopes, but in different contexts. In the theory-based MBL sequence, the work on linear relationships is not mixed up with the discovery of the force-acceleration relation, but is used in elaborating and enriching the study of force measurement. The technique will be used again in the work that immediately follows this unit to help establish the formal mathematical formulation of the second law and in the application of the second law to other forces and motions. In the PSSC unit and the theory-based MBL unit the initial definition of force is qualitative and kinesthetic. In the standard unit, the discovery of the force-acceleration relationship is a quantitative, sophisticated mathematical discovery, while in the theory-based MBL sequence the discovery is a qualitative event requiring only pattern comparison skills. (From a mathematical point of view, this could be

regarded as a sophisticated form of mathematical proof of relationship as the point by point identity of force-time and acceleration-time graphs establishes the relation precisely.) The theory-based MBL unit has students explore the force and motion relationship even farther by investigating and explaining the shapes of the force-velocity and the force-acceleration graphs. The PSSC sequence requires (from a student's point of view) a rather elaborate process of discovery (albeit probably the best available at the time it was introduced). The theory-based MBL sequence has a simple process of discovery and has students elaborate on the idea they have discovered.

CHAPTER THREE

Research Design and Procedures

Overview

The subjects of this study were students in three physics classes taught by the author. One class (group A) served as a pilot group, receiving the experimental instruction about one and a half weeks before the remaining two classes (groups B & C). At the end of every class period of instruction, each student was given a tape recorder and had 10 minutes to answer a set of written debriefing questions. On the basis of the pilot experience, revisions were made to the questions, and the treatment was repeated with the two remaining classes. The tapes were transcribed to provide a database of student responses for analysis. A test of understanding of physics concepts, the Force Concept Inventory (Hestenes, et al., 1992) was administered as a pretest at the beginning of the year, selected questions from the FCI were used as part of an immediate posttest, and the complete inventory was given as a posttest on the final examination. Additional questions from Thornton's Force and Motion Concept test (1992a) were included on the immediate posttest and on the final examination. The Motivated Strategies for Learning Questionnaire (Pintrich & DeGroot, 1990) was given as a pretest at the beginning of the year and again at the end of the semester in which the experimental treatment was used. Data from the pilot class was used to develop and refine the analysis procedures for each part of the research questions. Finally, the class with the best attendance was selected for analysis. As a check on the analysis of the transcripts, a graduate student with experience in physics and in MBL instruction was given portions of the analysis

protocol and relevant portions of the transcripts and a comparison made between the two sets of ratings.

Data collected by Hake (1994) and Thornton(1993)were used to make comparisons between the study group and other groups of students on the Force Concept Inventory and the Thornton Force and Motion test

Methodology

Participants

The participants were students in three physics classes (all sections of one course) taught by the researcher. The students were 10th, 11th and 12th grade males in a selective private school for boys. One section (A) had 17 students and the other two sections (B & C) each had 18 students. Section A consisted of 11 seniors, 5 juniors and 1 sophomore. Section B consisted of 8 seniors and 10 juniors. Section C consisted of 17 juniors and 1 sophomore. The physics course is the standard level course offered in the school and is open to any student at the 11th or 12th grade, with a few students taking it in the 10th grade. This sample included two 10th grade students. About 60% of a graduating class takes this course either in 11th or 12th grade. Other students may take an AP Physics course, but only a few students who take this physics course also take the AP course. In the judgment of the teacher, who has equal experience in public and private school instruction, the range of student abilities in this course is similar to those of students taking physics in a suburban public school, where about 30% of graduating seniors took a course of similar difficulty. The mean verbal PSAT score for students in the course was 535, with a standard deviation of 82, and scores ranging from 360 to 710. The mean mathematics PSAT score was 626, with a standard deviation of 73 and a range from 380

to 740. All students took the PSAT test in the fall of their junior year. All scores are before the 1994 re-normalization of SAT scores. Table 2 gives score statistics by class section and for the entire group.

	Verbal	Math	V+M
Class A:			
Mean	520	641	1161
Min	360	510	960
Max	650	740	1320
StdDev	79	68	117
Class B:			
Mean	567	622	1189
Min	470	380	910
Max	710	730	1420
StdDev	71	92	144
Class C:			
Mean	517	617	1134
Min	380	470	970
Max	660	710	1370
StdDev	90	56	119
All:			
Mean	535	626	1161
Min	360	380	910
Max	710	740	1420
StdDev	82	73	127

Table 2: PSAT scores for study group students

At the time of the experimental treatment, students had completed the study of kinematics using theory-based MBL techniques and a curriculum consistent with those described by Thornton & Sokoloff (1990), specifically a modified and supplemented version of the Real Time Physics curriculum (Sokoloff, et al., 1992).

Timing of Instructional Activities

Section A was used as a pilot class, studying the experimental material one and a half weeks before sections B and C. During this time sections B and C studied a unit on atomic theory and the properties of

matter. Section A studied this unit after finishing the experimental unit. As section B had a large proportion of seniors and many of these were absent on college trips during a portion of the experimental period, it was decided to use only Section C as the analysis group. An additional factor in this decision was a change in school policy in which seniors with a B average or better were exempt from the end of the year exam, resulting in incomplete data for many 12th grade students in Section B.

Data Sources

The research questions were addressed by collecting and analyzing data from the following sources:

1) Student learning beliefs were assessed using the Motivated Strategies for Learning Questionnaire developed by Pintrich and DeGroot (1990) (see Appendix D), with slight modifications to some questions to make them specific to this course. This instrument was administered at the beginning of the course, before any instruction, and again about one month after the end of the experimental instruction to explore possible changes in students' learning beliefs.

2) Students' conceptual understanding of mechanics was assessed using the Force Concept Inventory developed by Hestenes, Wells and Swackhamer (1992). This was administered as a pretest at the beginning of the course prior to instruction. Questions selected by the researcher as relevant to the instruction in kinematics and to the instructional unit on Newton's second law were administered as part of a posttest following the instructional unit. In addition, long term retention was assessed by including the entire Force Concept Inventory on the final examination at the end of the course. Data for the Force Concept Inventory have been

obtained for a variety of classes instructed with traditional techniques and with various other forms of theory based instruction. These results from this test form part of the basis for a comparison of the students in this study with other students (See Appendix B).

3) Questions on motion from the Questions on Force and Motion test developed by Thornton (1992a) were used as part of a classroom test to assess students understanding of kinematics concepts immediately preceding the instructional unit on Newton's second law (See Appendix C). This information served as one measure of students' prior knowledge of concepts needed for understanding Newton's second law. The scores on this test were also used to compare the study group after kinematics instruction with other groups of students taking similar courses.

4) Questions on force concepts from the Questions on Force and Motion test (Thornton, 1992a) were given as part of a classroom test shortly after the instructional unit to assess students understanding of force concepts. Some of these questions were also included on the final examination to see if the change persisted. Finally, a small number of the students took the Force and Motion test one year after the end of the course. These questions were used to compare the study group with other groups of students in theory based MBL courses and in traditional courses.

5) Every day during the instructional unit, each student took the last ten minutes of class (classes are either 55 minutes long or 40 minutes long) to record responses on audio tape (one recorder per student) and paper to a set of ten written questions relating to the day's instructional activities. The questions were developed during the pilot class instruction and revised on the basis of the initial survey of the pilot results. The

responses were later transcribed for analysis. These questions were intended to elicit information about reasoning and learning during the activities and included questions on the perceived goals of experiments, specific questions on concepts and applications of concepts, and probes about the nature of the learning process. Pilot versions of similar questions were used during the kinematics instruction to both refine the questions and to familiarize students with the process of audio-taping responses. The audio recording of responses to written questions was intended to facilitate student's responses, and to insulate the interview process from the teacher, who is also the researcher. Advantages of this technique were that it allowed the rapid debriefing of students on the work they had just completed, the acquisition of rapid verbal responses without the overhead of requiring written responses, and the acquisition of simultaneous data from an entire class. Disadvantages of this technique were that it did not permit follow-up questions or probing which can be done in an individualized interview, some data was lost through operator error in using the tape machines, and a few students were not completely serious in their taping sessions.

Audio Tape Debriefing Questions

The debriefing questions for each day were designated by a code such that question Q203 would be the third question asked on day 2 of the unit. The student answer corresponding to that question would be A203, meaning the answer to the third question on day 2. Nine questions were asked on day one, seven on day four, and ten on all other days. The questions for each day were designed to elicit information on several topics. A complete copy of the question sets for the experimental group

appears in Appendix E, as well as two sample transcripts in Appendix F.

Some questions were intended to probe students' prior knowledge about force and the relationship of force and motion. Thus Q102 asks "From your previous studies and knowledge, when you think of the word 'force', what thoughts come to mind? What does the word force usually mean to you?" This question is intended to probe for prior declarative knowledge of the concept of force. Other questions were designed to have students demonstrate application of either prior knowledge or of newly acquired knowledge, and to identify changes in knowledge. Question Q103, "What effect do you think a force or forces would have on the motion of an object? Give an example to illustrate your ideas", asks for a fairly general application of the students' concept of force to the general problem of motion, while question Q203, "Suppose you arranged to apply a steady force to an object, how do you think it would move? Give any examples you can think of.", probes the students' idea of the effect of force on motion in a more specific context. This question occurs early in the experimental sequence to elicit prior knowledge. A similar question, Q609, given on day 6 of the sequence is probing for the application of student's newly acquired knowledge to this same situation, and looking for changes in knowledge that may have occurred. The specific questions asked varied from day to day based on expectations of students' learning for that day.

Another set of questions was used to obtain students' notions of the goals of the day's laboratory experience, the students' understanding of the graphs made and how they related to the purpose of the experiment, and the immediate general conclusions students drew from the experiment. Additional questions asked students what was the most

memorable or surprising thing they learned that day, and what aspects of the day's work were most effective or helpful to them. These two sets of questions appeared with only minor variations on each day of the unit.

A final set of questions asked about specific knowledge from a particular day's experiment without relation to prior knowledge. Thus Q306 asks "What properties of a spring do you think make a spring scale a good standard of force? What is the evidence for your answer?" Only a few of these questions were used, and they were intended to monitor student progress through the laboratory sequence.

Preparatory experiences.

During the kinematics unit, students were given practice with the audio-recording technique using questions about kinematics. This was intended to introduce students to the use of the recording technique and to improve the efficiency of data collection during the experimental period. In addition, these questions and responses were partially transcribed and analyzed to aid in designing the final questions for the study. All classes had a total of four days of practice with the taping technique prior to the experimental period.

Pilot group.

The pilot group (Section A) took seven days to complete the unit, one day longer than expected, due to a number of equipment difficulties on the second day. No questions were answered on that day. Some of those questions were moved to the third day. Based on the pilot experience, some changes were made in the experimental unit to remove a typographical mistakes and clarify instructions. Based on a sampling of the verbal responses, the questions used each day were revised to clarify them

and to include probes for information that was not readily elicited by the original questions.

Experimental group.

Sections B and C completed the revised experimental unit in seven days, although Section C had substantially completed work by end of the sixth day, which led a few students to give only cursory responses to questions on day 7. The difference in completion time was partly due to the class schedule, in that section C had one more long period (55 minutes rather than 40 minutes) than section B in the seven class days of the experiment. The immediate posttest was administered two days after the end of the experimental unit. Due to absences during parts of the experimental unit, 12 of the 18 students in this section were selected for inclusion in the final analysis group, as they had a substantially complete data set. For parts of the analysis, one or two other students in this group were included, where their missing data did not affect that portion of the analysis. The set of 38 students with complete pretest and posttest data was also used for some comparisons.

Data Analysis

Audio tape records of student responses for all students in the pilot study and the main study were transcribed from the tapes and entered into a database so that responses could be selected and compared by question and by student. Responses to particular questions were selected for use in answering each of the research questions. The specifics of this analysis follow in the discussion of each research question, but in general student responses were edited by underlining the significant portions of the response, and the resulting shortened responses were analyzed or classified

as needed. Test question responses were tabulated for statistical analysis in a spreadsheet, and relevant portions of the data were then subjected to statistical analysis. The significant portions of the response were selected to transform and reduce the raw statement into a set of propositions which reflected the underlying concept or opinion expressed by the student. Thus in the student response "I think a steady force would produce a steady acceleration or a constant acceleration. I think the velocity would go up steadily or constantly just like the uh the uh acceleration graph would predict," the underlined portions identify two propositions, one describing the behavior of the acceleration and the other the behavior of the velocity for an object acted on by a steady force.

The detailed description of analysis procedures is organized below by the portion of each research question which is addressed by the analysis. In each case, the analysis of the pilot data was carried out first, the analysis method refined on that basis and applied to the experimental group. The analysis descriptions that follow describe the procedures developed from the pilot analysis and then used for the final study group.

Analysis For Research Question 1a

Research Question 1a: What is the nature of student reasoning activities and cognitive change during classroom MBL instruction, in particular the understanding derived from real-time graphs of experimental data.

Analysis Procedure

In the pilot analysis, it was found that the data from the taped questionnaires did not provide enough information to make reasonable inferences concerning the nature of student reasoning activities, in part because there was no way to probe students for more information during the audio tape questionnaire. Thus the analysis for this question was limited to the description of the cognitive change that took place. It was expected that MBL real-time graphing experiments would make an immediate impression on students' recognition of the relationship between force and acceleration which would be reflected in their statements about this relationship, but there would be less effect on students' immediate ability to apply this knowledge. A mixed performance on questions relating to the relationship between force and acceleration was expected to persist until students had sufficient experience with the new ideas to make new sense of their experience.

Cognitive change for each student was analyzed by:

- a) describing an initial knowledge state from answers to interview questions on days 1-4, before the real time graphing experiments (A102, A103, A202, A203), and from questions on the FCI pretest, using the Hestenes (1992) classification scheme for force conceptions,
- b) describing the immediate knowledge change of each student on

days 5-7 when the real time graphing experiments took place in terms of:

- i) the relationship between force and acceleration determined from answers to interview questions (A505, A506, A605, A606, A705, A706, A707),
- ii) the application of this knowledge to questions about the motion of an object determined from answers to interview questions (A507, A609, A610, A708, A709) and from questions on the immediate posttest (Questions 1-7 from the Thornton Force and Motion Test),
- c) describing the final state of knowledge of the student as determined from questions on the final examination (FCI posttest) and questions 1-7 from the Thornton Force and Motion Test on the final examination,
- d) describing the long-term knowledge state of those students who took the one-year delayed Force and Motion test.

Detailed Analysis Procedures

a) Initial knowledge state.

The initial knowledge state was determined from pretest questions on the Force Concept Inventory and from interview answers A102, A103, A202, A203. These answers were transformed to propositions by underlining significant words and phrases describing the students statements about the relationship of force and motion. The propositions were then classified according to the Hestenes classification scheme (Table 1) to arrive at a description of the initial knowledge state as described below. This state was expressed in a table (Table 3) showing the Newtonian

conceptions and misconceptions from the Hestenes classification scheme and the numbers of test responses for each category with the pretest data on one line and the identified knowledge from the questionnaire questions on the next line.

	AF2	AF3	AF4	AF5	AF6	Ia	Ib	IIa	Fr
From Pretest:									
From Tape:									

Table 3: Initial conceptions and misconceptions

The instructional design was intended to support the development of certain Newtonian concepts, specifically those dealing with the relationship between the combination of forces and the acceleration in one dimensional motion. In the Hestenes, Wells and Swackhamer Force Concept Inventory, the following list (Table 4) gives the correct conceptions and FCI responses that are expected:

First Law:		RESPONSE
Ia	with no force, speed constant	8A and 27A
Ib	with canceling forces, speed constant	18B and 28C
Second Law:		
IIa	constant force => constant acceleration	24E, 25B
Kinds of Force:		
Fr	friction opposes motion	29C.

Table 4: Newtonian responses to selected FCI questions

In addition, the instructional design should define procedures to help students resolve certain misconceptions. In particular we would expect to see fewer misconceptions associated with the Active Force category, AF2-AF6 in the Hestenes classification (Table 5).

Active force Misconceptions (See also table 1):		FCI RESPONSE
AF2	motion implies active force:	29A
AF3	no motion implies no force:	12E
AF4	velocity proportional to applied force:	25A, 28A
AF5	acceleration implies increasing force:	17B
AF6	force causes acceleration to terminal velocity: 1	7A, 25D

Table 5: Active Force Misconceptions from selected FCI questions

The pretest results were tabulated for these questions for each student, and a correct conceptions score and a misconceptions score were generated. In addition a table of responses showing correct conceptions and misconceptions for each student was made.

b) Immediate knowledge change.

i) Force-acceleration relationship.

The nature of the force-acceleration relationship learned from the real-time graphing experiments in Investigation 2 was determined from audio tape responses A504, A505, A506, A605, A606, A705, A706, and A707.

Analysis for day 5 (A504, A505, A506)

To determine if the experiment enabled students to immediately make the relation between force and acceleration, responses were classified as to whether the student:

- i) expressed relation between force and acceleration
(correct conception)
- ii) expressed a lack of relation between force and velocity
(correct conception)
- iii) expressed a relation between force and velocity
(incorrect conception)
- iv) expressed a lack of relation between force and acceleration
(incorrect conception)

Each expression of a relationship was rated as expressed Clearly (2), Adequately (1), Not expressed (0), or as Missing (blank). If a student stated that force and velocity were related, but qualified the statement through use of terms that showed he recognized it was not a direct relation, he was classified as having a correct conception.

These results were displayed in a matrix to indicate the strength and clarity of the student's expressed perception of the relationships among these variables (Table 6).

	F & A	F & V
YES		
NO		

Table 6: Force, acceleration and velocity relationship matrix

Finally the pattern and value of entries in the matrix were used to classify the student's conclusion as strongly Newtonian (+2), Newtonian (+1), non-Newtonian (-1), strongly non-Newtonian(-2), undetermined (U) or missing (M). Matrices with F&A YES and F&V NO were rated as strongly Newtonian, with only F&A YES, rated as Newtonian, F&A yes but also F&V yes were rated as non-Newtonian and matrices with F&A no and/or F&V yes were rated as strongly non-Newtonian.

Analysis for days 6 & 7 (responses A605, A606, A705, A706, A707)

Analysis for A605 and A606 and A705, A706 and A707 was carried out using the same technique, resulting in a second matrix. Since over half of the students finished the experimental work in Investigation 2 in only two days instead of the three taken by the pilot group, the data for days 6 and 7 were combined for analysis.

ii) Force-acceleration application: verbal responses.

To assess students' ability to apply their knowledge of the

relationship between force and motion to particular situations which typically evoke misconceptions, responses A609, A708 and A709 were selected and propositions identified and underlined. A table of responses was constructed for the two cases represented in the questions: acceleration and velocity caused by a steady force and acceleration and velocity caused by a steadily increasing force. The steady force case reflects an experiment (the towing experiment) actually performed on one of the last days. The steadily increasing force case was not tested experimentally, and represents an application that goes beyond the students' experience in the laboratory. Both sets of questions were phrased without reference to specific experiments. As the steady force question was asked on two days, there was a table entry for each day for that question. For each question the acceleration and the velocity responses were classified as correct (1), unclear (0), or incorrect (-1). In addition, if a misconception was expressed, the Hestenes classification for the misconception was recorded. The responses were then assigned a score of 2 for strongly Newtonian (all 3 correct), 1 for Newtonian (2 of 3 correct), -1 for non-Newtonian (2 of 3 incorrect), and -2 for strongly non-Newtonian (3 of 3 incorrect) for comparison with students' conclusions about the force acceleration relationship.

c) Force-acceleration application: immediate posttest.

Questions on force and motion from the immediate posttest were used as a second measure of students' application of the force-acceleration relationship.

Questions 1-7, the force-sled questions, and questions 14-21, the force-graph questions from the Thornton Force and Motion test, and questions 22, 25 and 26 on the immediate posttest (Force Concept Inventory

question numbers 18, 28 & 29) were used for this analysis. Students were rated as strongly Newtonian (+2), partly Newtonian (+1) or non-Newtonian (0) depending on the number of correctly answered questions on each of the three sets according to the criteria in Table 7:

Rating:		+ 2	+ 1	0
Questions	1-7	6-7 correct	4-5 correct	<4 correct
Questions	14-21	6-8 correct	4-5 correct	<4 correct
Questions	22,25,26	3 correct	2 correct	0-1 correct

Table 7: Newtonian conception rating criteria for immediate posttest Thornton and FCI questions.

d) Force-acceleration application: final exam.

Questions 1-7, the force-sled questions, from the Thornton Force and Motion test, and questions from the FCI were used as a third measure of students' application of the force-acceleration relationship. For the Thornton test questions, the same scoring scheme used on immediate post test was employed, as described above. For the FCI questions the same scoring was used as in the FCI pretest as described above. For the FCI questions, the Newtonian conceptions were counted and a Newtonian score generated with 6-7 correct rating a 2, 4-5 correct rating a 1 and less than 4 correct rating 0.

From the above data, a summary table (Table 8) was created for each student showing the initial knowledge state, the force-acceleration relationship from real-time graphing, the force-acceleration application by verbal response, the force-acceleration application by immediate posttest and the force-acceleration application by final exam for use in describing the knowledge states and knowledge changes for that student.

Student: 301		Non-Newtonian	Newtonian
Initial Knowledge:	FCI		
	Verbal		
Immediate Knowledge	F&A Matrix-day 5		
	F&A Matrix-day 6&7		
	Application Questions		
	Thornton Questions 1-7		
	Thornton Questions 14-21		
Final Knowledge:	FCI-3 Questions		
	Thornton Questions 1-7		
	FCI		

Table 8: Sample table of student conceptions and changes in conceptions during experimental sequence. (Underlines represent possible range of entries, entries to right of vertical line are Newtonian conceptions, entries to left are non-Newtonian.)

Each table 1) shows the pattern of student responses, 2) shows the changes in student thinking from the initial knowledge state to the immediate knowledge state to the final knowledge state, 3) indicates the source of information, and 4) forms the basis for summarizing each student's knowledge changes.

Finally, an opportunity arose to give the Thornton Force and Motion test to some of the students one year after the end of the course. For those students the Thornton questions 1-7 (force-sled questions) and 14-21 (force-graph questions) results are shown as a delayed posttest. For the subset of students who took a force and motion posttest one year later, the scores for these tests were added to the summary table.

Data from the individual tables were then interpreted and the knowledge changes for each student were described. Finally, the individual

data were combined to describe patterns of knowledge change for the group of students as sampled by these measures.

Analysis For Research Question 1b

Research Question 1b: What evidence is there that the nature of the conceptual change is consistent with the mechanisms posited in the instructional design, in particular that the “iconographic” experiment relating force and motion is an effective learning activity

Analysis Procedure

Evidence relating to this research question came from tape interview questions which probed for students' initial conception of the relationship between force and motion, from questions which probed students' description of the experiment and their notion of its purpose, from questions which requested students' immediate conclusions and descriptions of the graphs they had made, from questions which asked about surprising results or results which contradicted their beliefs, and from questions which looked at the short term (2 and 3 day) persistence of students' conclusions.

1. The major conceptual change that this curriculum attempts to induce is to have students change from the prior conceptual view (expected for most students) that force and velocity are proportional to a view that force and acceleration are proportional. Thus we look for evidence of the initial conception before the critical experiment, for the immediate conclusion and the persistence of the conclusion.

2. The mechanism of change is expected to be efficient recognition with a low search cost -(Larkin & Simon, 1987) that a matching pattern of force and acceleration graphs and a mismatch of force and velocity graphs means that force and acceleration are directly and causally related.

Evaluating students' initial conception.

Evidence from many studies (Halloun & Hestenes, 1985a) suggests that students' prior knowledge before formal physics instruction would lead most students to state the initial conceptions that:

- 1) a steady force will cause a steady velocity,
- 2) an increasing force would be needed to cause an increasing velocity, beliefs coded as AF4 and AF5 respectively in Hestenes' taxonomy of misconceptions.

Questions Q103, Q202 and Q203 served as probes to elicit students' initial conceptions. It is also expected that a few students may believe that a force causes acceleration up to a terminal velocity, code AF6. Analysis of the initial conception consisted of selecting responses A103, A202 and A203, selecting propositions by underlining, and classifying the propositions by the Hestenes scheme. The classification codes used included one or more of the beliefs NT for Newtonian belief, AF4, AF5 and AF6 as well as Unclear or Missing if the questions were not answered. On the basis of the codes, students were assigned a score for this portion of the analysis as follows:

Code NT, which contradicts the notion that students will have prior beliefs that are non-Newtonian, was scored as -1.

Codes AF4, AF5 and AF6, which support the expected model of students' prior beliefs, was scored as +1.

Codes U and M, which give no evidence, were scored as 0.

Evaluating understanding of the description and purpose of the experiments.

It was expected that the nature of the experimental design would

enable students to readily appreciate and thus be able 1) to describe the setup of the experiment, and 2) to clearly state the purpose of the experiment.

Questions Q502 and Q503 served as probes to test students' ability to describe the setup and clearly state the purpose of the experiment. Analysis consisted of selecting responses A502 and A503, transforming them to propositions by editing and rating them for clarity and completeness. The description of the experiment was rated as clear and complete (C), adequate (A), poorly expressed but probably correct, (P), unclear (U) or missing (M). Ratings C, A and P were considered to support the hypothesis that the MBL experiment enabled students to describe the experiment and were assigned a value of +1. Ratings of U and M gave no evidence in support of the hypothesis and received a score of 0.

The statement of purpose was classified as clearly expressed in terms of goals (CG), partially expressed in terms of goals (PG), clearly expressed in terms of sub-goals (CSG), partially expressed in terms of sub-goals (PSG), unclear (U) or missing (M). This classification scheme is also used for research question 1c, and is discussed further in that section. Ratings of CG, PG, CSG, and PSG were considered to support the hypothesis that the experiment is effective in promoting recognition of the purpose of the experiment and received a score of +1, U and M were considered to give no evidence of support and received a score of 0.

Immediate Conclusion and Graphs

Underlying the instructional design of the iconographic force and motion experiment is the hypothesis that visual pattern matching will allow students to "see" the relation between force and acceleration rapidly,

that is the experiment will 1) enable students to observe the relation between force and acceleration, 2) prompt students to realize a contradiction between their prior beliefs and the result, and 3) be memorable enough so that the experiment will be cited as evidence by students in describing their conclusions. Questions Q504, Q505, Q506, Q507 and Q508 served as 1) immediate probes for students' recall of the graphs (A504), 2) of their conclusions from the experiment (A505 and A506) and 3) of their assessment of the effectiveness of the experiment (A507, A508).

Analysis of A504 consisted of looking at the sketch graphs made by the student and any remarks about the graphs and deciding if the graphs showed the expected correlation between force and acceleration clearly (C), adequately (A), possibly correctly (P), inconclusively (I) or were missing (M). Ratings C and A were considered to support the hypothesis that the experiment is effective and received a score of +1, while ratings P, I, or M were considered to give no evidence, and received a score of 0.

Analysis of A505, A506 and A507 consisted of selecting the responses, transforming them to propositions by underlining, and rating students on relation, realization of contradiction, and memorability of experiment. To determine if the experiment enabled students to see the relation between force and acceleration, propositions were classified as to whether the student:

- i) expressed relation between force and acceleration
(correct conception)
- ii) expressed a lack of relation between force and velocity
(correct conception)

- iii) expressed a relation between force and velocity
(incorrect conception)
- iv) expressed a lack of relation between force and acceleration
(incorrect conception).

Each relation expressed was rated as Clear (2), Adequate (1), Not at all (0), or as Missing (blank). If a student stated that force and velocity were related but qualified that by use of terms that showed he recognized it was not a direct relation, he was classified as having a correct conception. These results were displayed in a matrix (Table 9) to indicate the strength and clarity of the student's expressed perception of the relationships between these variables.

	F & A	F & V
YES		
NO		

Table 9: Force, acceleration and velocity relationship matrix

Finally the entries in the matrix were used to classify the student's conclusion as strongly correct (+2), correct (+1), incorrect (-1), strongly incorrect (-2), undetermined (U) or missing (M). Matrices with F&A YES and F&V NO were rated as strongly correct, with only F&A YES were rated as correct, with F&A YES but also F&V YES were rated as incorrect and matrices with F&A NO and/or F&V YES were rated as strongly incorrect.

To determine if the experiment prompted students to realize a contradiction between their prior beliefs and the result of the experiment, responses were rated as expressing surprise (S), contradiction(C), no surprise or contradiction (N), unclear (U) and missing (M). Ratings of S, C, SC were regarded as supporting the effectiveness of the experiment in making students conscious of a conflict with their prior knowledge and

were given a score of +1, while ratings of N, U and M were considered to give no evidence and received a score of 0.

Persistence of conclusions.

Another hypothesis of the instructional design is that the experiment will be sufficiently memorable to make a lasting impression on students. Evidence for this would be 1) persistence of correct conclusions in the students' statements one day and two days after the experiment and 2) continued citation of the comparison of the graphs as evidence for the conclusions. Questions Q606 and Q706 served as probes for recall on the two days following the experiment.

The responses A606 and A706 were analyzed for expression of correlations between force, acceleration and velocity in the same fashion described above for the immediate conclusion, and were also analyzed for expression of the memorability of the graphical evidence. To determine if the experiment was memorable enough to be immediately cited as evidence, statements were looked for that used the keyword "evidence" or that were interpreted as stating evidence by references to comparisons of the graphs or to the shapes of the graphs. The statements were rated as citing the experiment as evidence (C), giving no expression of evidence (N), missing (M), or unclear (U). A rating of C was considered to support the effectiveness of the experiment and was given a score of +1, while ratings of N, M or U gave no support and received a score of 0.

Summary table.

Finally a summary table was prepared for all of the students' results and each sub-result rated as supporting the hypothesis (+1), giving no evidence or support (0), or as contradicting the hypothesis (-1). There are

eight sub-results described above, so a perfectly supporting summary score would be +8. All results can have positive scores, but only three categories can have negative scores. A composite score of 5 is required to assure that there are more supporting results than neutral or negative results.

Therefore a composite score of 5 or more was taken as support for the hypothesis that the iconographic force and motion experiment was an effective learning activity for a student.

Analysis For Research Question 1c

Research Question 1c: What evidence is there that this instructional design allows students to identify and focus on important conceptual goals of experiments, rather than subgoals.

It was expected that the reduction in processing load in experiments which used real-time graphing would allow students to more readily attend to the important conceptual goals of the experiment. The laboratory work in days 1 through 4 of the curriculum unit relied very little on real-time graphing of data, while the work on days 5 through 7 relied heavily on real-time graphing of data. Thus it was expected that there would be a difference in students' ability to identify and focus on goals rather than sub-goals between days 1-4 and days 5-7.

Analysis Procedure

From each day's transcript the responses to questions

- a) describe what you did in the lab,
- b) what was the main purpose or goal,
- c) what did you learn,

were selected and words and phrases which were judged to be the essential parts of the propositions were underlined.

From the student descriptions of the experiment each day, the activities dealt with during that day were determined. If students focused on sub-goals, it was expected they would talk about experiments in terms of the measurements and graphs as end-products. If students focused on goals, it was expected that they would talk about the physical quantities, citing graphs and measurements as evidence for conclusions about the relationship between force and motion.

The curriculum guide for the unit refers to 6 objectives or goals, but one was inadvertently left out of the guide and one was included which was not significantly emphasized in the modified curriculum unit. Thus there were 6 objectives or goals actually used in the analysis, but they were numbered 1,2,3,4,5, and 7. Goals 1 through 5 correspond to the goals presented in the curriculum guide, while goal 7 was the goal which was left out of the modified curriculum guide. The curriculum goals are given below in association with the particular activities most closely associated with each. For each day the propositions were used to determine to what extent students identified goals or sub-goals corresponding to those in the curriculum guide and to what extent students expressed results in terms of goals or sub-goals.

Decision criteria were whether students used language relating closely to measurements, graphs, or particular experimental actions, interpreted as a focus on sub-goals, or used language relating to concepts, variables and relationships, interpreted as a focus on goals. Completeness and clarity of responses were used to distinguish partial and clear focus ratings. Unclear was used when a response was ambiguous, or so poorly expressed that no interpretation could be made. Missing was used to describe statements which should have been made, but were not. Absent was used to identify days on which students were absent from the class. Thus for each of the seven lab days students were rated for identifying goals and focusing on goals with ratings for each goal mentioned of missing (M), unclear (U), partial sub-goal(PSG), clear sub-goal(CSG), partial goal (PG), clear goal (CG), or absent (A).

Description of activities and objectives.

The activities and their associated objectives for the curriculum unit as expressed in the student manual are given in Table 10.

days 1,2, 3,4	
1-1 :	(1) To develop the concept of force in terms of how it is measured
1-2:	(2) To understand the relationship between the force applied to a spring and its extension
1-2,1-3,	(3) To learn how to use a spring scale to measure force
1-4, 1-5	(4) To learn how to use a force probe to measure force
days 5,6,7	
2-1	(5) To understand the relationship between forces applied to an object and its motions
2-2,2-3	(7) To find the effect of adding more "stuff" on the acceleration of a moving object (missing from goal description in student manual.)

Table 10: Activities and objectives of the instructional unit

A brief description of the lab activities follows:

Investigation 1 Measuring forces.

Activity 1-1 establishes a stretched rubber band as a primitive force standard.

Activity 1-2 establishes continual scale with spring , using computer to get a linear equation for graph.

Activity 1-3 using force probe in arbitrary units.

Activity 1-4 calibrating the force probe in standard units.

Activity 1-5 combining pulls in two directions.

Investigation 2 Force and Motion

Activity 2-1 force and motion experiment- simultaneous real-time graphing of force, acceleration and velocity as a function of time. Also making real-time force-acceleration graphs and force-velocity graphs.

Activity 2-2 adding more "stuff" (mass) to the cart.

Activity 2-3 using a fan-driven cart towing the force probe cart.

The activities in Investigation One, which occupied the first four days of the unit, did not make significant use of real time graphing, while those in Investigation Two, which occupied the last three days of the unit, make extensive use of real time graphing. Thus we would expect that if real time graphing activities using MBL allow students to focus on goals rather than sub-goals, there might be a change in identification and focus on goals from the first investigation to the second.

In the pilot analysis several ways to look at the data were explored. From this exploration, it seemed reasonable to only focus on goal identification by day, as it proved difficult to completely sort out which specific activity of two related ones in a given day students were referring to in their statements. The crucial change in the activities occurred on day 5 for all students. No student was involved in more than two activities on one day. Thus the data were broken down in two ways, 1) by day, and 2) by Investigation. A summary tabulation was made for each case and the results displayed in graphs for evaluation.

Analysis For Research Question 1d

Research Question 1d: Which instructional activities and what aspects of the instructional design do students identify as effective for their learning?

Analysis Procedure

Each day one question asked students to identify the parts of the day's laboratory work which they thought were most effective. In another question on some days (2, 3, 5, 6), students were asked which activities were most memorable. It was expected that students would identify as effective those activities which made the most impression on them or which they felt were most helpful in learning. The responses related to effectiveness (A109, A209, A210, A309, A310, A407, A509, A510, A608, A710) were selected, propositions and keywords were underlined, then catalogued and summarized. As these questions were usually one of the last questions of each taping session, some students referred to their responses to earlier questions using "this" or "these" or making other references. In these cases the full transcript was consulted to clarify meaning. In some cases interpretations which did not use the students' own words were recorded parenthetically in the edited transcript. As a check, the full transcripts were also consulted to make sure nothing was missed. In a few cases, statements from answers to earlier questions which clearly addressed the question of effectiveness were included in the transcript. Data from 14 of the 18 students was used, the data from the remaining 4 being eliminated due to excessive absence. Students absent for only one day during the laboratory sequence were retained for this analysis. For each day, the number of similar responses was tabulated, to draw conclusions about the frequency

with which various features of the laboratory work were cited as most effective. The final interpretation of the data was based on this tabulation.

Analysis For Research Question 2a

Research Question 2a: What are the changes in student success rates on measures of conceptual understanding applied before and after instruction specifically in regard to Newton's second law.

Test Instruments

The Force Concept Inventory developed by Hestenes, Wells and Swackhamer,(1992) based on the earlier Halloun and Hestenes Diagnostic Mechanics Exam (1985b) was used as a diagnostic tool to determine conceptual change. The entire exam (29 questions–reproduced in Appendix B) was administered as a pretest before any instruction and was given again as part of the final examination at the end of the course. A subset of 5 questions judged most relevant to the instructional unit (questions 18, 20, 21, 28, 29) were administered as part of the test given a few days after the end of the instructional unit (immediate posttest). Of the 53 students in the course, all except one took the pretest. Due to school policy seniors with a grade of B or better in the course were exempt from the final examination, and some seniors who were engaged in an out of school senior project were also exempt from the final examination. It was not considered feasible or reasonable to ask these students to take the Force Concept Inventory separately, so only 38 students took the final examination. Most of the missing students were doing well in the course, so it is expected that their absence would lower the average results. Group C, the group used for the final analysis, had no seniors and was not affected by this, but did include the one student who had not taken the pretest. Section C statistics were thus analyzed for the whole group (17 of 18 students) and for the 12 of 18 students who were present for the whole instructional unit (denoted as

"C-drops" in the tabulations).

Statistical Tests

A one-tailed paired t-test was used to check for significant differences between mean scores, since it was expected that students would show a gain in score. For the full 29 question FCI test, the gain was determined from the pretest to the final examination. For the 5 question sub-test, gains were compared for pretest to immediate posttest, for immediate posttest to final examination and for pretest to final examination. The comparisons were carried out for the whole course (38 students), for each section, and for the 12 students in section C selected for the analysis for Research Question 1a.

Analysis For Research Question 2b

Research Question 2b: Do changes in student success rates on conceptual measures relate to students' descriptions of their learning activities and conceptual understanding?

Overview

The analysis for this question was divided into two parts. The first considered the relationship of changes in student success rates on conceptual measures to the characterization of students' description of their learning activities. The second considered the relationship of changes in success rates to students' verbal descriptions of their conceptual understanding. For both parts of the analysis, three measures of change in student success rates were used. Two of the measures were based on Force Concept Inventory scores and a third used the Thornton Force and Motion questions from the immediate posttest. Two measures of students' verbal descriptions of their learning activities were used, one based on the student's identification of effective learning activities as described in the analysis procedure for research question 1d above, and the other based on a score for the student's learning activities derived from the analysis of student responses used in research question 1b. The measure of student conceptual understanding of the force and motion relationship was compiled from the verbal responses to questions about the relationship of force and motion from questions on days 5, 6 and 7 discussed in the analysis for research question 1a.

During the pilot analysis, it became clear that there was a limitation on the detail available about student thinking from the audio tape debriefings. Thus it was decided to categorize each of the 12 students

considered in this part of the analysis as rating High or Low on a given measure and to investigate the resulting patterns of relationships. The small number of students and the limited detail led to the decision not to employ more sophisticated statistical measures.

Force Concept Inventory Measures

The first measure of student success rates used a 3 question sub-test of the Force Concept Inventory composed of the most relevant questions from the FCI (18, 28, 29) which were included on the immediate posttest as discussed above in the analysis procedure for research question 1a.

Students with 2 or 3 questions correct were rated as High on this measure and students with 0 or 1 question correct were rated as Low. The advantages of this measure were that it was administered immediately after the instructional unit, and that the questions chosen were those most directly relevant to the instructional unit.

The second measure of student success rates based on the Force Concept Inventory considered the change in score on the entire inventory from pretest to posttest. Following the example of Hake (1994) a "gain parameter" or relative gain ratio, g , was calculated for each student based on the ratio of the actual gain relative to the maximum possible gain ($g = (\% \text{ gain}) / ((100\% - \% \text{ pretest}))$). Students with a gain parameter of 0.5 or greater were rated as High, those with less than 0.5 were rated as Low. The advantage of this score is that it relies on much more information than the 3 question sub-test, but a significant limitation is that the posttest was administered long after the end of the instructional unit.

Thornton Force and Motion Test Measures

As no pretest data were obtained for students in the study for the

Force and Motion questions 1-7 and 14-21, only the immediate posttest score for these questions was considered. It is quite reasonable, however, to consider this score as measuring a change in success rates as there is a considerable body of data which shows that both high school and college students have very low pretest scores on these questions (Thornton, 1995) . Assuming that the students in this sample are not very different in their prior knowledge from other high school students taking introductory physics, an assumption that will be argued in chapter 4 in the results for research question 2c, the final score on these questions should be representative of the gain on these questions. A score of 10 or better out of 15 was taken as a High score and a score of less than 10 was taken as a Low score. The disadvantage of a lack of a pretest scores was a compromise that was judged necessary to avoid overtesting the students. The advantages of this measure are that it was given immediately after the instructional unit, its questions relate well to the material being learned, and there are a reasonable number of different questions to more fully explore student understanding than the FCI 3 question sub-test.

Student Descriptions of Their Learning Activities

Two measures of student descriptions of their learning activities were constructed by returning to the data used in research questions 1b and 1d, this time looking at the response pattern for each student, instead of the responses for the whole group. An important tenet of theory-based MBL instruction is that computer graphing, particularly real-time graphing is effective in promoting learning. It follows that student awareness of and attention to the graphical presentation of information as indicated by citing graphs as effective for learning might indicate that they are using and

attending to the graphs in their learning. Accordingly the responses in the analysis for research question 1d for each of the 12 students in the C period group were examined and the number of responses explicitly citing graphs was tabulated for each student. Students explicitly citing the use of graphs as effective for learning 4 or more times were rated High and those citing graphs 3 or fewer times were rated Low on this measure.

A second measure of student descriptions of their learning activities was based on the analysis employed in research question 1b. In that analysis a composite score was generated for each student based on the initial conception of the relation of force and motion, ability to describe the experiment, ability to understand the purpose of the experiment, immediate conclusion drawn from the experiment, ability to represent and reason from graphs, persistence of their conclusions, and ability to continue to cite evidence for their conclusions. For this question, all of these sub-scores except the student's initial conception and immediate conclusion were considered as relating also to the learning activities of the student. Consequently a score was generated for each student by removing the ratings for initial conception and immediate conclusion from the score calculated in research question 1b and using the residual score as a measure of student learning activities, with scores of 4 or higher rated as High. This measure has the advantage that it draws on several sources of information to generate a rating for each student.

Student Description of Conceptual Understanding

A measure of each student's description of his conceptual understanding was generated by combining the scores from the force and acceleration matrices and the application question scores used to assess

immediate knowledge in the analysis of research question 1a, described above. A score of 3 or higher was rated as High, while lower scores or negative scores were rated as Low.

Organization and Analysis of Data

On the basis of the scores computed for each measure above, each student was classified as rating High or Low on each measure. A table showing the ratings for all students was made. Finally, for each pair of variables, a matrix was prepared showing which students were high on both measures, which were low on both measures and which were high on one and low on another. Conclusions were then drawn based on the patterns in each matrix.

Analysis For Research Question 2c

Research Question 2c: What is the comparison between student success rates on conceptual measures of students in this study and the student success rates reported for students in traditional instructional settings and in other theory based settings?

To address this question, two sets of comparison measures were used. The first set used the Force Concept Inventory pretest and posttest measures previously described. The second set consisted of comparisons using questions from the Thornton Force and Motion Test (1992a).

Data Sources

Data on the performance of various groups of high school and college students on the Force Concept Inventory was obtained from two sources. One source was the 1992 article describing the Force Concept Inventory and its use (Hestenes, et al., 1992). A second source was a larger collection of data from about 3500 students made by Richard Hake (1994). This collection includes both classes taught using traditional pedagogy and curricula and using what Hake refers to as Interactive Engagement methods, a label which includes a variety of theory-based instructional techniques.

Another set of comparisons was made using the Thornton Force and Motion Test (1992a) between the posttest performance of students in the study group and other students both with traditional instruction and curricula and with theory based MBL instruction. Not as much high school data were available for these tests and some of the comparisons were thus made with students taking introductory college courses.

Comparisons Using the Force Concept Inventory

The students in the study were compared with other high school students using both traditional instruction and theory based instructional methods. The data for comparison were collected from various sources by R. Hake (1994). This data includes data from the Hestenes, Wells and Swackhamer studies using the Force Concept Inventory.

Students in this study were analyzed in two groups. Study-reg included all 38 students who took the pretest and final examination posttest. Study-C-12 which included the 12 students in group C who were present during the entire instructional unit, and took all the tests.

A comparison was made between pretest scores to establish how the study group compares on the FCI with other high school classes. A t-test was used to compare the study group mean with the mean performance of the entire set of students for which data were available. Additional comparisons were made between posttest scores and gain scores for the study group and the other groups, and in these comparisons the difference between groups using traditional instruction and groups using Interactive Engagement methods was examined.

An additional set of comparisons was made for the five question sub-test of the FCI inventory that related most directly to the instructional unit. These questions appeared not only on the pretest and final examination posttest, but were also included on the immediate posttest at the end of the instructional unit. These comparisons could only be made with four other groups as sufficient data was not available to make the comparisons with all groups. Again, t-tests were used to look for significant differences between means.

Analysis For Research Question 3a

Research Question 3a: How are motivational and self-regulated learning beliefs of students related to success rates on conceptual measures in the MBL classroom?

The analysis of this question is based on the Motivated Strategies for Learning Questionnaire (MSLQ, see Appendix D) developed by Pintrich and DeGroot (1990). The questionnaire is broken into three motivational components (Intrinsic Value, Self-Efficacy, and Test Anxiety) and two learning strategy components (Cognitive Strategy Use and Self-Regulation). The questionnaire was administered twice, once at the beginning of the semester, before any instruction, and again at the end of the first semester, which consisted primarily of MBL instruction, including the experimental unit.

In the Pintrich and DeGroot study cited above, the relationship of motivational and cognitive variables to student performance was investigated for four measures of student performance for students in seventh-grade science and English classes. Variables investigated were year grade, seatwork grade, examination and quiz grade, and essay and report grade. Pintrich and DeGroot were interested in 1) the inter-relationship of the motivational and cognitive variables, 2) the interactions between motivational and self-regulated components, and 3) the relationship of the motivational and cognitive variables to student performance. In this study, research question 3a is similar to the third focus of the Pintrich and DeGroot study, with the Force Concept Inventory and Thornton Force and Motion tests as the performance variables. Research question 3b reverses this and asks whether theory-based MBL instruction has any obvious effect

on the motivational and self-regulated learning measures of the Motivated Strategies for Learning Questionnaire.

Statistical investigation in the Pintrich and DeGroot study included:

- 1) determining zero order correlations between the learning variables and the performance variables.
- 2) performing separate regression analyses using the learning variables as predictors of the performance variables.
- 3) ANOVAs with the learning variables as independent dichotomous variables to look for two or three way interactions on the four student performance outcome measures.
- 4) a procedure to detect suppressor variables was then used.

In the present study, the test scores on conceptual questions on the immediate posttest and the final examination were examined for correlations with the motivational and self-regulated learning components of the questionnaire for pretest results, to see if the MSLQ scores were reasonable predictors of success on the test questions. Specifically, comparisons were made with the Force Concept Inventory scores on the final examination, with the 15 questions from the Thornton Force and Motion Test used on the immediate posttest, and with the force-sled questions (1-7) from the Thornton Force and Motion Test used on the final examination. This was done for all 38 students who took the final examination and the Force Concept Inventory pretest.

The data were tabulated and a statistical analysis carried out to investigate correlations between the motivation and self-regulated

learning variables and between those variables and the four performance measures described above. Finally, multiple regression analysis was used to investigate how the motivational and self-regulated learning variables functioned to predict test performance.

Analysis For Research Question 3b

Research Question 3b: What effect does theory-based MBL instruction have on the motivational and self-regulated learning beliefs of students?

The analysis of this question is also based on the MSLQ. The questionnaire was administered twice, once at the beginning of the semester, before any instruction, and again at the end of the first semester, which consisted primarily of MBL instruction, including the experimental unit. The data used were from the 38 student sample including all students who took the final exam. To test the hypothesis that MBL instruction may contribute to higher levels of motivation and increased cognitive strategy use, a t-test for dependent samples was used to test for significant differences in the sub-test scores between the pretest and the posttest administration of the questionnaire.

Reliability Of Ratings

The analysis of results for Research questions 1a, 1b, 1c, and 1d relied heavily on interpretation of student verbal responses to questions. To assess the reliability of the interpretations, a graduate student in physics education, with experience with MBL and with the Hestenes work was given partial transcripts of student responses and a description of the rating schemes used for research questions 1a, 1b, and parts of 1c. The outside rater first applied the scheme to a set of transcripts which were not used as part of the study. The results were compared with those of the author. Then the transcripts from the study group of 12 students were rated. The outside rater did not have access to the audio tapes or to full transcripts of the question sessions. The number of rating decisions was counted and the

number of agreements were compared in two ways. By the first method, a rating was considered the same if the two raters agreed or if they agreed on the nature of the students expression, but disagreed on the level of the classification. For example, in deciding whether students discussed experiments in terms of goals or sub-goals, the ratings of Clear Goal and Partial Goal were counted as agreement and the ratings of Clear Goal and Clear Sub-Goal were counted as a disagreement. Of 208 decisions, the ratings were in agreement on 84% of the decisions. In the second scoring, ratings which agreed on the nature of the response but disagreed on the level of classification were counted as half agreement. By this counting scheme, the raters were in agreement on 78% of the ratings. No attempt was made to resolve rating differences on the 12 students in the study group. Given the limited exposure of the second rater to the transcripts, the lack of access to the actual audio tape responses, and the complexity of the rating schemes, this was considered adequate agreement between raters.

CHAPTER 4

Results and Discussion

Overview

This chapter contains the results and discussion of the analysis described in Chapter three. Again the discussion is organized by the research questions, and within research questions by each sub-question.

Confounding factors

Attendance.

The teaching of this unit occurred in the fall semester, at a time when a number of seniors in the course were heavily involved in visiting colleges. Thus absenteeism was higher than would usually have been the case had the treatment occurred at a different time, leading to the decision to select only the class composed entirely of juniors for the detailed parts of the analysis.

Small numbers and incomplete test results.

Although this study involved entire classes of students, it took place in a private school with moderate class sizes. In addition, the new school policy to exempt seniors with a B average or better from final examinations made it impractical to give the best senior students the FCI posttest, reducing the pool of students with complete data to 38, and selectively removing some of the best students from the group. This may have compromised the attempts to compare MSLQ scores with some of the performance measures. In addition, the small numbers of students reduce the power of statistical analysis.

Overtesting.

Students have expectations of what are reasonable classroom

events and what it is reasonable to ask them to do. Adding pretests and questionnaires to their work load may lead some students to resent what they perceive as extra work, and perhaps not to take it seriously. Certain test questions were not given as pretest questions to avoid this overloading, requiring assumptions to be made about what pretest results might have been.

Audio tape debriefing.

Because the tape debriefing questions carried no "credit", some students may have taken them lightly and not thought as hard as they might or even given answers that they did not believe in while responding to the questions. Judging from the tapes, all of which were transcribed by the researcher, some students took a light tone, imitating a radio or TV announcer, but no students deliberately gave misleading or false answers. Some students were quite laconic in many of their responses, where it would have been desirable to have more details. This could lead to a problem in deriving ratings from verbal responses, as lack of detail may lead to mis-representation by rating a student as low on some response, when a higher rating would be a better description of the student's understanding on that measure. It is less likely that a student would mistakenly be given a high rating.

Research Question 1a Results

Research Question 1a: What is the nature of student reasoning activities and cognitive change during classroom MBL instruction, in particular the understanding derived from real-time graphs of experimental data.

Overview

It was expected that most students would have non-Newtonian views about force and motion before instruction, would be able to state the connection reliably between force and acceleration immediately after instruction, but not necessarily apply it immediately after instruction, and would ultimately be able to apply it with reasonably high skill. This section will first look individually at the work of 12 students chosen for analysis and then look at the patterns for the whole group of 12 students. For each student, the data from the analysis of the Initial Knowledge state, the Immediate Knowledge and the Final Knowledge states are presented in a table followed by a short discussion. Finally conclusions are drawn about the group of students.

Student 301.Student:301

	Non-Newtonian	Newtonian									
Initial Knowledge:		AF2 AF4 AF5	1a	1a							
FCI		AF4 AF5									
Verbal											
Immediate Knowledge											
F&A Matrix-day 5				2							
F&A Matrix-day 6&7				2							
Application Questions				2							
Thornton Questions 1-7		6	1	2	3	4	5	7			
Thornton Questions 14-21		21	14	15	16	17	18	19	20		
FCI-3 Questions		CI1	1b	Fr							
Final Knowledge:											
Thornton Questions 1-7		6 5	1	2	3	4	7				
FCI			1a	1a	1b	1b	11a	11a	Fr		

Table 11: Knowledge changes for student 301

This student's initial knowledge shows the expected pattern of Active Force misconceptions, that motion requires an active force(AF2), that the velocity is proportional to the applied force (AF4), and that acceleration requires an increasing force (AF5). Part of his response to Q202 was "I guess the force needed to have an object move with a steady speed would be uh I don't know a positive force, not increasing, moving from the positive direction. moving with increasing speed would have to be an increasing force I suppose," and to Q203 "if I applied a steady force to an object, I think it would move .. in a steady non-increasing speed." The FCI results are confirmed by the audio tape responses, showing that this student has a predominantly non-Newtonian viewpoint, although on two of the FCI questions, the student gave a Newtonian response by indicating that an object could maintain a constant speed with no force. Apparently this subject does not have a consistent view point, but gives situation specific responses.

The immediate knowledge acquired by this subject shows a significant change to a more Newtonian view. His answers on days 5 and on days 6 and 7 show strongly Newtonian responses to questions on the relationship of force to acceleration and on the application of the relationship. His response to Q506 was "...I think that the acceleration increases and decreases proportionally to the force" On the application question, Q709, he said "a steadily increasing force would uh give a steadily increasing acceleration and one of those really neat curves in the velocity." On the immediate posttest, he got 6 of the 7 force sled questions correct, 7 of 8 force graph questions correct, and two of the three FCI questions correct. He still gives one answer that indicates a belief that the largest force determines the motion of an object. Nonetheless, this suggests a significant shift in response during the course of the instruction, from interpreting the effects of forces in terms of his daily experience when other invisible and unmentioned forces are acting to interpreting forces in the more abstract terms of the physicist, where all forces are explicitly identified. By the final exam, he still gets 5 of the 7 force sled questions correct and all of the FCI questions relating to the unit are also correct.

Apparently student 301 has made, and maintained a shift from a non-Newtonian concept to a much more strongly Newtonian view.

Student 302.

<u>Student:302</u>		Non-Newtonian		Newtonian						
Initial Knowledge:				1a	1b					
FCI		AF4AF5								
Verbal										
Immediate Knowledge										
F&A Matrix-day 5				2						
F&A Matrix-day 6&7				1						
Application Questions		- 1								
Thornton Questions 1-7		6		1	2	3	4	5	7	
Thornton Questions 14-21		20 21		14	15	16	17	18	19	
FCI-3 Questions		13		1b	1b					
Final Knowledge:										
Thornton Questions 1-7		6		1	2	3	4	5	7	
FCI		AF6		1a	1b	1b				

Table 12: Knowledge changes for student 302

This student had no Active Force misconceptions as shown by the seven FCI pretest questions, and gave Newtonian responses to questions about Newton’s first law. However, his responses to the audio tape questions did reveal Active Force misconceptions, namely that velocity is proportional to the applied force (“you push it faster obviously it will go faster”...) and that acceleration implies an increasing force (“a steadily increasing force I mean would uh, would have uh would force an object to have an increasing speed”...). This suggests a mixed set of conceptions, probably involving situation specific reasoning. The Newtonian responses on the pretest may have been learned, at least in a surface manner, in earlier courses. It also points out the limitations of paper and pencil tests alone in probing student understanding.

The immediate knowledge demonstrated after the force and motion experiment seems strongly Newtonian based on the force-motion matrix, but this is apparently not a strong change, as the matrix for days 6 &

7 is less strongly Newtonian, and the responses to the application questions were scored as non-Newtonian. This is actually a conservative scoring as the student had correct relations between force and acceleration, but incorrect ones between force and velocity. (A709: "with a steadily increasing force is applied to the cart, the acceleration would also be steadily increasing and the uh as would the velocity") This student is probably still having difficulty with distinguishing velocity from acceleration, although he may instead be having difficulty in expressing the idea that velocity would have to increase in a non-linear way. The immediate posttest results suggest a better understanding of force and acceleration, with 6 of 7 force sled questions, 6 of 8 force-graph questions and 2 of 3 FCI questions answered correctly. The pattern here suggests a student who has more of a Newtonian viewpoint, but is still giving situation specific responses in some areas, or having difficulty with the velocity and acceleration distinction. The final exam questions show that the knowledge change is persistent, with 6 of 7 force sled questions correct and only one active force misconception.

Student 304.

<u>Student:304</u>		Non-Newtonian					Newtonian				
Initial Knowledge:	FCI	AF5					1a	1b	11a	Fr	
	Verbal	AF4AF5									
Immediate Knowledge	F&A Matrix-day 5						2				
	F&A Matrix-day 6&7						1				
	Application Questions						2				
	Thornton Questions 1-7	3	6	7	1	2	4	5			
	Thornton Questions 14-21	20	21	14	15	16	17	18	19		
	FCI-3 Questions	R2					1b	Fr			
Final Knowledge:	Thornton Questions 1-7	6	7	1	2	3	4	5			
	FCI	AF5					1a	11a	11a	Fr	

Table 13: Knowledge changes for student 304

Student 304 shows a mixed initial knowledge profile, with predominantly Newtonian responses on the FCI pretest, but clearly showing Active Force misconceptions on the audio tape application questions. (A202: “forces needed to move an object at a steady speed would be ... a force which is constant ... to move at an increasing speed, the force would need to be increasing”) Again this may indicate situation specific reasoning, but with some learned Newtonian ideas in the mix. It again demonstrates the limitation of the FCI used alone.

Immediately after the day 5 force and motion experiment, the student expresses strongly Newtonian answers to the questions on the force acceleration relationship (A505: “the graphs that we made that were closely related to each other were the acceleration force graphs”), and less strong, but still Newtonian responses to similar questions on the next two days. His responses to the application questions are also correct (A609: “if an object was acted with a steady force the acceleration would also be

steady. the velocity would be constantly accelerating”), and in the increasing force question response you can hear some of the reasoning process (A709: “...steady increasing force applied to a cart, the velocity increases er uh the velocity stays constant, no. the velocity increases more with the time and the acceleration is steadily increasing along with the force.”). The phrase “increases more with time” is his way of saying that the velocity time relation would not be linear, but would be curved upward. This student did not do as well on force sled or force-graph questions, although he has more Newtonian than non-Newtonian answers, and has two of the three FCI questions correct. He still seems to persist in the notion that motion can occur only when a force is sufficient to overcome resistance (R2).

By the final exam, there has been a slight shift towards correct responses on the force-sled questions, but on one of the FCI questions, he still holds that an acceleration requires an increasing force. Apparently this student has not fully acquired a Newtonian view even by the end of the course.

Student 305.

Student:305													
Initial Knowledge:	FCI	Non-Newtonian					Newtonian						
	Verbal	AF6					Ila	Fr					
Immediate Knowledge	F&A Matrix-day 5	AF4AF5											
	F&A Matrix-day 6&7						1						
	Application Questions						- 1						
	Thornton Questions 1-7						0						
	Thornton Questions 14-21	3 6 7					1	2	4	5			
Final Knowledge:	FCI-3 Questions	20					14	15	16	17	18	19	21
	Thornton Questions 1-7	AF1 R2 I1											
	FCI	1	2	3	4	6	7	5					
	Delayed(1yr) posttest	AF6					Ia	Ia	Fr				
	Thornton Questions 1-7	2 3 6 7					1	4	5				
Delayed(1yr) posttest	Thornton Questions 14-21	14 17 18 19 20					15	16	21				

Table 14: Knowledge changes for student 305

This student starts with a mixed record on the FCI pretest, showing some Newtonian answers and some non-Newtonian responses. His audio tape answers clearly show both the AF4 and AF5 misconceptions, however. (A202: “you would need a steady constant force to move something at a steady speed....and you would have to increase the force ...to move it with an increasing speed.”)

Immediately after the force-motion experiment this student has a Newtonian response to questions about the relationship of force and motion variables, but it is apparently not a strongly held notion as on days 6 and 7 his responses to similar questions do not make clear distinctions between the effects of force on velocity and on acceleration. His response on the application questions is complex (A708: “when there is a constant force, the velocity increases slightly but it’s fairly constant as is the acceleration with a constant force”), showing a recognition that force and

acceleration are related, but not giving a good account of the effect of a constant force on velocity. This may reflect continued difficulty with the velocity-acceleration distinction.

By the final exam, this student has not resolved his difficulties, and his responses on the force-sled questions are almost all incorrect, although he does better on the FCI questions.

This student was one of those who took the delayed posttest one year after completing the course. On the force-sled questions, he missed four questions, giving answers that reflect a belief that a decreasing opposing force is needed to slow down an object or to keep it moving at a constant speed. His answers to the force-graph questions are rather mixed, some reflecting velocity proportional to force thinking and some apparently giving a position-time graph corresponding to the motion, instead of a force-time graph.

All told, this student has a mixed record and seems to have reverted to a predominantly non-Newtonian understanding by the end of the course, and does not seem to have a Newtonian understanding one year later.

Student 307.

<u>Student:307</u>													
Initial Knowledge:	FCI	Non-Newtonian					Newtonian						
	Verbal	AF3AF5 Ia											
Immediate Knowledge	F&A Matrix-day 5						2						
	F&A Matrix-day 6&7						1						
	Application Questions						2						
	Thornton Questions 1-7	1	2	3	4	6	7	5					
	Thornton Questions 14-21	17 19 20 21					14 15 16 18						
FCI-3 Questions						ClI Ib Fr							
Final Knowledge:	Thornton Questions 1-7	1	2	3	4	6	7	5					
	FCI						IIa IIa						

Table 15: Knowledge changes for student 307

This student starts out with FCI responses indicating a primarily non-Newtonian view, but with at least some notion about Newton’s first law. Unfortunately, his verbal responses for day 2 are missing and his response to a question on day one (A103: “force would make the motion of an object change”) is equivocal, as he does not specify which motion variables would change and how they would change. If we interpret his statement to mean that the velocity would change, then this might be a Newtonian response, but in that case it is in conflict with the FCI results. Again, it seems that this student does not have any consistent understanding of the relationship of force to motion before the instructional unit.

His responses after the force and motion experiment to the force and acceleration relationship questions and the application questions are predominantly Newtonian, and he gave a good, well phrased response to Q708 (“if constant force is applied to a cart, the acceleration is constant and

the velocity is constantly increasing.”) and a good response, after some hesitation about the effect of an increasing force on the velocity, to Q709 (“if the force was steadily increasing, the acceleration would be steadily increasing and the velocity would be constant. ..velocity is curved...curved into a positive slope”) In sharp contrast, this student’s responses on the force-sled questions were mostly incorrect, and indicated a strong notion that force and velocity were the correlated quantities. He had a mixed performance on the force-graph questions, with as many wrong as right. His answers indicated difficulty with situations that involve objects moving in a negative direction, or slowing down, and his problem seems partly to be difficulty with the relationship between velocity and acceleration, as well as holding onto a force causes velocity idea. This student’s knowledge still seems to be situation specific, but with some new responses learned from the experiment.

This student’s mixed understanding persists as evidenced by the final exam, where he missed all the force-sled questions but one, while having a number of correct responses on the FCI questions. Apparently he can give a response that indicates that force causes acceleration in some circumstances, but cannot readily apply this knowledge, and has not yet reached a consistent Newtonian understanding of force.

Student 308.

Student:308		Non-Newtonian										Newtonian									
Initial Knowledge:	FCI	AF6 Ia																			
	Verbal	AF4AF5																			
Immediate Knowledge	F&A Matrix-day 5	- 1																			
	F&A Matrix-day 6&7											1									
	Application Questions	- 2																			
	Thornton Questions 1-7	1	2	3	4	6	7	5													
Thornton Questions 14-21												14 15 16 17 18 19 20 21									
FCI-3 Questions		I3 R2 CI1																			
Final Knowledge:	Thornton Questions 1-7	1 2 4 5 6										3 7									
	FCI											Ia Ia Ib IIa IIa Fr									
Delayed(1yr) posttest	Thornton Questions 1-7	3 6										1 2 4 5 7									
	Thornton Questions 14-21	16 17 18 19 20										15 21									

Table 16: Knowledge changes for student 308

This student’s audio tape responses indicate a non-Newtonian initial understanding of the force-motion relation (A103: “ like if there’s a lot of force the object would move very forcefully and fast probably”, A202: “... apply more force to it, it goes faster”, A203: “apply steady force to an object,... uh probably move steadily and at a constant rate...”).The FCI answers indicate some understanding of Newton’s first law, but also a response consistent with a belief that force causes acceleration up to a terminal velocity.

This student did not apparently achieve a good immediate understanding of the force-acceleration relationship from the experiment on day 5 (A505: “um the graphs that were most closely related were force and velocity”), although he has some sense of the relationship by day 6 (A606: “...acceleration, it has a lot to do with force. the evidence is in the graphs that we did.”) His responses on the application questions on day 6

and 7 indicate a persistent idea that force and velocity are directly related, especially his response to a question about motion with a constant force. (A609 : "the acceleration of the object would uh probably be zero. acceleration time graph would be simply.. the x axis. um the velocity of the object would probably be constant")

The results on the immediate posttest are indicative of a very mixed understanding of the effects of force. On the one hand, all but one of his force-sled answers show a force causes velocity concept, while on the other hand, his answers to the force-graph questions are completely correct, while the FCI questions are incorrect. The strong inference here is that this student is reasoning from primitives of experience in dealing with the rather concrete questions on the force-sled set, but is able to evoke his recently learned responses on the force-graph questions, which suggests that he can use his recently acquired knowledge in the form in which he learned it, but cannot transfer it to questions which require using the information in a non-graphic form.

By the final exam, the results are still mixed, with predominantly force causes velocity responses on the force-sled questions. Interestingly, the two questions this student gets right involve situations where the sled slows down at a constant rate. It may be that these questions, which are usually difficult for students who otherwise have correct answers, caused this student to think more formally about cause and effect and to access his formal knowledge, rather than his intuitive feelings. The FCI results on the final exam for this student were good, and he had correct answers to six of the seven FCI questions. Apparently, this student has not achieved a consistent synthesis of his ideas, although he has acquired some

Newtonian responses.

This student also took the delayed posttest. He missed only two of the force-sled questions, suggesting a better understanding of the relationship of force and acceleration than he had while taking the course, however, he did very poorly on the force-graph questions. A review of his incorrect answers suggests that he selected the graphs which would correspond to the velocity-time graphs, rather than the force-time graphs. This may reflect a confusion between the graphs, or it may reflect velocity proportional to force thinking on these questions. In any case, it seems that this student did not achieve or retain a consistently Newtonian viewpoint.

Student 309.

Student:309		Non-Newtonian		Newtonian																													
Initial Knowledge:				1a		1a		Fr																									
		AF4AF5																															
Immediate Knowledge						2																											
F&A Matrix-day 5				1																													
F&A Matrix-day 6&7				2																													
Application Questions				6		1	2	3	4	5	7																						
Thornton Questions 1-7						14	15	16	17	18	19										20	21											
Thornton Questions 14-21				C11		1b	Fr																										
FCI-3 Questions						1	2	3	4	5	6										7												
Final Knowledge:						1a	1a	1b	1b	11a	11a										Fr												
Thornton Questions 1-7																																	
FCI																																	

Table 17: Knowledge changes for student 309

Student 309 has a mixed status on initial knowledge, with several Newtonian responses on FCI pretest questions, but with answers reflecting the idea that force causes velocity on the audio tape responses. (A202: “To move with a steady speed ... an object would have to have a force acting on it that is a constant force,... to move with an increasing speed you would need an ever harder force.”)

His immediate response to the day 5 force and motion experiment is that the force and acceleration graphs are directly related, and he notes that this conflicts with his expectations (A506: “I wouldn’t have thought that force and acceleration were similar, I would have thought that force and velocity but I was wrong!”)

This student makes quite a rapid and complete change in his idea about force and motion. His statement in response to Q606 shows a clear expression of his conclusion and his evidence for that conclusion (A606: “I’d say acceleration is most directly affected by forces acting on an object.

My evidence is the apparent similarity between force graphs and acceleration graphs. I would say that the experiment in which we had the uh cart go back and, where we applied a force to it and let it go back and forth, working off the force, that one showed me, because the graphs, the acceleration and force graphs were almost identical with just some small variations.”)

The application questions and the immediate posttest performance are all correct with the exception of the very difficult force-sled question 6, and this student maintains a Newtonian view on both the force-sled questions and the FCI questions on the final exam.

Student 310.

Student:310		Non-Newtonian							Newtonian		
Initial Knowledge:	FCI	AF2AF5							Ia	IIa	
	Verbal	AF4AF5									
Immediate Knowledge	F&A Matrix-day 5	- 1									
	F&A Matrix-day 6&7								1		
	Application Questions								1		
	Thornton Questions 1-7	2	3	4	5	6	7	1			
	Thornton Questions 14-21	17 18 20 21							14	15	16 19
Final Knowledge:	FCI-3 Questions	AF2 R2 CI1									
	Thornton Questions 1-7	2 3 5 6							1	4	7
	FCI	AF2AF6							Ia	Ia	IIa

Table 18: Knowledge changes for student 310

Student 310 starts with a predominantly non-Newtonian set of responses to applied questions although he does answer some of the FCI pretest questions with first and second law ideas. For example, his response to Q102 sounds Newtonian (“I understood force to be something that influences another object and causes it to be accelerated.”) but when asked to apply his knowledge, he gives responses consistent with a force causes velocity model (A202: “um a steady force would correspond to a steady speed. increasing force would make it increasing speed.”).

On the force and motion experiment, he makes no clear statement distinguishing the force-acceleration relation from the force-velocity relation (A505: “the set of force, the acceleration and velocity graphs were the most closely related to each other.”), so this experiment was apparently not immediately effective for his learning, but on days 6 and 7 he finally makes statements reflecting a relation between force and acceleration (A706: “the variable most directly affected by force is the acceleration. the

evidence for this is that acceleration is exactly the same as the amount of force put upon an object.") in which he apparently is citing the identity of the graph shapes as his evidence. He does not, however, make any clear statements to indicate that the force is not directly related to the velocity. His day 6 response to the application questions shows some confusion (A609: "if an object were acted on by a steady force I would think that the acceleration of an object would increase. the velocity of the object would also increase.") although this is cleared up the next day (A709: "a steadily increasing force results in a steadily increasing acceleration and an exponentially increasing velocity.") (Many of the students used the phrase "exponentially increasing" to describe a power law relationship such as a quadratic, so this student is actually describing a graph with an upward curvature.)

This student's knowledge of the Newtonian ideas proves to be weak on both the immediate posttest and the final exam. His responses to the force-sled questions consistently indicate a belief that a decreasing force would cause a constant acceleration. The force-graph questions have some correct responses, but in other responses he apparently uses the idea that force causes velocity. The FCI questions on the final exam turn up some Newtonian responses, but some active force misconceptions as well. This student has not acquired a consistently Newtonian understanding.

Student 313.

Student:313		Non-Newtonian				Newtonian						
Initial Knowledge:		AF4AF6				Ia	Ila	Fr				
Verbal		M										
Immediate Knowledge						1						
F&A Matrix-day 5						1						
F&A Matrix-day 6&7						1						
Application Questions						1						
Thornton Questions 1-7		6	1	2	3	4	5	7				
Thornton Questions 14-21		20	14	15	16	17	18	19	21			
FCI-3 Questions						Ib	Ib	Fr				
Final Knowledge:												
Thornton Questions 1-7		6	1	2	3	4	5	7				
FCI						Ia	Ia	Ib	Ib	Ila	Ila	Fr

Table 19: Knowledge changes for student 313

Due to a tape malfunction, there is no audio tape information for student 313 for day one and two, so his initial knowledge can only be inferred from the FCI pretest data, which indicate some Newtonian conceptions and some misconceptions, including the ideas that velocity is proportional to applied force (AF4) and the force causes acceleration to terminal velocity (AF6). The mix of responses on the FCI pretest suggests that this student applies his ideas about force and motion in a situation specific way.

This student replies to the force and motion experiment with immediate recognition of the relation between the force and acceleration graphs, (A505: “the two graphs that were most closely related were the force and the acceleration”) but makes no comments about the lack of correlation between force and velocity. On day 6 he reiterates the connection between force and acceleration, but with some hesitation, and a reversal of cause and effect in his statement (A606: “the velocity, no the

acceleration most directly affects the force of an object.”). He gives generally correct responses to the application questions on days 6 and 7 with some ambiguities of phrasing. Thus his response to Q709, about motion with a steadily increasing force requires some interpretation to see that he is describing an increasing acceleration (“the velocity would be getting greater and greater, but not at a steady rate, it would be exponentially increasing [meaning an upward curve] and there would be some acceleration going up”). In spite of the imprecision of expression, this student seems to have made a successful transition to a Newtonian view on both the immediate posttest and the final exam, getting all but question 6 correct on the force-sled questions on both tests, all but question 20 right on force-graph questions, and all the FCI questions correct on both tests. Without the audio tape record of his initial knowledge, it seems likely that he had a mixed knowledge state before instruction, and acquired a predominantly Newtonian view after instruction.

Student 314.

Student:314

Initial Knowledge:

FCI

Verbal

Immediate Knowledge

F&A Matrix-day 5

F&A Matrix-day 6&7

Application Questions

Thornton Questions 1-7

Thornton Questions 14-21

FCI-3 Questions

Final Knowledge:

Thornton Questions 1-7

FCI

Delayed(1yr) posttest

Thornton Questions 1-7

Thornton Questions 14-21

Non-Newtonian

Newtonian

No Data

AF4 AF5AF6

1

2

- 1

1

2

4

5

6

3

7

20

14

15

16

17

18

19

21

AF4CI1

Fr

6

1

2

3

4

5

7

AF4

Ia

Ia

Ila

Ila

Fr

3

6

1

2

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21

Table 20: Knowledge changes for student 314

This student entered the school several weeks late, and did not take the FCI pretest, but he has been retained for this portion of the analysis, as all the other data is available for him. His initial responses mostly indicate the belief that velocity is proportional to force (A202: "the force needed to have an object move with a steady speed would have to be a steady force whereas to increase an object's speed you would have to have a steadily increasing force") but with some more complicated possibilities. (A203: "with a steady force on an object, um the object would probably go at a steady speed. um actually it may go at a highly increased ..at a highly increased speed and then slow down to a steady speed") This statement was unclear, but from the tape, it seems as if he is trying to say that a force will initially cause an object to speed up, but it will eventually "settle down" to a steady speed, an interpretation that is not obvious from the text of what he says, but was made from listening to his use of language on the

audio tapes.

After the force-motion experiment on day 5, he notes the close relationship between force and acceleration, but does not comment on a relationship or lack of one between force and velocity, but by the next day his comments are detailed, refer to the graphs as evidence, and contrast the force-acceleration similarity with the lack of similarity between force and velocity. On the application questions, however, he persists with the idea of force accelerating an object up to a limiting velocity (A609: "... steady force would accelerate steadily and keep accelerating and then reach a point where it could not accelerate any more with the current force and level off to keep that velocity as long as the force was applied") On day 7, he did not answer the question about motion with a steadily increasing force.

His results on the immediate posttest are mixed. On five of the force-sled questions, he gives answers which indicate a belief that velocity is proportional to force, and he missed two of the three FCI questions; however, he got all but one of the force-graph questions correct. This suggests that he is still reasoning in a situation specific fashion, giving correct answers in the more abstract force-graph questions which relate to what he has just been studying, but reverting to his "gut feeling" for questions which evoke his long term experience, and is unable to transfer his new knowledge to non-graphical form.

By the final exam, this student has apparently learned to apply Newtonian ideas to the force-sled questions, and only misses one of them, although he still answers one of the FCI questions with velocity proportional to force reasoning. This student has apparently acquired much of the Newtonian view, but still reverts to other ideas in some

specific situations.

This student took the delayed posttest, and missed a total of four questions out of the 15. His incorrect answers on the force-sled questions seem to imply the idea that a decreasing opposing force is needed to slow an object down at a steady acceleration. His incorrect answers on the force-graph questions suggest that he is confusing the force graph with the velocity graph for the motion. Nevertheless, he does demonstrate predominantly Newtonian thinking on these questions after one year.

Student 315.

Student:315		Non-Newtonian					Newtonian				
Initial Knowledge:	FCI	AF4 AF4 AF5					1a 1a Fr				
	Verbal	AF4 AF5									
Immediate Knowledge	F&A Matrix-day 5						2				
	F&A Matrix-day 6&7						1				
	Application Questions						1				
	Thornton Questions 1-7	3	6	7	1	2	4	5			
	Thornton Questions 14-21	20					14	15	16	17	18 19 21
FCI-3 Questions							1b	1b	Fr		
Final Knowledge:	Thornton Questions 1-7						1	2	3	4	5 6 7
	FCI						1a	1a	1b	1b	11a 11a Fr
Delayed(1yr) posttest	Thornton Questions 1-7	6					1	2	3	4	5 7
	Thornton Questions 14-21	17					14	15	16	18	19 20 21

Table 21: Knowledge changes for student 315

Student 315 has some Newtonian responses on the FCI pretest to questions about Newton’s first law, but gives other answers indicating the belief that velocity is proportional to force and that acceleration implies an increasing force. This is consistent with his audio tape responses, such as A203 (“...to move at a steady speed it would have to have a steady force behind it, ... and an increasing force would result in an increasing speed”)

His commentary on day 5 shows recognition that force and acceleration are related and the force and velocity are not. His day 6 and 7 comments reiterate recognition of the force and acceleration relationship. Although he had stated that velocity behavior was different from force behavior, his answers to the application questions reveal some confusion. On day 6 he gives a response that fails to distinguish the effects of force on velocity from those on acceleration, (A609: “...if an object were acted on by a steady force, um the acceleration would be steady also. um the velocity

...the velocity would also be steady.”) but on day 7 he correctly describes the effect of a steady force on motion and of an increasing force on the motion of an object (A709: “if a steadily increasing force were applied to the cart, then there would be an increasing acceleration and the velocity would increase, would not have a steady increase, but more of an increase at every time for more time that passed”). On the force-sled questions, he missed three questions which dealt with objects slowing down with constant acceleration, giving answers that indicated that a decreasing force was needed. On the other hand he got the remaining four questions right, got 7 of the 8 force-graph questions correct, and got the FCI questions right as well. On the final exam, he got all the force-sled questions right and all the FCI questions correct as well. This indicates an immediate partial mastery of the ideas with some recourse to velocity proportional to force reasoning on difficult questions, but an ultimate mastery of the Newtonian viewpoint, as far as these questions went.

This student took the delayed posttest and missed only two questions, suggesting a reasonably permanent change to Newtonian responses, at least on these questions.

Student 316.

Student:316													
Initial Knowledge:	FCI	Non-Newtonian						Newtonian					
	Verbal	AF6						1a 1a 1a 1a Fr					
Immediate Knowledge	F&A Matrix-day 5	AF5											
	F&A Matrix-day 6&7							2					
	Application Questions							1					
	Thornton Questions 1-7							1 2 3 4 5 6 7					
	Thornton Questions 14-21							14 15 16 17 18 19 20 21					
Final Knowledge:	FCI-3 Questions							1b 1b Fr					
	Thornton Questions 1-7	6						1 2 3 4 5 7					
	FCI							1a 1a 1b 1b 1a 1a Fr					
	Delayed(1yr) posttest												
	Thornton Questions 1-7	7						1 2 3 4 5 6					
Delayed(1yr) posttest	Thornton Questions 14-21							14 15 16 17 18 19 20 21					

Table 22: Knowledge changes for student 316

Student 316 had a high score on the FCI pretest questions, with one response indicating the belief that force causes acceleration up to a limiting velocity. His responses to the questions on day 2 indicate a mixture of ideas about the effects of force. In particular his response to Q202 (A202: “to move with a steady speed it requires no or few outside influences or outside forces. ...to move with an increasing speed, it needs an increasing outside force.”) seems to be a mix of a response for steady speed based on Newton’s first law, but a velocity proportional to force response for increasing speeds.

His response to the force and motion experiment on day 5 clearly indicates his observation that force and acceleration are closely related and the force and velocity are not, and he repeats this on day 6. Unfortunately, his responses to some of the application questions were taped over by

another student. The responses that remain assert that a constant force would cause a constant acceleration, but his response to the effect of an increasing force is missing. This student did very well on the immediate posttest, with perfect scores on the force-sled questions, the force-graph questions and the FCI questions, and on the final examination missed only the difficult question 6 on the force-sled questions. The pattern of responses for this student suggest that he had already acquired some Newtonian views before taking the course, and successfully acquired the Newtonian viewpoint during the course.

This student was one of those who took the delayed posttest and his results show that his Newtonian responses persist, as he missed only one of the force-sled questions after one year.

Student 317.

Student:317		Non-Newtonian						Newtonian							
Initial Knowledge:	FCI	AF2AF6						1a	1a	1a					
	Verbal	AF4AF5													
Immediate Knowledge	F&A Matrix-day 5							1							
	F&A Matrix-day 6&7	- 1													
	Application Questions	- 2													
	Thornton Questions 1-7	1	2	4	6	3	5	7							
	Thornton Questions 14-21	20 21						14	15	16	17	18	19		
	FCI-3 Questions	R2 CI1						Fr							
Final Knowledge:	Thornton Questions 1-7	3 6 7						1	2	4	5				
	FCI							1a	1a	1a	1a	Fr			
Delayed(1yr) posttest	Thornton Questions 1-7	6						1	2	3	4	5	7		
	Thornton Questions 14-21							14	15	16	17	18	19	20	21

Table 23: Knowledge changes for student 317

Student 317 had a mixed set of responses to the FCI pretest, giving some answers consistent with Newton’s first law, but others indicating non-Newtonian views. His responses to the questions on day 2 (A203: “a constant force would be needed to have an object move with a steady speed, and to move with an increasing speed a force would have to be gradually increasing.”) clearly show a belief that velocity is proportional to force.

His immediate response to the force and motion experiment on day 5 was to observe that the force and acceleration graphs were similar and that they differed from the velocity graph. However, on day 6 he admits some confusion about the relationship of force and velocity, while still holding that force and acceleration are related, and on day 7 he asserts that force and velocity are proportional. His responses to the application

questions clearly indicate a velocity proportional to force belief. (A708: "when a constant force is applied to a cart, the velocity is going to be constant and there will be no acceleration" and A709: "...a steadily increasing force was applied to the cart, the velocity.... graph would be increasing and the acceleration graph would be a horizontal line um above uh the axis.")

This student had a mixed response to the force-sled questions on the immediate posttest, with answers to three questions indicating a velocity proportional to force view. He did better on the force-graph questions, missing only two of those. Apparently the graph questions were better at triggering his newly acquired knowledge, but he did not consistently apply it in situations where his velocity proportional to force ideas dominated his thinking. By the final examination, he had improved slightly on his answers to the force sled questions, and got the FCI questions predominantly right.

This student took the delayed posttest and missed only one of the force-sled questions, the difficult question 6, so apparently his Newtonian response pattern improved after the end of the course.

Summary: initial knowledge.

Several patterns were apparent in the data for these 13 students. Ten of the 13 students gave audio tape responses to initial knowledge questions indicating beliefs that velocity was proportional to applied force and that an increasing force was required for acceleration. The tape data was missing for two of the remaining three students. Only student 316 seemed to give answers that suggested a belief that an object could move at a constant speed when no force was applied, although 10 other students had at least one FCI response that was consistent with Newton’s first law.

Summary: immediate knowledge.

It was expected that students who performed the “iconographic” force and motion experiment on day 5 would 1) immediately be able to recognize the relationship between force and acceleration and the lack of a simple relationship between force and velocity, 2) that this recognition would be persistent, and 3) that they would be able to apply this knowledge to some extent. Table 24 shows the distribution of Newton scores (+2–strongly Newtonian to -2–strongly non-Newtonian) for student responses to the day 5, day 6 & 7 and application questions from the individual student tabulations.

day5		day6&7		application	
Score	N	Score	N	Score	N
2	7	2	2	2	4
1	4	1	9	1	3
0	0	0	0	0	1
- 1	2	- 1	2	- 1	2
- 2	0	- 2	0	- 2	2

Table 24: Newtonian score for day 5, day 6&7, and application questions

The day 5 results show 7 of the 13 students had a strongly Newtonian view, meaning that they recognized the relation between the force and acceleration and recognized the lack of relation between force and velocity. An additional 4 students recognized the force and acceleration relation, but did not comment on the force and velocity relationship. This accords with expectations, and is strong evidence that the “iconographic” force and motion experiment is immediately effective. The day 6 & 7 results show that 11 students at least recognized that force and acceleration were related. An inspection of the data shows that actually two students went from a positive score on day 5 to a negative score on days 6 & 7, and two went from negative to positive. Thus 9 of the 13 persisted in a Newtonian response, and two moved from a non-Newtonian to a Newtonian response. Again this is consistent with the expectation that the force and motion experiment would promote cognitive change. On the application questions, most of the students who gave Newtonian responses on day 5 and days 6 & 7 also gave Newtonian responses on the application questions, with the exception of two students (302 and 314). Student 302 observed that a steadily increasing force would give a steadily increasing acceleration, but also a steadily increasing velocity, while student 314 believed the object would accelerate at first, but would reach a terminal velocity. As expected, students were less able to apply their new knowledge than to state it, but the fact that 7 of students could apply their new ideas suggests that the MBL pedagogy is quite effective. (The discussion for research question 2c compares the test results for these students with those for similar groups of students with traditional instruction.)

Summary: final knowledge

The selected test questions from the Force Concept Inventory, and the Thornton force-sled questions 1-7 were used to assess the final knowledge state, and were supplemented by the 1 year delayed questions for some students. Table 25 gives a Newton score (2, 1 or 0) for each student for the 7 most relevant FCI questions from the final exam, and for the Thornton force-sled (Q1-7) and force-graph (Q14-21) questions from the immediate posttest, the force-sled questions from the final exam and the force-sled and force-graph questions on the 1 year posttest. In addition Table 25 gives the distribution of Newton scores for each test measure. The distribution numbers for the subset of students who took the 1 year posttest are given in parentheses.

Student	FCI:final	Imm Q1-7	imm Q14-21	Final Q1-7	1 year Q1-7	1 year Q14-21
301	2	2	2	1		
302	0	1	2	1		
304	1	1	2	1		
305	0	1	2	0	0	0
307	0	0	1	0		
308	2	0	2	0	1	0
309	2	2	2	2		
310	0	0	1	0		
313	2	2	2	2		
314	2	0	2	0	1	2
315	2	1	2	2	2	2
316	2	2	2	2	2	2
317	1	0	2	1	2	2
Nt. Score:	Distribution					
+2	7... (4)	4 (1)	11 (6)	4 (2)	(3)	(4)
+1	2 (1)	4 (2)	2 (0)	4 (1)	(2)	(0)
0	4 (1)	5 (3)	0 (0)	5 (3)	(1)	(2)

Table 25: Newtonian scoring for FCI final, and Thornton test questions for immediate posttest, final and delayed posttest.

Slightly more than half the students (7/13) had strongly Newtonian responses (6 or 7 correct) on the selected questions from the FCI

posttest. The distribution of strongly Newtonian responses on the force-sled questions stayed the same between the immediate posttest and the final exam, although four individuals changed their scores. No student changed score by more than one Newton score level, however. When the subset of students who also took the test a year later is considered, the number of Newtonian scores actually increases from 3 out of 6 to 5 out of 6 on the force sled questions, although it decreases from 6 out of 6 to 4 out of 6 for the force-graph questions. This is interesting, and it may be conjectured (with the caveat of small sample size) that the skill at detailed comparison and interpretation of text and graphs has been eroded with time, but the ability of the students to apply their knowledge across situations has increased.

Research Question 1b Results

Research Question 1b: What evidence is there that the nature of the conceptual change is consistent with the mechanisms posited in the instructional design, in particular that the “iconographic” experiment relating force and motion is an effective learning activity

The summary table (Table 26) gives the breakdown by student and by category of evidence as described in Chapter 3. Each sub-result is rated as supporting the hypothesis (+1), giving no evidence or support (0), or contradicting (-1) the hypothesis. There are eight sub-results described above, so a perfectly supporting summary score would be +8. Since there were fewer opportunities to assign negative scores, the criterion for deciding that the composite of a student’s scores supports the effectiveness of the experiment was chosen so that there are more supporting results than neutral or negative results, i.e. a composite score of 5 or more was taken to support the conclusion that experiment is an effective learning activity.

STUDENT#	301	302	304	305	307	308	309	310	313	314	315	316	317
InitialConcept	1	1	1	1	-1	1	1	1	0	1	1	1	1
Description	1	0	0	1	0	1	1	1	0	1	1	1	1
Purpose	1	1	1	1	1	1	1	0	1	1	1	1	1
Graph	0	0	0	0	1	1	1	0	0	0	1	1	0
ImmediateCon	1	1	1	1	1	-1	1	-1	1	1	1	1	1
Surprise&cont	0	1	1	0	0	0	1	0	0	0	1	0	0
PersistenceCon	1	1	1	-1	1	1	1	1	1	1	1	1	-1
PersistenceEvi	1	0	0	0	0	1	1	0	0	1	1	0	1
Total	6	5	5	3	3	5	8	2	3	6	8	6	4
avg	4.9												

Table 26: Summary of scores for RQ 1b

As seen from the table, 8 of the 13 students in the study group had composite scores which support the idea that the nature of the conceptual change in the iconographic experiment is consistent with the mechanisms

posited in the instructional design. If student 314, who did not take the FCI pretest, is dropped from the group, then 7 of the remaining 12 students had composite scores of 5 or more.

Of the 13 students, the responses showed that 11 had an initial conception that was consistent with expectations, one showed no evidence, and only one had a Newtonian conception before the experimental lesson. A majority (9 of 13) gave a clear or adequate description of the setup of the experiment, and 12 of the 13 phrased their description of the purpose in terms of goals rather than subgoals.

The immediate conclusions drawn by students showed that 11 of the 13 correctly concluded that acceleration was related to the combination of forces acting on the object, but the scores for sketch graphs are less clear. Five of the 13 students made graphs which clearly or adequately showed the correlation between force and acceleration, while 4 had graphs that were possibly correct, 1 was incorrect and 3 were missing graphs.

Relatively few students (4 of 13) stated that the results were surprising to them or that the results contradicted their expectations. It is not clear from the taped responses whether the students were aware that the results conflicted with their statements about the relationship of force and acceleration made a few days before. The lack of surprise suggests that their prior views were not strongly held, at least in a consciously articulated theory. This finding tends to support the position of diSessa, that students have a collection of pieces of knowledge about motion which they apply in a situation specific fashion, rather than a more or less consistent theory of motion such as an impetus theory (diSessa, 1993).

The results on the persistence of conclusions are mixed. Over the

next two days, 11 of the 13 student responses showed correct conclusions about the relation of force to acceleration, but only 6 of the 13 clearly cited the graphs as evidence for the conclusions. Three students made statements that were unclear, while 4 made statements that gave no specific evidence in support of their conclusions. Of the students who had incorrect immediate conclusions on day 5, two gave correct conclusions on days 6 and 7. One student who gave a correct conclusion on day 5 gave an incorrect conclusion on days 6 and 7.

Research Question 1c: Results

Research Question 1c: What evidence is there that this instructional design allows students to identify and focus on important conceptual goals of experiments, rather than subgoals.

It was expected that the reduced processing load associated with real time graphing would allow students to both identify and focus on goals rather than sub-goals. As described in Chapter 3, the evidence from audio tape debriefing questions was compared A) for each day and B) between the experiments on days 1-4 which did not involve significant real time graphing of data and the experiments on days 5-7 which did involve real time graphing of data.

A) Comparison by day.

For each day, identification and focus on goals was compared by looking at the percentages of identified goals/identified subgoals/missing, unclear or no data conditions. Table 27 gives the percentages of goals identified and focused on by students for the 18 students in group C.

	Identify			Focus		
	G	SG	M	G	SG	M
Day1	36	21	43	14	21	64
Day2	38	44	19	0	12	88
Day3	36	29	36	0	14	86
Day4	44	31	25	38	44	19
Day5	81	12	6	69	31	0
Day6	81	12	6	81	0	19
Day7	29	6	65	47	0	53
OVERALL	49	22	29	36	18	47

Table 27: Goal and Sub-goal percentages by day.

Goal/Subgoal/Missing, Unclear, No data in %

The graphs below also show these results. On day 5, the first day with a real time graphing experiment (experiment 2-1), there was a large

increase in the percentage of students identifying the experimental goal, and using goal related statements in their conclusions. Days 5 & 6 had the highest percentage of students identifying and focusing on goals, and day 5 was the only day with no Missing or Unclear results. Notice also that on days 5 & 6 the percentage of students identifying sub-goals drops very low. The high percentage of missing or unclear results on day 7 were due to the fact that this class, with few exceptions, finished all the lab activities on days 5 & 6, and for the most part were only writing their results on day 7.

The data for focus on goals and sub-goals shows a low percentage of focus on either goals or subgoals for the first three days of the experimental sequence, with a high percentage of missing, unclear or no data conditions. This may indicate that students had difficulty figuring out what the focus of the first several days experiments were and were correspondingly unclear in their responses to the taped questions (most of the MUN-missing, unclear or no data-responses for those days were actually rated Unclear).

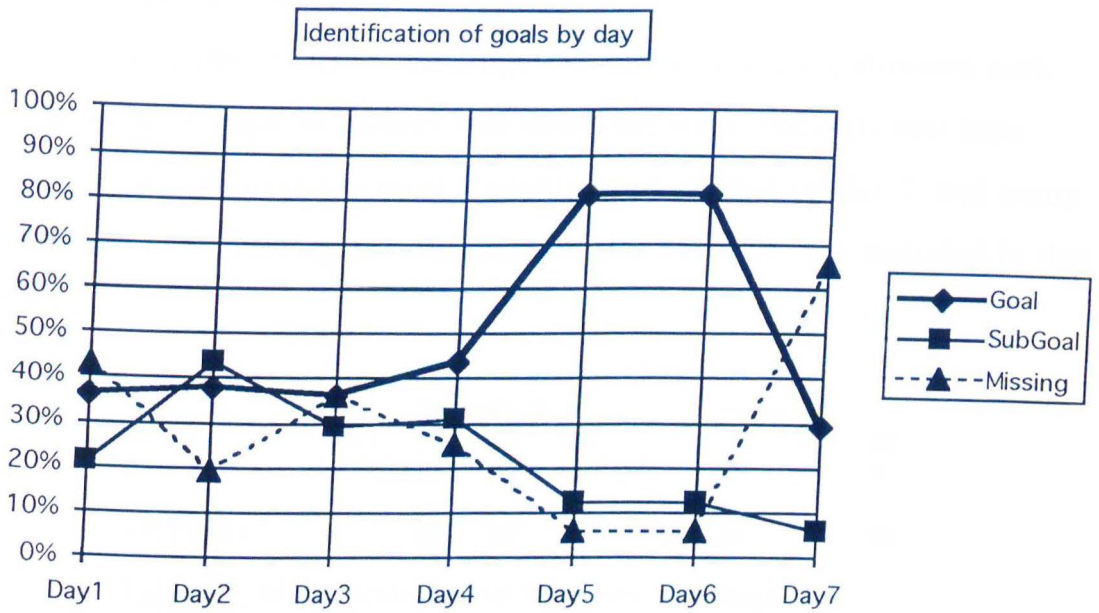


Figure 8: Identification of goals by day

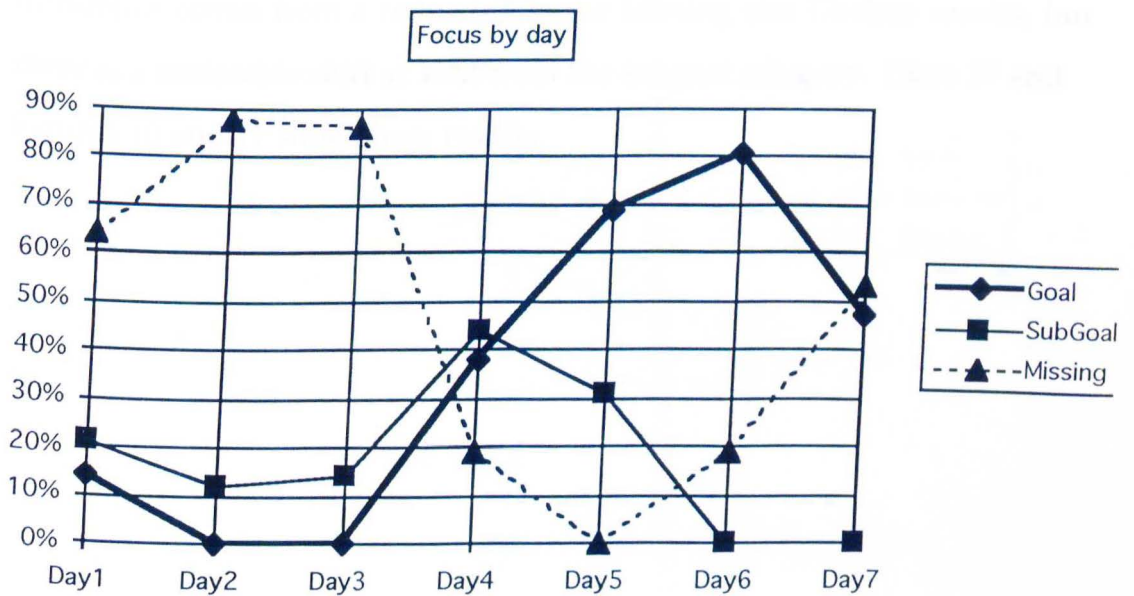


Figure 9: Focus on goals and sub-goals by day

B) Comparison by Investigation.

Here the results for Investigation 1 (days 1-4) are contrasted with those for Investigation 2 (days 5-6) which involves primarily real time graphing experiments (As most students were finished by day 7, and many responses were missing, the numbers for this day were not included in this analysis.

		Identify %			Focus %		
days 1-4	Inv 1	38	32	30	13	23	63
days 5-6	Inv 2	81	12	6	75	16	9
OVERALL		53	25	22	35	21	45

Table 27: Identification and focus by investigation

There are considerable differences in identification and focus in the two investigations, with the real time graphing investigations having considerably higher numbers of goals identified and focused on. Part of the difference comes from a reduction in the Missing and Unclear results, but there is a noticeable shift as well from the subgoal category. Table 27 and Figures 10 and 11 show these results.

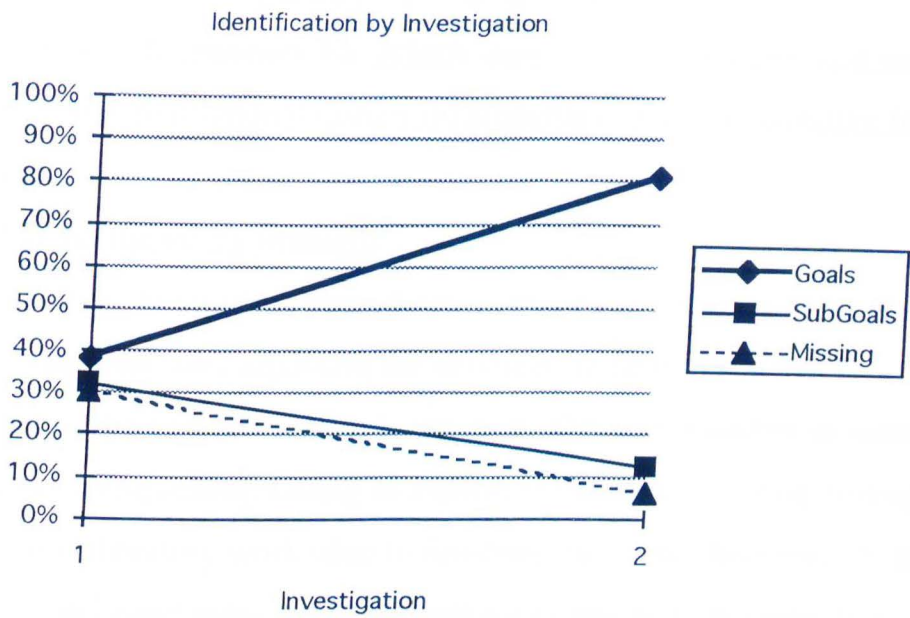


Figure 10: Identification of goals and sub-goals by investigation

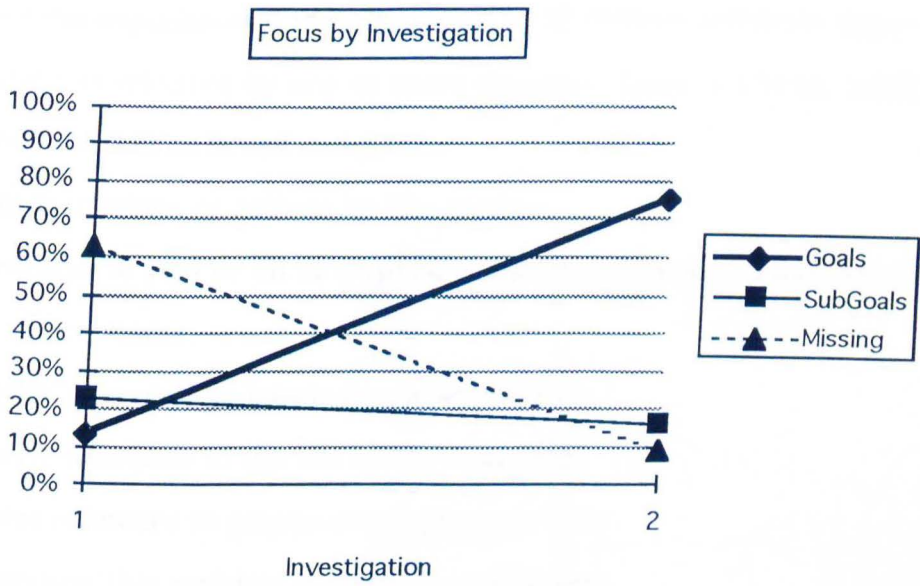


Figure 11: Focus on goals and sub-goals by investigation

Research Question 1d: Results

Research Question 1d: Which instructional activities and what aspects of the instructional design do students identify as effective for their learning?

Activities Identified by Students

For the 14 students considered in this part of the analysis, there were 94 opportunities, adjusting for absences, to respond to the 10 questions relating to this research question. The total number of instances of students being absent, failing to answer the question, or responding that they did no laboratory work (due to finishing early that day) was 25. Since some students cited more than one activity as effective on some days, there were a total of 129 responses identifying effective activities. Over the seven days of the experimental period, a total of 25 distinct activities were identified as effective by one or more students. These activities were grouped into seven broad categories:

- A: demonstrations or actions by the teacher,
- B: references to part or all of a specific experiment, subdivided into five experiments,
- C: generic reference to hands-on experiments,
- D: generic reference to the use of the computer,
- E: generic reference to graphs or graphing of data
- F: declaration that nothing that day was effective,
- G: no response, absent or did no laboratory work that day.

Tables 28 and 29 show the breakdown of responses first on a day by day basis, then in broad categories over all seven days.

Day 1: A109

1	D	demonstration
1	EXP	experiment
1	HO-RB	hands on rubber bands
1	M	measuring
1	RB	rubber bands
4	RB&S	rubber bands and spring
1	RB&SS	rubber band and spring scale
4	N	nodata

Day 2: A209 & A210

2	C	computer
10	G	graph
4	EQN	equation or linear relation
1	RB&SS	rubber band and spring scale
1	ABS	absent
1	N	no data

Day 3: A309 & A310

2	C	computer
4	G	graphing
1	LR	linear relationship
4	FP	force probe
1	FP&SS	force probe&spring scale
1	SS	spring scale
1	RB	rubber band
1	NE	nothing effective
5	N	no data

Day 4 : A407

3	C	computer
3	G	graphs
4	F+&-	+and - forces
2	FP	force probe
3	FP & S	forceprobe &spring scale
2	FP CAL	force probe calibration
3	N	no data

Day 5: A509, A510

1	C	computer use
3	EXP5	oscillating cart experiment
3	RTG	real time graphing
4	G-FAVT	simultaneous graphs, F, a, v vs time
2	G	graphs
5	G-F&a,V	graphs of force vs acceleration, force vs velocity
2	F&A	f-a relation
1	ABS	absent
1	N	no data

Day 6: A608

5	G	graphing
3	G-FAVT	graph F, a, v vs time
1	G-F&A,V	graph F vs A,V
1	RTG	real time graphing
1	M	adding mass
3	T	towing experiment
2	HO	hands on experiments
1	N	no data

Day 7: A710

3	G	graphs
1	RTG	real time graphing
1	HO	hands on experiments
3	T	towing expt
8	NLW	no lab work today
1	N	no data

Table 28: responses by day

A: Demonstration or actions of the teacher N = 1
1 D demonstration

B: Specific experiments:
Experiment with rubber bands, springs and spring scale N = 16

1	EXP	experiment day 1
1	MS	measuring
1	HO-RB	hands on activity with rubber bands
2	RB	rubber bands
4	RB&S	rubber bands and spring
2	RB&SS	rubber band and spring scale
5	EQN&LR	equation or linear relation

Experiment: force probe, spring scales, calibration, combining forces N = 17

1	SS	spring scale
6	FP	force probe
4	FP&SS	force probe&spring scale
2	FP CAL	force probe calibration
4	F+ &-	combining + and - forces

Experiment with the oscillating cart N = 23

3	EXP5	oscillating cart experiment
5	RTG	real time graphing
7	G-FAVT	simultaneous graphs, F, a, v vs time
6	G-F&a, V	graphs of force vs acceleration, force vs velocity
2	F&A	f-a relation

Experiment of adding mass to the cart			N = 1
1	M	adding mass	
Experiment with fan cart towing force probe cart			N = 6
6	T	towing experiment	
C: Generic references to hands on experiments			N = 3
3	HO	hands on experiments	
D: Generic reference to the use of the computer			N = 8
8	C	computer	
E: Generic reference to graphs and graphical representation			N = 27
27	G	graph	
F: Nothing effective			N = 1
1	NE	nothing effective	
G: No response, absent or no lab work today			N = 24
8	NLW	no lab work today	
16	N	no data	
2	ABS	absent	

Table 29 responses by category

A large number of the responses identified the use of graphs and real-time graphing, either explicitly (45 responses) or implicitly (13 responses) as effective learning activities. Thus about 45% of the total number of responses identified graphical activities as effective for learning, consistent with the expectations that graphs are powerful tools for learning.

A number of responses made reference to a particular experiment as being an effective activity. Table 30 summarizes the references to the particular experiments. Column one gives the number of citations referring to the experimental design relative to the number of students responding. Column two gives the number of students present but not responding, and column three gives the number of students absent.

	Fraction Citing Design	No response	Absent
day 1 expt-RB, S	4/10	4	0
day 2 expt-RB, SS	3/12	1	1
day 3 expt-FP,SS	7/12	1	1
day 4 expt-+&-pulls	3/11	3	0
day 4 expt FP&cal	4/11	3	0
day 5 expt	7/12	1	1
day5-6 expt-f-a, f-v	5/12	1	1
day6 expt mass	1/13	1	0
day6-7 expt towing	5/13	1	0

Table 30: References to particular experiments

These data suggest that the experiments with the oscillating cart involving the real-time graphing of data (day 5 expt. and day 5-6 expt.) were regarded by most students as effective. The earlier table by category of response shows 23 responses identifying aspects of the day 5 oscillating cart experiment as effective, 17 of which were made that day, and 5 on the next two days. The experiments introducing the force probe on days 3 and 4 were identified as effective in a total of 17 responses, 6 on day 3 and 11 on day 4. The experiments with the rubber bands, springs and spring scales were identified as effective in 17 responses, 10 on day 1, 5 on day 2 and 2 on day 3.

These data suggest that the activities involving graphing and especially those involving the real-time graphing of data in the oscillating cart experiment (day 5) are regarded by the students as effective learning activities. The exception to this was the experiment of adding more mass to the cart, which was regarded as effective by only one of the 13 students. The effect of mass was developed more extensively in experiments done after the experimental unit was finished.

The other experiment rated effective by a large number of students was the day 3 experiment which introduced the force probe. This

experiment also has some real-time graphing, and it is also introducing a novel tool. The large positive response to this experiment is probably a combination of a response to real-time graphing and to a novel device.

Research Question 2a: Results

Research Question 2a: What are the changes in student success rates on measures of conceptual understanding applied before and after instruction specifically in regard to Newton’s second law.

Pretest to Final Exam Comparisons

This section compares student scores on the Force Concept Inventory pretest, given at the beginning of the year before any instruction, with the scores on the FCI posttest, given as a portion of the final examination at the end of the school year. The comparisons are done for the 38 students who took both exams, as well as for each class of students and for the 12 students in group C who formed the core group described in research question 1a for the study.

GROUP:	N	PRETEST to FINAL 29 QUESTIONS			
		Pre (SD)	Final (SD)	Gain (SD)	t(sig)
all sections – some seniors	38	9.5 (4.4)	18.8 (5.5)	9.3 (4.7)	12.2(<.0005)
A	8	10.3 (6.4)	20.5 (6.3)	10.3 (5.4)	5.4(<.0005)
B	13	8.2 (3.6)	18.5 (5.6)	10.2 (4.3)	8.5(<.0005)
C	17	10.1 (4.0)	18.2 (5.2)	8.2 (4.7)	7.1(<.0005)
C-core group	12	9.8 (4.6)	18.3 (6.1)	8.5 (5.1)	5.7(<.0005)

Table 31: FCI pretest and posttest comparisons

Pretest to Final Exam Commentary

Table 31 summarizes the statistical data for the paired t-test. As the standard deviations of pretest and posttest averages are reasonably close, the assumption of equal variances is reasonably satisfied. The table shows that there was a significant gain from pretest to final examination average for all the groups. The average gain of 9.3 questions out of 29 is a large gain and will be compared with gains in other settings in research question 2c. The three sections all had comparable average gain scores, ranging from 8.2 to 10.3. There were no large differences between gains for any of the groups, so the gain of the core group (section C) may be considered typical of the whole group.

Analysis of the 5 Question FCI Sub-test

The 5 question sub-test of the FCI includes all the FCI questions given on the immediate posttest administered two days after instruction in the experimental unit ended. In this analysis the scores are compared for the pretest, the immediate posttest and the final examination given at the end of the year for these questions, and the gains from pretest to immediate posttest, from immediate posttest to final examination and from pretest to final examination are considered (Tables 32 & 33).

Group	N	Scores(out of 5)			pre-imm		imm-final	
		Pre (SD)	Imm (SD)	Final (SD)	Gain (SD)	t(sig)	Gain (SD)	t(sig)
all periods, all students	53	1.1 (1.1)	2.6 (1.7)		1.5 (1.7)	6.5(<.0005)		
all periods – some seniors	38	1.0 (1.0)	2.7 (1.7)	3.5 (1.4)	1.6 (1.6)	6.6(<.0005)	0.8 (1.3)	3.7(<.0005)
A-some seniors	8	1.4 (1.2)	3.1 (1.8)	4.0 (0.9)	1.8 (1.6)	3.1(<.01)	0.4 (1.4)	1.8(<.06)
B-some seniors	13	.6 (.8)	2.5 (1.6)	3.5 (1.3)	1.9 (1.6)	4.5(<.0005)	1.0 (1.4)	2.6(<.02)
C	17	1.2 (1.1)	2.6 (1.9)	3.3 (1.6)	1.4 (1.7)	3.4(<.0005)	0.6 (1.2)	2.2(<.05)
C-core group	12	1.3 (1.3)	3.2 (1.7)	3.3 (1.8)	1.9 (1.4)	4.8(<.0005)	0.2 (1.0)	0.56(<.30)

Table 32: 5 question FCI sub-test gains

Group	N	PRETEST to FINAL 5 Questions				t(sig)
		Pre (SD)	Final (SD)	Gain (SD)		
all periods – some seniors	39	1.0 (1.0)	3.5 (1.4)	2.5 (1.4)		10.6(<.0005)
A– some seniors	8	1.4 (1.2)	4.0 (0.9)	2.6 (0.9)		8.1(<.0005)
B–some seniors	13	.6 (.8)	3.5 (1.3)	2.9 (1.6)		6.6(<.0005)
C	17	1.2 (1.1)	3.3 (1.6)	2.1 (1.5)		5.6(<.0005)
C–drops	12	1.3 (1.3)	3.3 (1.8)	2.0 (1.6)		4.45(<.0005)

Table 33: 5 question sub-test: pretest to final gains

The average gain from the pretest to the immediate posttest on the 5 question sub-test ranges from 1.4 to 1.9 for the different groups and averages 1.5 for the group of all students. The average gain from the

immediate posttest to the final exam ranges from 0.2 to 1.0 and averages 0.8 for all groups. Apparently for these five questions, more gain took place between pretest and the immediate posttest and less between the immediate posttest and the final examination. This means that for these five questions more conceptual change occurred before the immediate posttest (which includes the instructional unit under study). Indeed for the core group, there was no significant change from the immediate posttest to the final exam scores for these 5 questions.

Research Question 2b: Results

Research Question 2b: Do changes in student success rates on conceptual measures relate to students' descriptions of their learning activities and conceptual understanding?

Success Rate Results

The analysis for this question first considered the relationship of changes in student success rates on conceptual measures to the students' verbal description of their learning activities, then looked at the relationship of success rate changes to students' verbal descriptions of their conceptual understanding.

The measures of success rates were the gain parameter, g , described above for the Force Concept Inventory, a 3 question sub-test of the Force Concept Inventory from the immediate posttest, and the combined force-sled and force-graph questions score for the Thornton Force and Motion questions from the immediate posttest.

Students' verbal descriptions of their learning activities were measured by the learning activities identified as effective by students, specifically the use of graphs, using a score derived from the student responses used in research question 1b. Conceptual understanding of the force and motion relationship was determined from the verbal responses to questions about the relationship of force and motion used for research question 1a.

Table 34 summarizes the High and Low ratings for each student on each of the measures, and gives a tally of how many High and Low ratings each student had.

Success rates			Conceptual Knowledge from verbal	Learning Act.		HIGH S	LOWS
FCI 'g'	FCI3Q subtest	Thornton imm. post		1B Score	1D Graph		
301 H	301 H	301 H	301 H	301 H	301 L	5	1
302 L	302 H	302 H	302 L	302 L	302 H	3	3
304 L	304 H	304 H	304 H	304 L	304 H	4	2
305 L	305 L	305 H	305 L	305 L	305 H	2	4
307 L	307 H	307 L	307 H	307 L	307 L	2	4
308 H	308 L	308 L	308 L	308 H	308 L	2	4
309 H	309 H	309 H	309 H	309 H	309 H	6	0
310 L	310 L	310 L	310 L	310 L	310 L	0	6
313 H	313 H	313 H	313 H	313 L	313 H	5	1
315 H	315 H	315 H	315 H	315 H	315 H	6	0
316 H	316 H	316 H	316 H	316 H	316 L	5	1
317 L	317 L	317 L	317 L	317 L	317 H	1	5
6H/6L	8H/4L	8H/4L	7H/5L	5H/7L	7H/5L	41	31

Table 34: High and low ratings for research question 2b

Some patterns may be seen from table 4-29. On the measures of success rates, 5 of the 12 students rated high on all three measures, and 2 of the 12 students rated low on all three measures, so the measures match for 7 of 12 students. A total of 8 students had the same ratings on the gain parameter for the FCI and the Thornton questions, 8 had the same ratings on the gain parameter and the FCI 3 question subtest, and 9 had the same ratings on the FCI subtest and the Thornton questions. These patterns suggest that the three measures are correlated, but not perfectly, and that the FCI sub-test is better correlated with the Thornton Force and motion questions than the FCI gain parameter, but not by much. With larger numbers of students a statistical analysis could be made.

Of the two learning activities measures, only 4 students had the same ratings on both measures, so these are unlikely to be measuring the same things.

Finally, only 3 students had the same ratings across all 6 measures, with 4 more students have the same ratings on 5 of the 6 measures. A

more detailed look at the results was made by comparing the three success rate measures with each of the scores derived from the audio tape questionnaires. Note that the audio tape question rating process may be expected to yield a Low score more likely than a High score in instances where the student did not give a sufficiently detailed response.

Success Rates Related to Learning Activities Score from 1b

		gain parameter "g"	
		LOW	HIGH
Learning Activities Score from 1b	LOW	302	313
		304	
		305	
		307	
		310	
		317	
	HIGH		301
			308
			309
			315

		FCI 3 sub-test	
		LOW	HIGH
Learning Activities Score from 1b	LOW	305	302
		310	304
		317	307
			313
	HIGH	308	301
			309
			315
			316

		Thornton Immediate test	
		LOW	HIGH
Learning Activities Score from 1b	LOW	307	302
		310	304
		317	305
			313
	HIGH	308	301
			309
			315
			316

Table 35: 1b Learning activities score correlated with success rates

Table 35 explores the relationship between the learning activities score derived from the analysis in research question 1b, which was based on the students verbal responses to questions about the description of experiments, the purpose of experiments, representation of information in graphs and reasoning about the graphs, the persistence of their conclusions from the experiment and the continuing ability to cite the evidence for a conclusion. It was expected that students whose responses indicate high involvement in these activities would also have high scores on measures of change in their understanding. The converse is harder to argue, as the evidence for assigning a learning activities score may underestimate a student's involvement as described above. Thus if student reports are good indicators and if the learning activities score is correlated with the test score, a pattern with most students in the low-low or high-high categories, and few students in the low-high or high-low categories should result. If student reports are not necessarily good indicators of learning activities, but learning activities are correlated with test scores, scores are expected to cluster in the low-low, high-high and also in the low learning activities but high test score categories. If there is little correlation, there should be a roughly uniform distribution of scores.

The pattern in the matrix of the gain parameter, g , is largely diagonal, with all but one student scoring low-low or high-high suggesting that the learning activities score and the g value are probably correlated. The patterns in the other two matrices have a majority of students on the diagonal, but a large number also in the low learning activities, high test score category, consistent with the hypothesis that learning activities are correlated with the test scores, but that the learning activities score used

here may underestimate the involvement of some students in learning activities that relate to these two success rates.

Success Rates Related to Learning Activities Score from 1d

		gain parameter "g"	
		LOW	HIGH
Learning Activity Score from 1d	LOW	307	301
		310	308
	HIGH		316
		302	309
		304	313
		305	315
		317	

		FCI 3 sub-test	
		LOW	HIGH
Learning Activity Score from 1d	LOW	308	301
		310	307
	HIGH		316
		305	302
		317	304
			309
			313
			315

		Thornton Immediate test	
		LOW	HIGH
Learning Activity Score from 1d	LOW	307	301
		308	316
		310	
	HIGH	317	302
			304
			305
			309
			313
			315

Table 36: 1d Learning activities correlated with success rates

The matrices in Table 36 explore the relationship between the three test measures and the learning activities score derived from students' identification of activities they felt were most effective. Reflecting the idea that the effectiveness of MBL instruction is related to graphing of data,

Particularly real-time graphing, this score is simply based on the number of responses in which students explicitly cited graphs and real-time graphing as effective.

The first matrix has nearly equal numbers of students in each category, with a few more students in the low-high to high-low diagonal, indicating that the gain parameter for the Force Concept Inventory is not correlated with student reports of graphing as an effective learning activity. This contrasts sharply with the pattern for the learning activity score from 1b.

The pattern for the FCI 3 question sub-test indicates some correlation, with slightly more students in the low-low to high-high diagonal and more of the remaining students in the low score group on learning activity.

The matrix relating the score on the Thornton Force and Motion questions shows the most correlation with the learning activity score for this section, with 9 of 12 students on the diagonal from low-low to high-high. As eight of the 15 test questions on this test relate to graphs of force, this may indicate that students who report graphs as effective for their learning do well on questions involving graphs.

Success Rates Related to Conceptual Understanding

		Gain parameter "g"	
		LOW	HIGH
Conceptual Understanding Score from 1a	LOW	302	308
		305	
		310	
		317	
	HIGH	304	301
		307	309
			313
			315
			316

		FCI 3 sub-test	
		LOW	HIGH
Conceptual Understanding Score from 1a	LOW	305	302
		308	
		310	
		317	
	HIGH		301
			304
			307
			309
			313
			315
			316

		Thornton Immediate test	
		LOW	HIGH
Conceptual Understanding Score from 1a	LOW	308	302
		310	305
		317	
	HIGH	307	301
			304
			309
			313
			315
			316

Table 37: Conceptual understanding correlated with success rates

The matrices in Table 37 explore the relationship between the success rates on the three test measures and the students' conceptual understanding of the relationship of force and acceleration as determined from their audio tape debriefing questions analyzed in research question

1a. All three matrices show a pattern with responses predominantly in the low-low or high-high categories, indicating that all three test measures and the conceptual understanding score are roughly correlated.

Summary

The rather simple high-low classification of the success rates, learning activities measures and conceptual understanding measure reveals some correlation between the success rates and the 1b learning activities measure and between the success rates and the conceptual understanding measure. The evidence does not show correlation between the success rates based on the Force Concept Inventory and the learning activity measure from identification of graph as effective, but does show some correlation with that learning activity measure and success rates on the Thornton Force and Motion questions. In general, the patterns correspond with expectations for these measures, but the small numbers of students and large spreads in the underlying data suggest caution, as the correlations are statistically weak.

Research Question 2c: Results

Research Question 2c: What is the comparison between student success rates on conceptual measures of students in this study and the student success rates reported for students in traditional instructional settings and in other theory based settings?

For this question, two comparisons were made The first was made using the Force Concept Inventory pretest and posttest measures. The second was made using questions from the Thornton Motion Test.

Comparisons Using the Force Concept Inventory:

The students in the study were compared with other high school students for both traditional instruction and theory based instructional methods using data collected by Hake [(1994) (Table 38). This data includes data from the Hestenes, Wells and Swackhamer studies using the FCI.

High Schools	(1040 students)			DATA table from HAKE			
	Code	N	FCI Pre (%)	FCI Post (%)	GAIN g (%)	METHOD	Reference
	AZ-AP	33	41	57	16 0.27	TRAD	HWS
	AZ-HON	118	33	56	23 0.34	TRAD	HWS
	Az-reg	612	27	48	21 0.29	TRAD	HWS
	CHICAGO-REG	56	27	42	15 0.21	TRAD	HWS
	CL-reg	20	35	62	27 0.42	IE	CL
	DB-reg	27	36	59	23 0.36	IE	DB
	ELM-hon	20	18	74	56 0.68	IE	ELM, M
	GS-Hon	63	28	66	38 0.53	IE	HWS
	GS-AP	11	73	85	12 0.44	IE	HWS
	LT-Hon	16	32	61	29 0.43	IE	T
	LT-reg	16	23	42	19 0.25	TRAD	T
	MW-reg	18	28	64	36 0.50	IE	HWS
	MW-Hon	30	42	78	36 0.62	IE	HWS
	RAM-reg	38	33	65	32 0.48	IE	
	RAM C-12	12	34	63	29 0.44	IE	

A difference of 3.4% represents a 1 question difference.
There were 29 questions on the Force Concept Inventory

Table 38: FCI comparison data

In Table 38, the code and reference identify the data source. Method refers to Hake's classification of teaching methods as either traditional or using some form of theory based instruction, termed Interactive Engagement. The scores are given in percentages of questions answered correctly of the 29 questions on the Force Concept Inventory. The references (Hake, 1994) are:

- CL. Cherie Lehman, West Lafayette High School, private communication 1/94
- DB Dewayne Berry, Buffalo State College, private communication.
- ELM. A.L. Ellermeijer, B. Landheer, P.P.M. Molenaar, "Teaching Mechanics through Interactive Video and a Microcomputer Based Laboratory, 1994, preprint.
- HWS. D. Hestenes, M. Wells, G. Swackhamer, "Force Concept Inventory," Phys. Teach. 30, 141(1992)
- M. private communication from P.P.M. Molenaar. 6/94
- T. Lou Turner, Western Reserve Academy, private communication, 6/94

The students in this study will be looked at in two groups, one group labeled Study-reg which includes all 38 students who took both the pretest and the final exam posttest, and the Study-C-12 group which includes the core group of 12 students in group C who were present during the entire instructional unit. Several comparisons can be made by simply resorting the table.

Comparison of Pretest scores:

SORTED By Pretest Score (% correct)						
Code	N	PRE	POST	GAIN	g	METHOD
ELM-hon	20	18	74	56	0.68	IE
LT-reg	16	23	42	19	0.25	TRAD
Az-reg	612	27	48	21	0.29	TRAD
CHICAGO-REG	56	27	42	15	0.21	TRAD
MW-reg	18	28	64	36	0.50	IE
GS-Hon	63	28	66	38	0.53	IE
LT-Hon	16	32	61	29	0.43	IE
AZ-HON	118	33	56	23	0.34	TRAD
RAM-reg	38	33	65	32	0.48	IE
RAM-C	12	34	63	29	0.44	IE
CL-reg	20	35	62	27	0.42	IE
DB-reg	27	36	59	23	0.36	IE
AZ-AP	33	41	57	16	0.27	TRAD
MW-Hon	30	42	78	36	0.62	IE
GS-AP	11	73	85	12	0.44	IE
WEIGHTED AVERAGES (N total = 1078)						
pretest:	29.5%	posttest:	53.1%	gain:	23.6%	g: 0.34

Table 39: FCI comparisons sorted by pretest score

In Table 39 above, the data have been sorted by pretest score, from lowest to highest. The students in this study fall a little above the middle of the range of pretest scores, with 34% and 33% on the pretest in comparison with the overall group average of 29.48%. The four nearest groups in pretest scores, having averages which differed by less than one question from the study group, were the AZ-HON or Arizona honors students, a group of 118 students in first year honors courses in Arizona public schools, the LT-Hon group of 16 first year honors students in an Ohio private school, the CL-reg group of 20 first year physics students in a suburban public school, and the DB-reg group of 27 first year physics students (school description unknown). An additional four groups had

averages which were less than that of the study group by no more than two questions. Those groups included the 612 students in the regular first year physics courses in a set of Arizona public schools and the 56 students in regular physics classes from a Chicago area public school. On the basis of the pretest scores, the students in this study seem to be comparable in performance to a large proportion of the students in the comparison sample. (930 students or 86% of the total group are within 2 questions or a 6.8% score difference of the study group.) This means that the study group is not very different from the comparison group in performance on the pretest, and suggests that the study group students are reasonably comparable to other groups of high school physics students.

t-test for differences				
	pre	post	gain	g
N	38	38	38	38
Std Dev	15.31	18.96	16.28	0.24
Std Err	2.483	3.076	2.641	0.0389
sample mean	32.67	64.79	32.12	0.48
group mean	29.5	53.4	23.9	0.34
difference	3.17	11.39	8.22	0.14
t=dif/se	1.28	3.70	3.11	3.6
	t critical(one-tailed test)			
p<0.1	1.3			
p<0.005	2.7			

Table 40: T-tests for differences-study and comparison groups

A one-tailed t-test was used to compare the mean pretest, posttest, gain and relative gain (g) scores of the study group (38 students) with the mean scores of the comparison group of 1078 students. An inspection of table 4-35 shows no significant difference ($p<.10$) between the study group and the comparison group on the pretest, but does show significant differences ($p<.005$) between the study group and comparison group on the posttest, gain and relative gain (g) scores. (Standard deviations were not

available for all groups, but the largest groups, AZ-reg (N= 612) and AZ-hon (N= 118), had standard deviations of 11% and 13% on the pretest, compared with the study group SD= 15% and these groups had SD = 16% and 19% on the posttest compared with 19% for the study group. These were judged to be sufficiently close to satisfy the assumption of equal variance for the t-test.)

Comparison of Posttest Scores:

Table 41 compares the study groups with the other groups, sorted by increasing posttest score. In addition the teaching method (Traditional or Interactive Engagement as determined by Hake (1994)) is shown and those classes which used some form of MBL instruction are labeled MBL.

SORTED BY Posttest Score

Code	N	PRE	POST	GAIN	g	METHOD	
CHICAGO-REG	56	27	42	15	0.21	TRAD	
LT-reg	16	23	42	19	0.25	TRAD	MBL
Az-reg	612	27	48	21	0.29	TRAD	MBL
<u>AZ-HON</u>	<u>118</u>	<u>33</u>	<u>56</u>	<u>23</u>	<u>0.34</u>	<u>TRAD</u>	
AZ-AP*	33	41	57	16	0.27	TRAD	
<u>DB-reg*</u>	27	36	59	23	0.36	IE	
<u>LT-Hon</u>	16	32	61	29	0.25	IE	MBL
<u>CL-reg*</u>	20	35	62	27	0.42	IE	MBL
RAM-C group	12	34	63	29	0.44	IE	MBL
MW-reg #	18	28	64	36	0.50	IE	MBL
RAM-regular	38	33	65	32	0.48	IE	MBL
GS-Hon #	63	28	66	38	0.53	IE	MBL
ELM-Hon #	20	18	74	56	0.68	IE	MBL
MW-Hon*	30	42	78	36	0.62	IE	MBL
GS-AP*	11	73	85	12	0.44	IE	MBL

WEIGHTED AVERAGES (N total = 1078)

pretest: 29.5 posttest: 53.1 gain: 23.6 g: 0.34

Table 41: FCI comparisons sorted by posttest scores

In table 41 the four nearest groups in pretest score to the study group have been underlined, groups which had higher pretest scores than

the study group have been marked with a star, and the groups which had lower pretest scores but higher posttest scores are marked with a # sign. This table shows that the study group students moved ahead of the four groups that were closest on pretest scores. As can be seen from table 4-36, the study group had a significantly higher posttest average (63% for RAM-C and 65% for RAM-reg) than the mean for the entire comparison group (53.4%).

All the groups using Interactive Engagement methods of one sort or another had higher post test scores than those classes using traditional methods. The combination of Interactive Engagement methods with MBL techniques was associated with high posttest scores. The combination of MBL techniques with traditional methods was not associated with high posttest scores. (As MBL use in any form is still a relatively novel technique, this argues that the success of theory based MBL is not simply a case of a novel technique causing more student and teacher interest and activity.) In terms of posttest scores the study groups did about as well as all but the best of other groups using similar teaching techniques. There were 5 other groups within a 2 answer range (6.8% score difference) of the study group. This suggests again that the study group has similar final achievement on the Force Concept Inventory to other groups with similar pretest scores taught by Interactive Engagement methods. A two-tailed t-test was run to compare the study group (38) with the "upper division" group mean on the posttest score, where the upper division includes all the Interactive Engagement groups. Table 42 summarizes the t-test.

N=38	SD =18.96%	SE= 3.078%
study mean = 64.79%	upper level group mean = 67.26%	diff = -2.47 %
t = diff/SE = -0.80	t critical = 1.3	
	(two-tailed test $p<0.2$)	

Table 42: T-test for study group and Interactive Engagement posttest scores

The t-test shows that the study group mean was not significantly different from the mean post test score for the rest of the Interactive Engagement groups.

Comparisons with 5 Question Sub-test of FCI.

This comparison was done only with four groups, the AZ-REG, AZ-HON, MW-HON and GS-HON groups, as explained in Chapter 3. The percentage of students correctly answering each of the five questions was determined for each group and the mean percentage correct was also calculated. This was done for the study groups for the pretest, immediate posttest and the final examination, and for the comparison groups for the pretest and posttest. Finally, t-test comparisons were done to look for significant differences. between the RAM-reg group and the comparison groups.

Table 43 gives the comparison data for the pretest for the study groups and the comparison groups.

GROUP	N= 38 RAM-reg %CORR	12 RAM C %CORR		612 AZ-REG %CORR	118 AZ-HON %CORR	30 MW-hon %CORR	63 GS-hon %CORR
Question							
18	5	8		7	7	11	5
20	21	33		28	35	50	41
21	21	25		6	14	36	19
28	8	8		16	23	28	7
29	51	50		48	67	67	36
	1.07	1.25	Mean	1.05	1.46	1.92	1.08
	21.4	25.0	% Mean	21.0	29.2	38.4	21.6
SD	1.04	1.3					
SE	0.166		Difference	Not Sig p > .1	SIG p < .05	SIG p < .01	Not Sig p > .1

Table 43: FCI sub-test comparisons

The RAM-reg group had a mean pretest score of 21.4 % on the 5 question sub-test, which was not significantly different from the pretest means for the AZ-REG or GS-Hon groups, but was significantly lower than the pretest average for the AZ- HON and MW-hon groups, the latter having by far the largest score on the pretest. Inspection of the individual questions shows similar percentages of correct responses for all the groups with the exception of the MW-Hon group. Certainly, the study groups most resemble the AZ-Reg and the GS-hon groups in the pattern of answers.

Table 44 gives the comparison data for the immediate posttest for the study groups and the posttest for the comparison groups.

GROUP	N= 38 RAM-reg %CORR	12 RAM C %CORR		612 AZ-REG %CORR	118 AZ-HON %CORR	30 MW-hon %CORR	63 GS-hon %CORR
Question							
18	35	42		25	32	62	35
20	62	75		38	48	76	57
21	70	75		37	50	90	57
28	47	58		28	39	76	38
29	61	67		59	60	76	52
	2.75	3.17	Mean	1.87	2.29	3.8	2.39
	55.1	63.3	% Mean	37.4	45.8	76	47.8
SD	1.716						
SE	0.275		Difference	SIG p <.005	SIG p < .05	SIG p < .005	SIG p < .1

Table 44: FCI sub-test comparisons by question-immediate posttest

This data indicates that on the immediate posttest, the study groups made a significant increase in their scores, doing significantly better than the AZ-Reg and AZ- Hon groups, both of which had traditional instruction and also doing better than the GS-Hon group which used Interactive Engagement instruction and MBL techniques. Neither of the study groups did as well as on these five questions as the MW-Hon group, which also used Interactive Engagement and MBL techniques. The large gains on this five question sub-test tend to support the argument that this instructional method is effective in comparison with traditional methods and with some other theory-based instructional methods.

Table 45 gives the comparison data for the final examination for the study groups and the posttest for the comparison groups.

GROUP	N= 38 RAM-reg %CORR	12 RAM C %CORR		612 AZ-REG %CORR	118 AZ-HON %CORR	30 MW-hon %CORR	63 GS-hon %CORR
Question							
18	50	50		25	32	62	35
20	92	83		38	48	76	57
21	79	67		37	50	90	57
28	58	58		28	39	76	38
29	74	75		59	60	76	52
	3.53	3.33	Mean	1.87	2.29	3.8	2.39
	70.5	66.7	% Mean	37.4	45.8	76	47.8
SD	1.41	1.83					
SE	0.226		Difference	SIG p <.005	SIG p < .005	Not Sig p > .1	SIG p < .005

Table 45: FCI sub-test comparisons by question-final exam

The final examination results for the study groups show that the effect persists, although the largest gains in scores were from pretest to immediate posttest. The study group means for the sub-test are significantly higher than all comparison groups except the MW-hon group, and by the final examination are only slightly (and not significantly) smaller than the posttest score for the MW-Hon group.

Comparison of Gain Scores: Entire FCI Test

Table 46 gives the comparison data for the whole FCI test in order of increasing gain from pretest to posttest.

Code	N	PRE	POST	GAIN	g	METHOD	
GS-AP	11	73	85	12	0.44	IE	MBL
Chicago-REG	56	27	42	15	0.21	TRAD	
AZ-AP	33	41	57	16	0.27	TRAD	
LT-reg	16	23	42	19	0.25	TRAD	MBL
Az-reg	612	27	48	21	0.29	TRAD	MBL
<u>AZ-HON</u>	<u>118</u>	<u>33</u>	<u>56</u>	<u>23</u>	<u>0.34</u>	<u>TRAD</u>	
<u>DB-reg</u>	<u>27</u>	<u>36</u>	<u>59</u>	<u>23</u>	<u>0.36</u>	<u>IE</u>	<u>MBL</u>
<u>CL-reg</u>	<u>20</u>	<u>35</u>	<u>62</u>	<u>27</u>	<u>0.42</u>	<u>IE</u>	<u>MBL</u>
<u>LT-Hon</u>	<u>16</u>	<u>32</u>	<u>61</u>	<u>29</u>	<u>0.43</u>	<u>IE</u>	<u>MBL</u>
<u>RAM-C</u>	<u>12</u>	<u>34</u>	<u>63</u>	<u>29</u>	<u>0.44</u>	<u>IE</u>	<u>MBL</u>
<u>RAM-reg</u>	<u>38</u>	<u>33</u>	<u>65</u>	<u>32</u>	<u>0.48</u>	<u>IE</u>	<u>MBL</u>
MW-reg	18	28	64	36	0.50	IE	MBL
MW-Hon	30	42	78	36	0.62	IE	MBL
GS-Hon	63	28	66	38	0.53	IE	MBL
ELM-hon	20	18	74	56	0.68	IE	MBL
WEIGHTED AVERAGES (N total = 1078)							
pretest:	29.5	posttest:	53.1	gain:	23.6	g:	0.34

Table 46: FCI comparison scores sorted by gain scores

Comparison of gain scores again shows that the combination of Interactive Engagement methods with MBL is usually associated with the highest gain scores. Five other groups have gain scores within a range of 2 questions (6.8% score difference) of the study groups, and only four groups have higher gain scores. (The GS-AP group has a low gain score, but a very high pretest score, so there is little room for gain. See the comparison in Table 48 by relative gain.) The comparison of the study group gain score with the average gain score shows that the study group had a significantly higher gain than the average gain for the comparison group (difference = 8.2 %, $p < .005$, one tailed test). A comparison with the average for the Interactive Engagement groups shown in table 47 indicates there is not a

significant difference between the study group gain and the IE group gain.

T-test for difference between study group gain and IE group gain.
N = 38
study group gain = 32.12%
t=diff/SE = -1.03

SD= 16.28%
IE group gain =34.84%
T critical(two-tailed test p <0.20) = 1.3

SE=2.64%
diff = -2.72%

Table 47: t-test for FCI gain score differences

This comparison indicates that the study group has comparable gains to those of other groups taught by Interactive Engagement methods.

Comparison with Relative Gain (g) Scores

Code	N	FCI Pre (%)	FCI Post (%)	GAIN(%)	g	METHOD	
CHICAGO-REG	56	27	42	15	0.21	TRAD	
LT-reg	16	23	42	19	0.25	TRAD	MBL
AZ-AP	33	41	57	16	0.27	TRAD	
Az-reg	612	27	48	21	0.29	TRAD	MBL
AZ-HON	118	33	56	23	0.34	TRAD	
DB-reg	27	36	59	23	0.36	IE	MBL
CL-reg	20	35	62	27	0.42	IE	MBL
LT-Hon	16	32	61	29	0.43	IE	MBL
GS-AP	11	73	85	12	0.44	IE	MBL
RAM C-12	12	34	63	29	0.44	IE	MBL
RAM-reg	38	33	65	32	0.48	IE	MBL
MW-reg	18	28	64	36	0.50	IE	MBL
GS-Hon	63	28	66	38	0.53	IE	MBL
MW-Hon	30	42	78	36	0.62	IE	MBL
ELM-hon	20	18	74	56	0.68	IE	MBL

WEIGHTED AVERAGES (N total = 1078)

pretest: 29.5 posttest: 53.1 gain: 23.6 g: 0.34

Table 48: FCI comparisons sorted by g scores

Using the relative gain score, g, as described in Chapter 3, the study group’s performance was notably better than groups receiving traditional instruction, and comparable to all but two of the highest scoring groups as shown in Table 48. Note that the groups with the closest pretest scores

(underlined in Table 48) had somewhat lower relative gain scores.

Comparisons Using the Thornton Motion Test

Although this study is a pre-experimental design with no control group, some comparisons can be made by using data from other comparable groups as a control. The Thornton Motion Test (1992a) in various forms has been given to a large number of college and high school students over a period of almost 10 years. A copy of the test appears in Appendix C. The velocity and acceleration questions (22- 33) were administered to all sections after instruction in kinematics but before the experimental instruction on force. The force sled questions (1-7) and the force graph questions (14-21) were administered to all sections as part of the posttest immediately after instruction. The force sled questions (1-7) were administered to all sections again on the end of the year final exam. The results for the 38 students who took all the tests are included in the analysis and are labeled "Study38" in the following graphs and tables. The comparison data are taken from Thornton (1993). Since no pretest data were taken for the Study38 group, their results are shown on the left of the pretest bars for the comparison groups, on the assumption (as discussed) that they would have similar pretest results.

Velocity question comparisons.

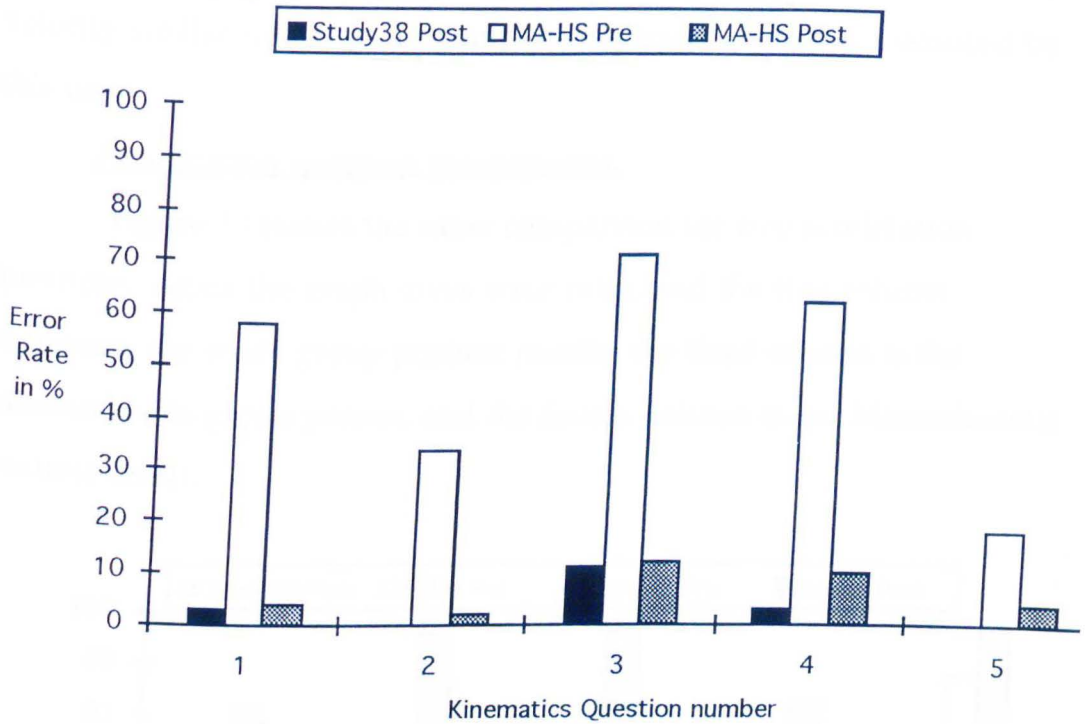


Figure 12: High School Kinematics: velocity questions: Study38 students posttest compared with 8 Mass. High Schools pretest and posttest results. (Thornton, 1993)

Figure 12 shows a comparison of error rates on 5 velocity questions from the Thornton Motion test, where the error rate is the percentage of students answering the question incorrectly. For this measure, a small value (low bar height) represents good results. The comparison group was a composite of eight high schools in Massachusetts, taken in 1988, which included 288 students. The white bars give the error rates before MBL instruction in kinematics. The dotted bars to the right for each question give the error rates on these questions after MBL instruction. The solid bars to the left on each question give the error rates for the Study38 group after kinematics MBL instruction. The error rates for the Study38 students after instruction are quite similar to the error rates for the Massachusetts

students. This indicates that the students in this study achieved mastery of velocity similar to that of the comparison group, at least as measured by this test.

Acceleration question comparisons.

Figure 13 makes the same comparison for five acceleration questions. Again the graph gives error rates, and the first column represents the study group posttest results, the third column is the Massachusetts group pretest, and the fourth column is the Massachusetts posttest result.

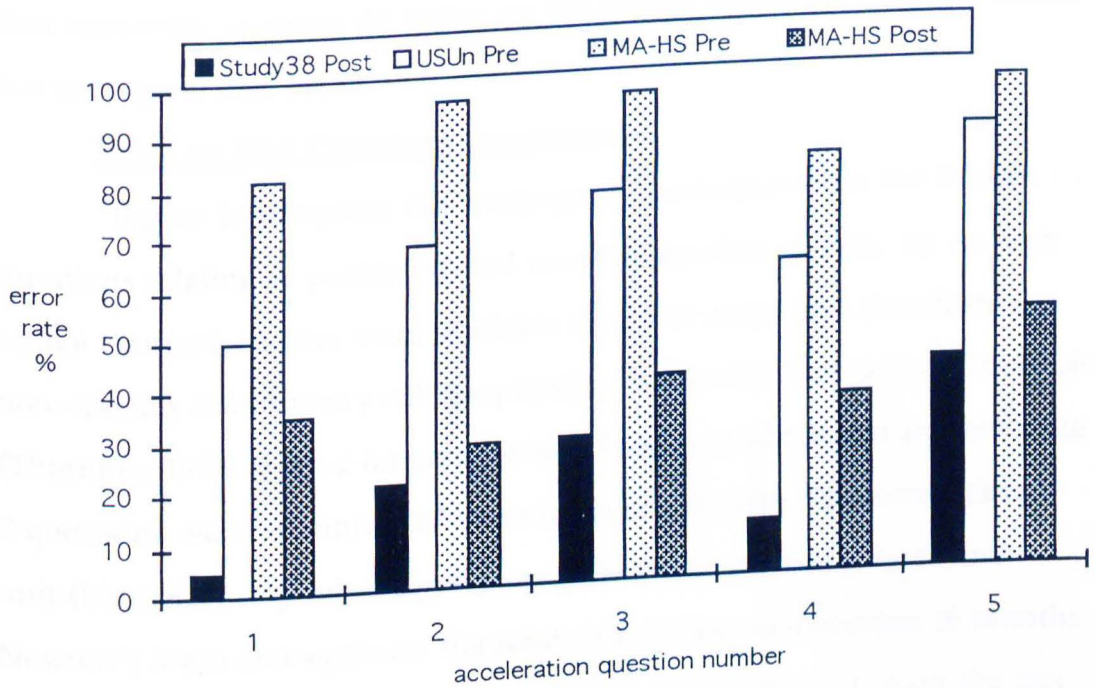


Figure 13: High School Kinematics: Acceleration Questions.

Study38 students posttest results compared with 8 Mass. high schools pretest and posttest results

Again the graphs indicate that the study group achieved similar mastery on the acceleration questions, and on some of the questions had

lower error rates than the comparison group. Taken together, these results suggest that the study group students were as well prepared before the unit on forces as other groups of high school students. Because there were no pretest kinematics questions given to the study group, these data only argue for the comparability of the groups after kinematics instruction.

The second column on Figure 13 shows pretest results for these questions for a group of US university students taking introductory physics. This group is included to compare the pretest performance of university students with those of high school students. The data indicate that university students do better on the pretest than high school students, but not a great deal better.

Force on Sled Questions comparison:

Figure 14 compares the study group performance on the 7 force questions relating to pushing a sled on a friction free surface. As no high school comparison data were available for these questions, data from a non-calculus introductory college physics class at the University of Oregon (Thornton, 1993) is used for comparison. For the study group students, the 7 questions were administered once immediately after the instructional unit (but before any other significant instruction involving force and Newton's laws) and again on the final end of year examination (6 months after the instructional unit). The comparison group ($N = 72$) took the test once before instruction and again after instruction.

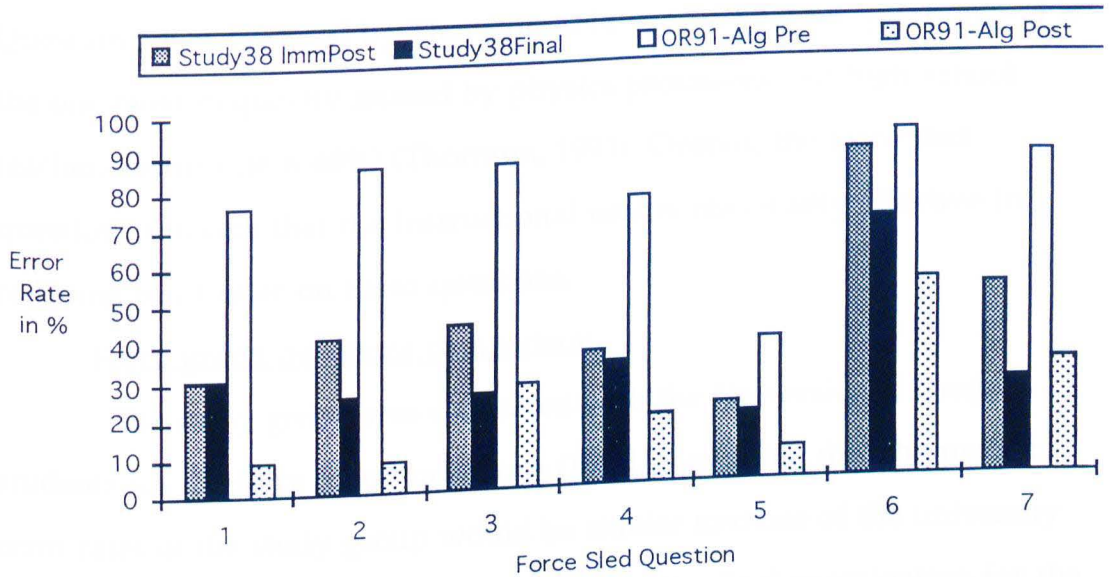


Figure 14: Force Sled questions: Study38 students immediate posttest and final examination compared with U. of Oregon non-calculus physics course pretest and posttest results.

With the exception of question 6, the study group immediately after instruction and on the final examination had a much lower error rate than the pretest error rate of the university students. University and high school students in other studies have shown similar high pretest error rates (Thornton, 1995), so it is assumed that the study group would also have a high pretest error rate. (Additional evidence for this is found in the lack of a significant difference in pretest scores on the Force Concept Inventory between the study group and comparison groups as discussed earlier in this section.) In all questions except question 1, the study group showed improvement between the immediate posttest and the final examination score, as expected since there was additional instruction and practice relevant to Newton's laws during the intervening period.

Question 6 is considered by Thornton to be a very difficult question and is the one most frequently missed by physics professors and high school teachers (error rate = 40%) (Thornton, 1993). Overall, the force sled questions indicate that the instructional unit is reasonably effective in reducing error rates on these questions.

Force graph questions comparison.

The study group was compared with the University of Oregon students for the force graph questions (14-21), assuming that the pretest error rates of the study group would be similar to those of the university group. As force graph questions were not on the final examination for the study group, only immediate posttest results are given.

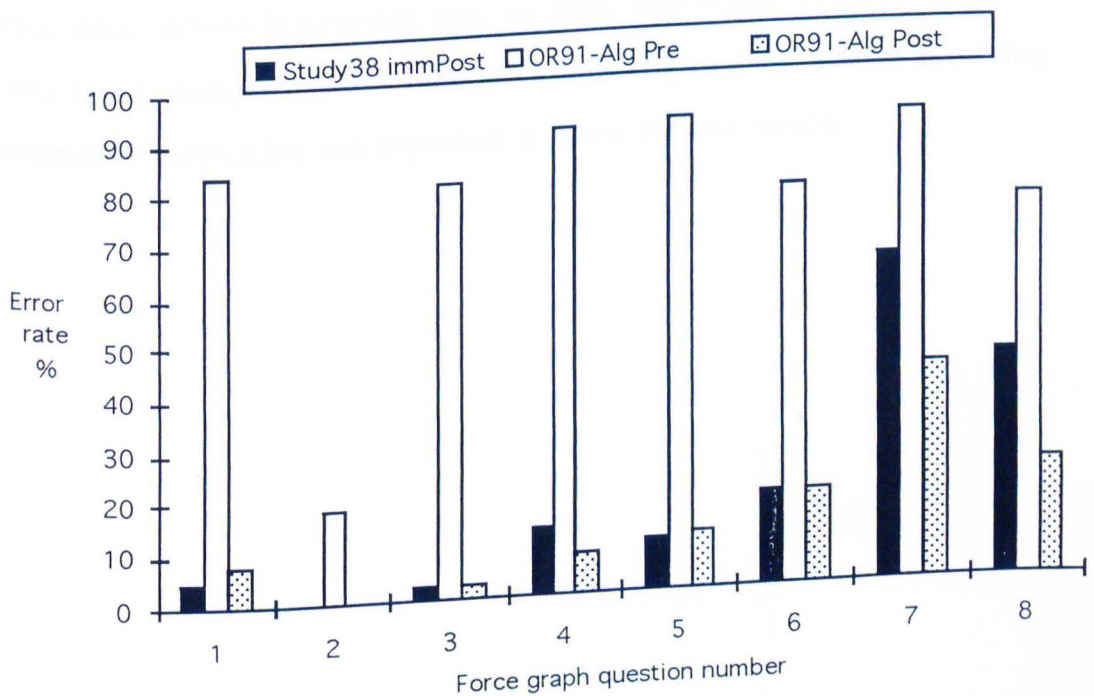


Figure 15:Force Graph Questions: Study38 students immediate posttest results compared with U. of Oregon non-calculus physics pretest and posttest results.

Question 2 is usually answered the same (but for different reasons) (Thornton, 1995) in both pretest and posttest, and was not given on the Oregon posttest. As seen in Figure 15, the study group had an error rate of 0% on this question on the immediate posttest and on the final examination. For questions 1,3,4,5, and 6, the error rates of the study group are nearly identical with those of the comparison group. On questions 7 and 8, which were more difficult for both groups, the study group did not perform as well as the comparison group.

To gauge the effect of MBL instruction compared with traditional lecture instruction, Figure 16 is included, showing the performance of a non-calculus physics class at the University of Oregon which received only traditional lecture instruction and no MBL instruction (Thornton, 1993). Only small changes in error rates occurred. High school classes receiving traditional instruction are expected to show similar results.

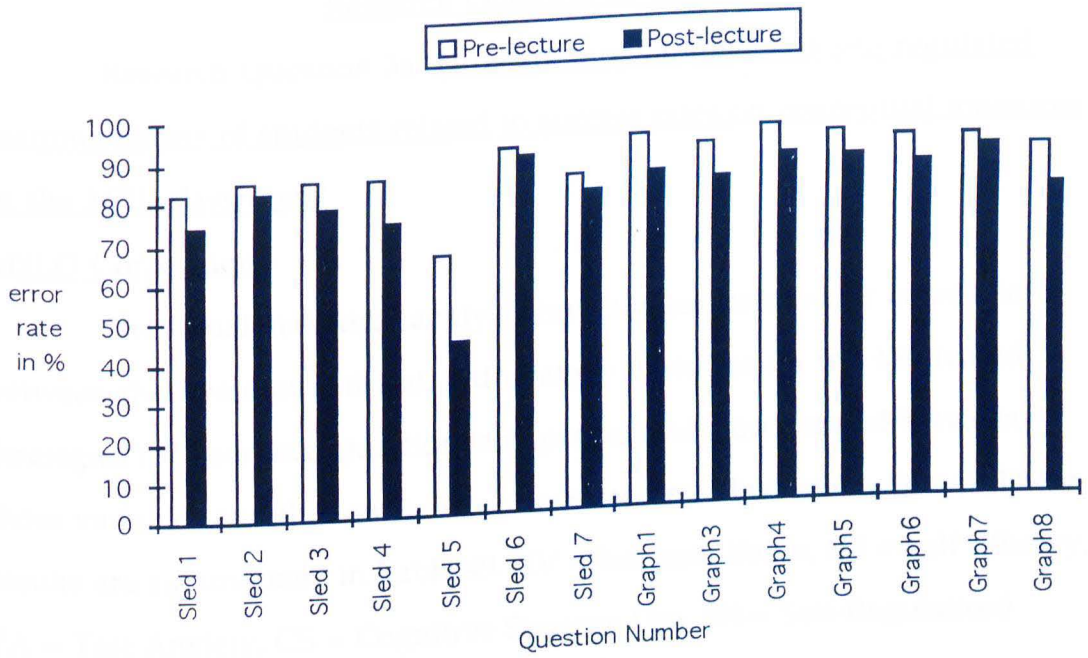


Figure 16: Oregon non-calculus 89/90 force questions, pre-lecture and post-lecture instruction results, with out MBL use

Research Question 3a Results

Research Question 3a: How are motivational and self-regulated learning beliefs of students related to success rates on conceptual measures in the MBL classroom?

MSLQ Correlations

The initial statistical analysis investigated zero-order correlations between the five motivational and strategy variables on the Motivated Strategies for Learning Questionnaire pretest and posttest and between those variables and the four test measures as described in Chapter 3. These results are summarized in Table 49. (IV = Intrinsic Value, SE = Self Efficacy, TA = Test Anxiety, CS = Cognitive Strategy Use, SR = Self-Regulation)

pretest correlations	IV	SE	TA	CS	SR	
IV	–					*p<.05
SE	.46**	–				**p<.01
TA	.63***	.31	–			***p<.001
CS	.71***	.32*	.67***	–		
SR	.76***	.45**	.42**	.63***	–	
posttest correlations	IV	SE	TA	CS	SR	
IV	–					*p<.05
SE	.54***	–				**p<.01
TA	.37*	.21	–			***p<.001
CS	.55***	.20	.46**	–		
SR	.62***	.57***	.27	.34*	–	

Table 49: Pretest and posttest MSLQ correlations

Motivational and Cognitive Strategy Correlations

As in the Pintrich and DeGroot study (1990), high levels of self-efficacy ($r=.32$) and intrinsic value ($r=.71$) were correlated with high levels of cognitive strategy use. In contrast to their study, high levels of test anxiety ($r=.67$) were also correlated with high levels of cognitive strategy

use. This suggests that students in this study who reported that they were anxious about tests also reported that they tried to study effectively. This may reflect a “prep-school” mentality of the specific population in this study, and it may also reflect some difference in the pattern of responses due to the age of the students, 11th and 12th grade in this study versus 7th grade in the Pintrich and DeGroot study. High test anxiety was in fact positively and significantly correlated ($p < .05$) with all the variables in this group except self-efficacy ($r=.31$, $p<.06$) where the correlation was still positive but slightly less significant. In the Pintrich and DeGroot study, test anxiety had a significant correlation only with self-efficacy and that was a negative correlation. As in the Pintrich and DeGroot study, all the other motivational and cognitive variables were positively correlated and all correlations were highly significant except that between self-efficacy and cognitive strategy use ($r = .32$) which was barely significant at the $p=.05$ level. The magnitude of this correlation is very close to that reported by Pintrich and DeGroot for this pair of variables ($r=.33$), although their result was significant at $p<.001$. Since the self-efficacy scale reflects student reports of their perceptions of their competence and confidence in their work, the moderate significance here may suggest that there is more variation among the study group students in their confidence that cognitive strategy use will be a successful method for this course.

Motivation, Self-Regulated Learning and Performance Relations

Table 50 shows the zero order correlations between the motivation, cognition and performance measures. In contrast to the results of Pintrich and DeGroot, few of the correlations were particularly strong and most were not significant even at the $p < .10$ level. However, the values of the correlation coefficients of all the motivation variables and the self-regulation measure with the FCI final score and the two Thornton test measures were similar, or in several cases larger than the correlations found in the Pintrich and DeGroot study between the four MSLQ variables and the Exams and Quizzes grades of students in that study. The difference in significance is due to the larger number of students ($N=173$) in that study versus the smaller number ($N = 38$) in the present study.

		FCI final	FCI gain	Thornton immediate	Thornton final
Intrinsic Value	pre	.19	.04	.09	.19
	post	.37*	.04	.24	.30
Self-Efficacy	pre	.16	-.15	.11	.16
	post	.45**	.30	.44**	.37*
Test Anxiety	pre	-.02	-.16	-.12	.04
	post	-.26	-.31	-.15	-.20
Cognitive Strategy Use	pre	.19	.09	-.05	.19
	post	.05	-.13	.06	-.06
Self-Regulation	pre	.20	-.07	.05	.24
	post	.35*	.15	.33*	.26
		* $p < .05$	** $p < .01$	*** $p < .001$	

Table 50: MSLQ and test performance correlations

Intrinsic Value had one significant correlation between the MSLQ posttest score and the FCI final examination score. and had moderate correlations with the scores on the Thornton force questions on the

immediate posttest and on the final examination, although the latter two correlations were not significant at the $p < .10$ level. Ignoring, for the moment the lower significance of the correlations in the present study, high intrinsic value and self-efficacy posttest scores were positively correlated with test achievement on both the Force Concept Inventory and the Thornton Force and Motion problems, and high test anxiety posttest scores were negatively correlated with the performance on the test measures. This is the same pattern that was found in the Pintrich and DeGroot study (1990). On the cognitive measures, posttest self-regulation was positively correlated with test performance, as it was in the Pintrich and DeGroot study, but posttest cognitive strategy use showed very little correlation with test performance. This may be an indication that the kind of cognitive strategies which are described in the MSLQ are not closely related to the kind of thinking required to deal effectively with the qualitative style of questions on these tests.

Performance versus posttest scores.

Despite the low significance of the correlations, it was decided to run multiple regression analyses for the three test performance measures. The FCI final score was negatively related to test anxiety ($p < .005$) and positively related to intrinsic value ($p < .005$) on the MSLQ posttest with $R^2 = .31$, but there were no significant relationships with the variables on the MSLQ pretest.

The immediate force question score was significantly related only to self-efficacy ($p < .006$, $r^2 = .19$) on the MSLQ posttest with no significant relationships with the MSLQ pretest, and the final examination force score was negatively related to test anxiety ($p < .03$) and positively to intrinsic

value ($p < 0.01$) with $R^2 = 0.20$. Again there were no significant relationships with the variables on the MSLQ pretest.

Given the low significance and small effect of the relationships with the MSLQ posttest and lack of significant relationships with variables on the MSLQ pretest, it was decided to forgo further analysis of this data.

Research Question 3b Results

Research Question 3b :What effect does theory based MBL instruction have on the motivational and self-regulated learning beliefs of students?

To test research question 3b, the questionnaire was administered twice, once at the beginning of the semester, before any instruction, and again at the end of the first semester, which consisted primarily of MBL instruction, including the experimental unit. The data used were from the 38 student sample including all students who took the final exam. Changes in scores between the pretest and posttest MSLQ were found, and tested for significant differences using a paired t-test. under the assumption that MBL instruction may promote self-efficacy and use of learning strategies.

Variable:	pretest mean (SD)	posttest mean (SD)	change mean (SD)	t	
Self -efficacy	4.79 (.70)	5.00 (.88)	0.21 (.72)	1.77	Significant at .05 (1-tailed)
Intrinsic value	5.12 (.93)	5.43 (.72)	0.31 (.80)	2.38	Significant at .05 (1-tailed)
Test Anxiety	4.36 (.82)	4.68 (.84)	0.32 (.73)	2.67	Significant at .01 (1-tailed)
Cog nitive Strategy Use	4.85 (.80)	4.87 (.74)	0.02 (.68)	.23	Not Significant
Self-Regulation	4.35 (.82)	4.39 (.64)	0.04 (.74)	.36	Not Significant

dF = 37

Table 51: Pretest to posttest comparisons of MSLQ scores

The results in Table 51 show small average increases in the motivational variables, but small average decreases in the cognitive variables. A one-tailed t-test indicates that the differences between pretest and posttest means are significant at the .05 level for the Self-Efficacy and Intrinsic Value components of the MSLQ. Only Test Anxiety showed a

significant change at the .01 level, increasing from an average of 4.36 to an average of 4.68. This is not necessarily surprising, as the pretest was administered before the start of instruction when summer had taken the sting out of the memory of testing, and the posttest was given after a semester of instruction, when students were immersed in the reality of test taking, and had just finished their semester exams. Otherwise, the significant differences represent quite small changes in the average values, and this suggests that no definitive conclusions may be drawn from this data. Certainly, there is no large change in any of the MSLQ scales.

CHAPTER 5

Conclusions

This study investigated the effect of theory-based MBL instruction on high school students' understanding of the relationship of force and motion in the context of a high school physics course taught by the researcher. The five goals of the study were 1) to generate a rich description of the process of conceptual change during a week of MBL instruction on Newton's Second Law for an entire class of students using several sources of data, including pretest and posttest measures, self-report surveys and interviews, 2) to describe the relationship of the instructional design to the process of conceptual growth and change using this description in order to improve understanding of how the elements of an instructional unit affect student learning, 3) to relate changes in conceptual understanding as seen with pretest and posttest questions to changes seen in student self-report interviews, 4) to use the pretest and posttest measures to compare the conceptual change and/or final conceptual state of students in this study with data obtained on the same measures for students experiencing other forms of instruction, 5) to examine and describe the interaction of students' cognitive beliefs, motivational beliefs, conceptual change and the instructional design. This section will look at the conclusions which can be made from the results in chapter four, first focusing on the individual research questions and then considering the study as a whole. Finally, the delimitations of the study will be discussed and suggestions made for further research.

1. Effect of Instructional Design

Research Question 1a

What is the nature of student reasoning activities and cognitive change during classroom MBL instruction, in particular the understanding derived from real-time graphs of experimental data?

As noted in chapter 3, the audio tape questionnaires did not yield sufficiently detailed statements from most students to make reliable inferences about the nature of student reasoning activities during MBL instruction, with the exception that the rapidity of students' change from a force-causes-velocity view to a force-causes-acceleration view supports the expectation that real-time graphing experiments using MBL can be powerful learning experiences. A follow-up to this study should try to develop questions that elicit more information about the nature of student's thinking, although this may need to be done by think-aloud techniques and/or live interviews. Videotaping small group discussions while students are using MBL tools would also give data about students' thinking as they are learning, but adds a significant data analysis load to the teacher-researcher's time.

The tables detailing the conceptual changes for individual students show the expected overall pattern of initial knowledge, partial conceptual change as a result of the iconographic force and motion experiment, and consolidation of the ability to apply that knowledge with time and more experience. Nearly all the students had the expected non-Newtonian ideas of the relationship of force and motion, most quickly recognized the relationship of force to acceleration after the force and motion experiment, most were able to state the correct relationship, but less able to apply it

immediately after they learned it, and most displayed eventual mastery of the ideas. However, a detailed look at individual students shows that the progress of change is complex, showing reversion to earlier ideas, context dependent reasoning and inconsistent application of knowledge to new circumstances. (Speaking as a teacher, some of the students who did not acquire the concepts, even in the long term were those who were more interested in passing the course with as little effort as possible than in learning physics as well as they could.) Ten of the 13 students profiled responded to probes of their initial knowledge with the belief that the velocity of an object was proportional to the applied force, consistent with expectations, and only one asserted that an object would move with a constant speed in the absence of a force. (Two were missing data for these questions due to tape malfunctions).

Immediately following the iconographic force and motion experiment, 11 of the 13 students profiled made statements which indicated they now recognized that force and acceleration were directly related, and 7 of the 13 explicitly stated that the force and velocity were not directly related, again a result that was consistent with the expectation that this kind of experiment would be an effective promoter of conceptual change. Over the following two days, 9 of the 13 students persisted in expressions of their new belief that force directly caused acceleration, 2 made statements indicating a return to their former belief that force directly caused velocity, and 2 who had not made a change on the day of the experiment, now changed their ideas and gave answers indicating a belief that force directly causes acceleration. On the immediate posttest, 8 of the 13 gave answers which were predominantly Newtonian. By the final

exam, 7 of the group gave clearly Newtonian responses to questions, and 4 of the 6 students who took a follow-up test a year later gave Newtonian answers.

Overall, the evidence from the test questions suggests that over half of this group of students acquired and maintained a reasonably Newtonian view of the relationship of force and motion during this course and that a large part of that change in viewpoint occurred during the course of the force and motion unit under study. Although the FCI pretest gave some indication of students' initial knowledge, the audio tape evidence gave a fuller picture of each student's knowledge, and particularly of his ability to apply his knowledge. In general the Thornton Force and Motion questions agreed with the evidence from the audio tape, although some students demonstrated good performance on some kinds of tasks but not on others. The preponderance of this evidence indicates that for most of the students there was a significant and detectable change in thinking about force and motion which occurred as a consequence of the iconographic force and motion experiment and which persisted as a long term change in their knowledge about force and motion. The conclusion for research question 1a is that the evidence from the detailed descriptions of student knowledge and knowledge change is consistent with the model of student understanding described in chapter two, and the expected changes in student understanding caused by theory-based MBL instruction.

Research Question 1b

What evidence is there that the nature of the conceptual change is consistent with the mechanisms posited in the instructional design, in

particular that the “iconographic” experiment relating force and motion is an effective learning activity?

This portion of the research question focused more narrowly on the nature of the conceptual change that occurred, but has some overlap with the first part of the research question. However, the aim here was less to describe the conceptual understanding and change of each student and more to determine if the results for the group of students supported the assumptions which were the basis of the instructional design. Specifically, the analysis considered whether the assumptions of the design were supported by eight factors: the students’ 1) initial conceptions, 2) ability to describe the experiment, 3) ability to understand the purpose of the experiment, 4) understanding and description of the graphs made in the experiment, 5) immediate conclusions from the experiment, 6) expression of surprise or perception of contradiction of their previous views, 7) persistence of conclusions and 8) ability to cite the evidence for their conclusions.

In evaluating the results, it was found that 8 of the 13 students had summary scores of 5 or more out of 8 possible points, which supports the conclusion that the nature of the conceptual change is consistent with the assumptions and that the iconographic force and motion experiment is an effective learning activity. The evidence was strongest for 4 of the 8 factors. The students’ initial conceptions, ability to understand the purpose of the experiment, immediate conclusions and the persistence of those conclusions were consistent with expectations for 11 or 12 of the 13 students, and the ability to describe the experiment matched expectations for 9 of the 13 students. Furthermore of the 104 individual entries in Table

26, only 5 contradict the assumption that the experiment is effective. This argues that the conceptual change seems to occur rapidly for nearly all the students, and this change is closely connected with the force and motion experiment. These scores, taken together with the more descriptive evidence from research question 1a make a strong argument for this conclusion.

Research Question 1c

What evidence is there that this instructional design allows students to identify and focus on important conceptual goals of experiments rather than subgoals?

This portion of the research question addressed the hypothesis that MBL experiments involving real time graphing reduce the mental processing load for students and allow them to more readily identify and focus on the fundamental goals of an experiment rather than attending primarily to the more immediate sub-goals of carrying out the analysis tasks. The results show a real difference between students identification and focus on sub-goals in the laboratory tasks during the first four days of the unit, which did not make much use of real-time graphing, and the tasks for the last three days which primarily involved real-time graphing. The tables and graphs in chapter four (4-17 through 4-22) show a distinctive change from the first investigation (days 1-4) where about 38% of students could identify the goals to the second investigation (days 5-6) where over 80% of students identified the goals of the experiment. A similar change (from 13% to 75%) occurred in ability of students to focus on the goals of the experiment in their description of their results and conclusions between the two investigations. As the difference here occurs within a

single unit, taught by the same teacher, using the same equipment, there is good reason to believe that the difference is connected with the real-time graphing experience. The size of the effect is quite large, an important criterion for deciding whether an educational change will have practical consequence in the classroom. This is strong evidence that the real-time graphing use of MBL is not only effective in supporting conceptual change, but that the effectiveness is associated with a reduction in sub-goal focus and increase in goal focus consistent with the model proposed by Simon (1991) . It would be extremely useful to have further research look at student's focus on goals versus sub-goals to confirm this finding, as this is a central argument for the efficacy of MBL and real time graphing.

Research Question 1d

Which instructional activities and what aspects of the instructional design do students identify as effective for their learning?

The analysis of this question attempted to determine what the students themselves identified as the most effective or memorable activities during the course of the instructional unit. Fourteen of the students were present for sufficient parts of the unit to be included in the analysis. Ten of the questions during the experimental period asked for responses which had a bearing on this analysis, and a total of 129 responses were made. Allowing for absences, there were 94 opportunities for this group of students to respond, as a portion of the students identified more than one activity on a particular day as effective. The detailed breakdown of these was given in tables 4-23 and 4-24. The variety of responses is significant, but out of this several clear patterns emerge. Three of the experiments done were frequently cited as effective, with 16 responses

citing the experiment with rubber bands, springs and the spring scale, 17 citing the initial experiments with the force probe, the spring scales, and calibration and combining of forces, and 23 citing the experiment with the oscillating cart, the iconographic force and motion experiment. An additional 27 responses made general reference to graphs and graphing without being more specific. An inspection of all the responses showed that 58 of them (about 45%) dealt with graphs either explicitly or implicitly as effective learning tools. Table 4-25 gave the daily breakdown of the number of students citing a particular experiment relative to the number of students present that day. Two experiments, the first experiment using the force probe and spring scales and the iconographic force and motion experiment received the most mentions, with 7 of 12 students present citing the specific experiment as effective. Overall, it seems that students identified activities involving graphing as effective learning activities, and most frequently referred to the iconographic force and motion experiment. Assuming that students are honestly and correctly picking the activities that they found most effective, the high percentage of responses identifying graphing activities supports the assumptions of MBL instruction, but an important caution is that graphing is a salient feature of MBL instruction, and it would be surprising if students did not identify graphing as important. Supplementing the tape questionnaires with selected interviews could help to refine this part of the investigation, a step that was not possible with resources available. A possible problem is that this would be a more intrusive technique, would depend on student's volunteering to spend time after the class, and might not be able to investigate a representative sample of students.

Conclusions from Research Question 1

This research question addressed the first two goals of the study, 1) to generate a rich description of the process of conceptual change during a week of MBL instruction on Newton's Second Law for an entire class of students using several sources of data, including pretest and posttest measures, self-report surveys and interviews, and 2) to describe the relationship of the instructional design to the process of conceptual growth and change using this description in order to improve understanding of how the elements of an instructional unit affect student learning. Overall, the evidence considered in this research question supports the model of student's prior knowledge, supports the model of the cognitive changes expected using theory-based MBL instruction, and provides experimental evidence that supports the assertions made by proponents of MBL instruction. Furthermore, it does this in the context of classroom instruction, with relatively few modifications to the classroom routine to facilitate the research program. The detailed description of each student's knowledge changes determined from both test results and audio tape questionnaires give a rich data set to support the conclusions, and to validate the model of student prior knowledge and learning in broad detail leading to the conclusion that the model of students described here was useful for the design of the instructional unit.

2. Test Measures of Changes in Conceptual Understanding

Research Question 2a

What are the changes in student success rates on measures of conceptual understanding applied before and after instruction specifically in regard to Newton's Second Law.

The limited patience of students and the limited class time available for all the activities that should be carried out in the course of a year place significant practical limits on how much pretesting of students can be done. Posttesting is somewhat easier, if posttest questions are embedded in the regular practice of classroom assessment. As a consequence of such practical limitations, only the Force Concept Inventory (Hestenes, et al., 1992) and the Motivated Strategies for Learning Questionnaire (Pintrich & DeGroot, 1990) were able to be given in full pretest, posttest mode. Tables 4-26 in chapter 4 shows that for the whole course of 38 students and for the various classes there was an average pretest to posttest gain of between 8 and 10 questions out of the 29 questions on the test, both a reasonably large gain in terms of the gross effect, and a statistically significant gain. Since the other two classes had very similar gains and variances, the 12 students in the C group are typical of the students in the whole course in their performance on the FCI. As was shown in the comparisons in research question 2c, this gain of about 30% is a large gain when compared with other students taking more traditional courses.

The five question sub-test of the FCI which was given as part of classroom assessment immediately after the experimental unit shows a substantial average gain of from 1.5 to 1.9 questions from pretest to

immediate posttest, and a much more modest gain of from .2 to 1 question between the immediate posttest and the final examination. Statistically, the significant gain occurs between pretest and immediate posttest, indicating that the major portion of the conceptual change occurred during the instructional unit. The average gain for the 38 students in the course with complete score information is also about a 30% gain.

The long term pretest and posttest results and the immediate posttest gains on the Force Concept Inventory support the hypothesis that this experimental unit is effective in helping students learn Newton's Second law. The pretest scores in comparison with other students argue for the conclusion that this group of students is not very different on these measures from a large number of other high school students. The posttest results, in comparison with those of other students argue for the conclusion that the theory based MBL instruction unit considered in this study is more effective than traditional instruction, and at least as effective as other forms of theory-based or interactive engagement instruction. An important caution in interpreting these results is that they are not the result of fully controlled experimental design. Although the comparison groups serve as a form of control, it is still possible to argue that the difference in results is due to a difference in either the student population, the effect of the teacher, or both.

Research Question 2b

Do changes in student success rates on conceptual measures relate to students' descriptions of their learning activities and conceptual understanding?

The small number of students considered in this question, and the possibility of false low scores on some of the measures derived from the audio tape questionnaires argued for a relatively simplistic analysis technique, which limits the strength of the conclusions that can be drawn. Of the two measures of student learning activities, the score generated from the multiple sources of information derived from data in research question 1b showed the most correlation between low and high scores with the two measures derived from the FCI tests, while the score based on identification of graphing as an effective learning activity showed a greater correlation with the Thornton Force and Motion questions, probably because these questions related more directly to graphs. The correlations are statistically weak (so weak in the pilot analysis that analysis in more depth was rejected), and although they agree more or less with expectations, this is a cautious conclusion.

The relationship between the success rates on tests and the conceptual understanding scores is stronger, and for all three test measures, shows good correlation within the limits of this analysis. The measure of understanding is probably more robust than those for the learning activities and it can be asserted with some confidence that students with high scores on the test measures also show a good conceptual understanding as determined from the audio tape questionnaires. This finding is important, as it lends support to the use of the test measures to determine students' conceptual understanding.

This part of the research question would benefit from replication with larger numbers of students, perhaps limiting the number of questions on the audio-tape questionnaire to focus more tightly on the conceptual

understanding aspects of the question. Another investigation is suggested by the differences between the Force Concept Inventory results and the Thornton Force and Motion question results. As both of these tests are in use in the physics education research community, an investigation into the extent that they correlate, perhaps using factor analysis, might be useful for developing further test measures.

Research Question 2c

What is the comparison between student success rates on conceptual measures of students in this study and the student success rates reported for students in traditional instructional settings and in other theory based instructional settings?

The results of the comparison analyses described in Chapter 4 for this sub-question are important for two reasons. First, they provide further evidence for conclusions about the conceptual change experienced by the particular group of students in this study. Second, they support the argument that this group of students is typical of other high school students taking physics and that conclusions about this group of students might be extended to apply to other students.

The FCI pretest results are the main basis for arguing that this group of students is reasonably comparable to other groups, with the mean pretest score for the 38 students group falling slightly above the mean score (by one question) of the 1078 students for which data was available. A t-test found the difference between the study group and the comparison students on the pretest score was not significant at the 0.10 confidence level.

The FCI posttest and gain score results do show a difference, with the study group having significantly greater posttest and gain scores than

the average for all the groups. When the comparison classes were broken down by teaching method, the study group did notably better than classes taught using traditional instruction and as well as all but the advanced placement and honors classes taught using theory-based MBL methods. When gain scores were compared, the study group had higher gain scores than all but four of the comparison groups, all of which were taught using variations of theory-based MBL instruction.

A detailed comparison of pretest scores was done for the five question sub-test of the FCI used on the immediate posttest for the study group. The pattern of responses and the pretest scores on this sub-test were not significantly different from those of the 612 students in the Arizona regular physics classes (AZ-REG) or from those of the 63 students in the GS-HON groups, but were lower than those of the 118 students in the Arizona Honors classes (AZ-HON) or the 30 students in the MW-HON class. This again supports the assumption that the study group students are comparable to the broad group of high school physics students with the exception of advanced and some honors classes.

The second set of comparisons made used only posttest results on the Thornton Force and Motion test. Three parts of this test were used for comparisons, the velocity and acceleration questions, the force sled questions and the force graph questions. Unfortunately, only a limited amount of comparison data was available, but this data serves to make several useful comparisons.

The velocity and acceleration questions were administered at the end of the kinematics unit and immediately before the force unit which is the focus of this study. The study group students had posttest scores on this

test which were essentially the same as those of a group of Massachusetts high school students in eight different schools who had also learned kinematics by theory-based MBL instruction. This supports the argument that the study group was as well prepared at the end of the kinematics study as other students taking MBL instruction.

There were no high school data available for comparison of the force-sled and force-graph questions, so a comparison was made between the study group and the group of students in an algebra based introductory physics course at the University of Oregon who were given theory-based MBL instruction. Thornton (1995) notes that in a large quantity of data there is no discernible difference in pretest scores between high school students and students in introductory algebra-based physics courses, so it will be assumed that the pretest scores for the study group students would be similar to those for the Oregon students. The force-sled question results and the force-graph question results for both groups are quite similar, with the Oregon students performing slightly better on some of the questions, and about the same on most of the questions. With the exception of the two most difficult questions, (force-sled question 6 and force-graph question 7, (Thornton, 1995)) the Oregon students had pretest error rates of about 70% to 90%, and the study group and Oregon students had posttest error rates of between 5% and 30%, a very large effect. This indicates that this experimental unit is about as effective as the Real-Time Physics unit which was taught to the Oregon students. In strong contrast, an algebra-based class at University of Oregon which received traditional instruction without MBL had pretest and posttest error rates of over 75% on all but one

question. It is assumed that high school classes receiving traditional instruction would have similar results.

Taken together, the Force Concept Inventory and Thornton Force and Motion test results argue for several conclusions:

- 1) That the study group, on the FCI pretest measures, is comparable to other groups of US. high school students taking introductory physics, and is likely to be comparable to other high school students on pretest scores for the Thornton Force and Motion test.
- 2) That the study group, after the theory-based MBL instruction on force, showed significantly better performance on the Force Concept Inventory and the Thornton Force and Motion questions than groups receiving traditional instruction.
- 3) That the study group, after the theory-based MBL instruction on force, performed as well on the Force Concept Inventory and the Thornton Force and Motion questions as other groups receiving other forms of theory based instruction, including theory-based MBL instruction.
- 4) That the differences in pretest and posttest scores are a large effect when compared with traditional lecture instruction.

Conclusions from Research Question 2

This research question addressed two goals of the study, 3) to relate changes in conceptual understanding as seen with pretest and posttest questions to changes seen in student self-report interviews, and 4) to use the pretest and posttest measures to compare the conceptual change and/or final conceptual state of students in this study with data obtained on the same measures for students experiencing other forms of instruction. The results from tests using the Force Concept Inventory and Thornton Force

and Motion questions support the conclusion that this group of students is not very different from other high school students taking physics, that they show a much larger gain in conceptual understanding than students receiving traditional instruction, and have similar gains to other students receiving theory-based MBL instruction. The comparison of the test measures with scores relating to conceptual understanding determined from audio tape questionnaires support the conclusion that the test measures and audio tape scores are reasonably correlated. The comparison of the test measures with scores derived from audio tape information about learning activities support a more cautious conclusion that students who report engagement in learning activities and attention to graphs do somewhat better on the test measures.

The importance of the comparison test data is that 1) it provides a virtual control group of similar students taking traditional instruction, and 2) it allows the argument that the conclusions reached for this group of students may be extended to other groups of high school students taking physics.

3. Effect of Student Learning Beliefs

Research Question 3a

How are motivational and self-regulated learning beliefs of students related to success rates on conceptual measures in the MBL classroom?

Research Question 3b

What effect does theory based MBL instruction have on the motivational and self-regulated learning beliefs of students.

The analysis for these portions of the study was based on the Pintrich and DeGroot study (1990) of the relationship of motivational and learning beliefs of students, as identified by the Motivated Strategies for Learning Questionnaire, to their performance on classroom measures including seatwork, homework and test performance. This study followed part of the methodology of Pintrich and DeGroot, but included only the test scores as performance measures. In addition, in this study an attempt was made to see if there were changes in the motivational or learning beliefs during the first semester of instruction which might be related to the use of theory-based MBL instruction which was the predominant mode of instruction during the first semester. Thus the MSLQ was administered twice, once as a pretest before instruction and once as a posttest after instruction. The analysis for research question 3a followed that used by Pintrich and DeGroot, except that both the pretest and posttest MSLQ scores were available for comparison.

According to the model relating motivation and self-regulated learning employed in the Pintrich and DeGroot study, the motivational variables of self-efficacy and intrinsic value were expected to have positive

correlations with the cognitive variables, and test anxiety was expected to have a negative correlation with the cognitive variables. They found the expected high positive correlations between intrinsic value and self-efficacy with cognitive strategy use and self-regulation, found a non-significant negative correlation between test anxiety and self-regulation and almost no correlation between test anxiety and cognitive strategy use.

On the MSLQ pretest, the 38 students in this study also showed a strong positive correlation between the motivational variables of intrinsic value and self-efficacy and the cognitive variables of cognitive strategy use and self-regulation, but also showed a strong positive correlation between test anxiety and the two cognitive variables.

The posttest results for this study were similar to the pretest results, but the correlations between self-efficacy and cognitive strategy use and between test anxiety and self-regulated learning, while still positive, were not significantly so, at least at the 95% confidence level.

The Pintrich and DeGroot study also looked for the relationship between the motivation and cognitive variables and performance on a variety of classroom measures of performance. Among those measures was performance on tests and quizzes, where all the variables except test anxiety showed significant positive correlations with test and quiz grades. Accordingly, in this study, the correlations between the motivational and cognitive variables and test performance were investigated. In particular, correlations between the FCI final exam score, the FCI gain score, the Thornton immediate posttest questions and the Thornton final exam force-sled questions and the pretest and posttest MSLQ scales were explored. None of the correlations between the test scores and the MSLQ

pretest scales were found to be significant, and several of the correlations were not in the expected direction (See Table 50).

The case is slightly different for the MSLQ posttest scores. Here the FCI final score, the Thornton immediate posttest score and the Thornton final exam score showed a significant positive correlation with self-efficacy, and a moderately strong, but not statistically significant positive correlation with intrinsic value. In addition, two of the three test scores showed a significant correlation with self-regulation. All of the test scores had a negative, but not statistically significant correlation with test anxiety. Although the pattern of correlations is roughly the same as in the Pintrich and DeGroot study, in the absence of larger statistical significance, it is difficult to justify conclusions about the relationship of the MSLQ scales and the performance of students in this study on the conceptual test measures. One difference between the studies which affects determining significance is the number of students involved, 38 in this study versus 173 in the comparison study. It is possible that the kind of test-taking skills needed to succeed in the conceptual, MBL classroom are sufficiently different from those which are probed for in the MSLQ questions that the MSLQ scores are not as good predictors of success. In addition, differences between seventh grade students and eleventh and twelfth grade students may be important.

The final comparison made using the MSLQ scores examined changes in each of the MSLQ scales between the pretest and posttest administration of the questionnaire. Given the more qualitative nature of theory-based MBL learning and less emphasis on the traditional mathematical problem solving style of physics instruction, it was expected

that this course might promote increases in self-efficacy and intrinsic value while reducing test-anxiety. Considering the differences between this instruction and traditional physics lecture and problem-solving work, it was unclear what the effect would be on cognitive strategy use and self-regulated learning. The results showed small but statistically significant increases in self-efficacy and intrinsic value as expected, but also a small but significant increase in test-anxiety. There were no significant changes in cognitive strategy use or in self-regulation. None of the changes were dramatic. It is possible that the increase in test anxiety was due to the difference in timing of the two questionnaire administrations. The first was at the beginning of the semester, before any tests, and when students had just finished the summer vacation, while the second administration was immediately after the midyear examination period when students may have been overloaded with test anxiety.

Conclusions from Research Question 3

Research question 3 was intended to address the last goal of this study, 5) to examine and describe the interaction of students' cognitive beliefs, motivational beliefs, conceptual change and the instructional design. The somewhat equivocal results suggest that it has not successfully done so.

Since the focus of this study is what works in actual classrooms, it is important to consider what are appropriate criteria for deciding whether results should have an effect on practice. Statistical significance by itself may not be sufficient grounds for considering a result to be useful, unless the size of the effect is large enough. In this case, the MSLQ failed to show any gross change between the pretest and posttest administrations. In

addition, the correlations between the MSLQ variables and test performance were relatively small. Given this situation, it is hard to draw conclusions which can guide classroom practice from this portion of the study.

The failure to find any large effects may, of course, be because there are none. It may also be a failure of the experimental design. It might have been better to tie the MSLQ administration more closely to the portion of the course that relied heavily on theory-based MBL, giving the MSLQ pretest a few weeks after the beginning of the semester, and the MSLQ posttest shortly after the immediate posttest for force and motion. This might have reduced any effect that the extra stress of midyear examinations placed on students. On the other hand, there is a limit to how many testing interventions and other data collecting intrusions can be made without interfering with student expectations of what is reasonable classroom operation. In this case, a teacher's judgment of the effect of testing on class morale may interfere with the judgment of what is the best practice for gathering research data—always a problematical aspect of the dual role of the teacher-researcher and classroom research.

Any attempt to replicate this portion of the present study would need to consider more carefully the appropriate timing for use of the MSLQ, and should probably consider a pilot study replicating more closely the Pintrich and DeGroot study with a larger number of high school students before attempting to extend its use to look for changes in motivation and cognitive variables. The different results relating to test anxiety also suggest an investigation comparing students in high pressure schools with those in lower pressure schools to see if the positive

correlation between test anxiety and cognitive strategy use found in this study occurs in other similar situations.

Some Commentary from the Perspective of the Teacher-Researcher

This section contains some comments intended to give some insight into my experience as a teacher and researcher in connection with this study. They are not intended to be exhaustive. Other comments have been made in Chapter 4 and in the rest of this chapter.

1. With the dual perspective of teacher and researcher, I can focus my attention on results that are likely to affect practice, a perspective which is part of the motivation for my research. If a research result is to affect practice, it must have a large enough effect size—make enough difference in what students learn or how efficiently they learn it—for teachers to be willing to invest the time and effort to change their programs.

2. Good curriculum design must be instructionally efficient, and allow teachers to deal with large numbers of students at once. Although there are many things that could be done to probe more deeply into individual student thinking and conceptual change, the techniques used here are practical for investigating the gross effects of a theory-based curriculum design innovation. The results from this level of investigation can be used to influence teaching practice on the one hand, and suggest directions for deeper investigation into learning on the other hand.

3. The teacher-researcher may have an advantage over an outside researcher in interpreting verbal protocols collected from students, through familiarity with the language used by those students. On some occasions a literal interpretation of the words used by students may give a false impression of their understanding. Some students used terms

relatively imprecisely or in idiosyncratic fashion. By listening to their responses in context, and being familiar with their verbal habits from having taught them over an extended period of time, the teacher-researcher can extract meaning from statements that apparently say something different. In this study students frequently used the term "fan cart" to refer to a dynamics cart with or without a fan unit attached, a usage that would have occasioned confusion in interpretation of the statements by an outsider. On the other hand, there can be a danger in too much familiarity, if the teacher-researcher tries to read more into a student's statements than is really there.

4. There is the possibility for conflict between the role of teacher and researcher. As a teacher, I am jealous of classroom time, conscious of students attitudes toward the use of that time, and wish to minimize "non-curricular" demands on that time. This may affect my judgment as a researcher. This research would have been strengthened by having pretest data for the Thornton Force and Motion questions. I elected not to give a pretest in order to reduce the number of pretest interruptions. On the other hand, I could have created a classroom culture in which pretesting was an established feature of the routine.

A second conflict originates in the possibility of "teaching to the test," or in this case, teaching to the interview. I am, after all, interested in having students learn. On the other hand, I am interested in this study in how the students learn from the curriculum unit under investigation. In retrospect, I feel I may have "under taught" the unit during the study compared to my usual approach. The most important answer to this concern would be to replicate the study with other teachers and students,

and to add control groups to the study. A full experimental design is a powerful convincer. It is also expensive in terms of management, time, equipment and the amount of data to be collected and analyzed. This argues for research collaborations growing out of preliminary results from teacher research.

Another conflict lies in the attention demanded from the teacher-researcher. Teaching is already an attention intensive profession, and I found that adding the role of researcher (without cutting back on anything else) was a significant drain on my resources, which may have affected the quality of both my teaching and my research work at the time. Pilot work, a long term series of investigations, and the accumulation of expertise in the joint role of teacher-researcher would address this problem. The quality of teaching and the relevance of educational research to practice might be significantly improved if the role of teacher-researcher became more commonly accepted as part of the normal practice of schools and research organizations.

5. I am convinced by my experience that teacher research can have significant value for curriculum improvement as well as adding to our knowledge base of learning. From the curriculum aspect, the results of this study suggest that theory-based curriculum design can promote effective learning. From the research aspect, the results on the goal and sub-goal focus of students in relation to the design of experiments are very interesting, and suggest further research.

Final Conclusions and the Importance of this Study

This study has demonstrated that an instructional unit for teaching Newton's second law using Microcomputer Based Laboratory instruction as a tool in an instructional design based on a model of students' prior knowledge and learning is an effective method of teaching a set of physics concepts which misconceptions research has indicated is difficult to learn. By investigating students' learning at a moderate level of detail, this study has shown that the students' initial conceptions are consistent with the expectations from past research, that details of the students' conceptual change are consistent with the mechanisms postulated for MBL instruction, and that the use of MBL experiments that rely heavily on real time graphing allows students to focus on the goals of the experiment, rather than being distracted by the processing needed to achieve complicated sub-goals in the traditional sequence of instruction. In the process, data has been gathered that supports what have previously been assertions about the effectiveness of MBL instruction. By comparisons of test measures with conceptual understanding as determined by verbal responses, this study, with some caution, establishes that the test measures chosen are related to the conceptual understanding developed by the students. By comparisons with test scores of other students, this study argues that the students here are typical of other high school students, shows that this instructional approach is more effective than traditional instruction and is as effective as at least some other theory-based approaches to physics instruction in Newton's second law. Except for the one conclusion noted with caution above, all these conclusions are based on large effects.

This study fails to achieve the goal of relating motivational, cognitive and performance measures, or to show that MBL instruction has any significant effect on motivational and cognitive measures as determined by the Motivated Strategies for Learning Questionnaire.

Finally, this study is closely linked to educational practice, using data and techniques which can be readily communicated to other teachers, and relying for its conclusions on effects which represent large changes in student performance. It demonstrates the practicality of classroom based research, and the specific technique of the audio tape questionnaire for gathering large amounts of data at a sufficient level of detail with a relatively small imposition on student time. The conclusions above validate the earlier action research report (Morse, 1992a) and article (Morse, 1993a) on which the research was based, and are already being communicated to other teachers and having an effect on the practice of physics teaching, which was one of the intentions of this research.

Delimitations of the Study

A fundamental limitation of this study is that it is a pre-experimental design, with no control group and without random assignment of students to treatments. In addition, the students are all males, and are students in a selective preparatory school. This limitation is addressed to some extent by the comparison of this student group with others to bolster the assumption that these students are typical of high school students taking introductory physics and that conclusions regarding this group may be extended to other students.

A second limitation is that the teacher is also the researcher, and knows what results are expected from the study. Part of the reason for

choosing the audio-tape questionnaire technique for gathering verbal data is that it at least insulates the students from the teacher during this data gathering phase. It is also essential that the teacher-researcher avoid teaching to the test, but in doing this, the teacher-researcher may choose to interact too little with the students, which may reduce the effect of the instructional technique.

A third limitation is inherent in the audio-tape questionnaire technique, which does not provide for follow-up questions to probe for more detail. The age and verbal experience of the students, sophistication of the subject and the context in which the interviews were conducted may significantly limit the information acquired, and in fact made it difficult to fully address some of the research questions in this study, as noted in detail above. Balancing this limitation, however, is the advantage that the audio tape questionnaire allows the rapid accumulation of selected evidence from a classroom of students with a very small investment of time and effort from each student.

A fourth limitation is that the small number of students in the final analysis pool limits the significance of statistical measures used in conjunction with descriptive measures.

A fifth limitation is that the data collection methods did not allow a continual trace of student thinking during the actual instruction but only sample students thinking immediately after each portion of instruction.

Directions for Future Research

Suggestions for future research have been made throughout this section. Clearly, replication of the first two parts of the study (research questions 1 and 2) by teachers other than this researcher, and in classrooms

which are more typical would be particularly valuable in overcoming some of the limitations of this research, as would be replications which included some in depth interviews of students to further validate the inferences drawn from the audio tape questionnaires. There is room for improvement in the choice and phrasing of the questions for the audio tape questionnaires.

The contrast between the focus on sub-goals in the more standard experiments and the focus on goals in the real time graphing experiments is striking and it would be very interesting to see replications of this portion of the study in the context of other MBL instruction.

Further comparisons of the Force Concept Inventory and the Thornton Force and Motion tests are another direction for research, particularly to establish how well these tests correspond with students verbal reports of their conceptual understanding.

A re-exploration of the data might focus more strongly on the students who did not achieve reasonable mastery of the ideas, looking in particular at differences between students who were high and low achievers on the pretest.

The combination of the advantages of the teacher as researcher and the limitations on the role of teacher-researcher suggest that one role of such work is to identify and try out areas of research that would be fruitful both for improving instruction and improving our understanding of learning. Successful trial efforts could pave the way for larger replications with the cooperation of other teachers and other researchers.

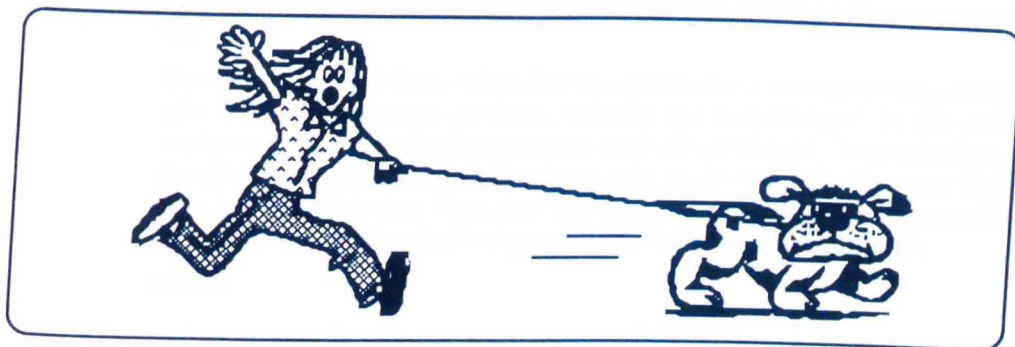
Implications for Instruction

Instructional design which combines a theory based approach, a solid knowledge of the underlying subject matter, and a practical knowledge of actual classroom conditions, and which takes advantage of new technology to reduce the need to focus on sub-goals can be very effective in helping students to learn difficult subject matter in some areas of science. Specifically, this study suggests that appropriate instructional design using Microcomputer Based Laboratory techniques can facilitate students' construction of a conceptual understanding of Newton's second law.

APPENDIX A: Experimental Teaching Unit

This appendix reproduces the teaching unit used in this study. The unit is a somewhat modified version of a Real Time Physics Laboratory written by Sokoloff, Thornton and Laws (1992) and modified by Robert Morse. In the version reproduced here, some blank spaces for student responses have been eliminated. Reproduced by permission.

LAB 4: FORCE AND MOTION



A vulgar Mechanik can practice what he has been taught or seen done, but if he is in an error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest til he gets over every rub.

Isaac Newton (1694)

OBJECTIVES

- To develop the concept of force in terms of how it is measured
- To understand the relationship between the force applied to a spring and its extension
- To learn how to use a spring scale to measure force
- To learn how to use a force probe to measure force
- To understand the relationship between forces applied to an object and its motions
- To find a mathematical relationship between the force applied to an object and its acceleration

OVERVIEW

In the previous labs, you have used a motion detector to display position-time, velocity-time and acceleration-time graphs of the motion of different objects. You were not concerned about how you got the objects to move, i.e. what forces (pushes or pulls) acted on the objects. From your experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must

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Real Time Physics: Lab 4: Force and Motion V1.11P--6/21/93
Authors: David Sokoloff , Ronald Thornton & Priscilla Laws (modified by R A. Morse)

step on the gas pedal to get the engine to apply a force to the road through the tires.

But, exactly how is force related to the quantities you used in the previous unit to describe motion--position, velocity and acceleration? In this unit you will pay attention to forces and how they affect motion. You will first develop an operational idea of a force as a push or a pull. You will learn how to measure forces. Then you will apply forces to a cart, and observe the nature of its resulting motion graphically with a motion detector.

Notes:

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Supported by National Science Foundation, U.S. Dept. of Education (FIPSE)

Modifications supported by St. Albans School

LAB 4: INVESTIGATION 1: MEASURING FORCES

In this investigation you will explore the concept of a constant force and the combination of forces in one dimension. You can use these concepts to learn how to measure forces with a force probe. You will need the following materials:

- MacMotion software (PC-Motion)
- force probe
- Universal Laboratory Interface (ULI)
- rubber bands
- coil spring
- spring scale

Note: Unless there is a motion detector plugged into Port 2, you should choose **Force Only Data** on the Collect menu in the MacMotion software.

Activity 1-1: How Large is a Pull?

If you pull on a rubber band attached at one end, you know it will stretch. The more you pull, the more it stretches. Try it.



1. Attach one end of the rubber band to something that can't move. Now stretch the rubber band so it is several centimeters longer than its relaxed length. Does it always seem to exert the same pull on you each time it is stretched to the *same* length? (Most people agree that this is obvious.)
2. Write down the length you have chosen in the space below. This will be your *standard length* for future measurements.
 Length of rubber band = ____ cm
3. Attach the ends of two identical rubber bands to something, and stretch them to the same length as above. How does the combined force of two rubber bands compare to what you felt when only one rubber band was used? Repeat this comparison of how strong the forces feel with three, four and five rubber bands.

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 Authors: David Sokoloff , Ronald Thornton & Priscilla Laws (modified by R A. Morse)

Question 1-1: Suppose you stretched a rubber band by pulling on it. Now you want to create a force ten times as large. How could you assure that you are being pulled with such a force?

Question 1-2: Suppose you applied a force with a stretched rubber band one day, and several days later you wanted to feel the same force or apply it to something. How could you assure that the forces were the same? Explain.

Question 1-3: Do rubber bands provide a convenient way of accurately reproducing forces of different sizes? Explain.

Activity 1-2 Constructing a Continuous Force Scale

To be more precise about the pulls and pushes you are applying, you need to construct a *continuous* force scale. Using rubber bands stretched a standard length, you can only reproduce forces which match an exact number of rubber band pulls. In this activity you will use forces measured by integer numbers of bands stretched a standard length to establish a continuous force scale for a coil spring.

1. Connect one end of a coil spring to something which can't move, and connect one rubber band to the other end. Tape a piece of paper to the table under the spring. With a pencil, mark the position of the end of the spring with no force applied to it.
2. Stretch the rubber band to the standard length. Mark the position of the end of the spring and label the mark "1." Hook a second band to the spring and stretch the two bands to the standard length. Mark the position of the end of the spring and label it "2."
3. Continue the process until you have a record of the extension of the spring with 5 rubber band forces applied.
4. With a ruler, measure the extension of the spring from its initial length (with no force applied) for each of the five applied forces, and record your results in the table on the top of the next page.

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Number of rubber bands	0	1	2	3	4	5
Spring extension						

Question 1-4: Does the extension of the spring increase as the applied force increases? Does the extension increase the same amount for each rubber band unit of force increase?

Question 1-5: If you were told the extension of the spring, could you estimate the amount of force in terms of your standard rubber band force units? Explain.

- To better see the relationship between applied force and extension of the spring it is useful to plot a graph. To do this open the *MacMotion* software, and load the experiment called **Lab 4 Force and Extension of a Spring**.
- Enter the data from your table for the extension of the spring corresponding to each force in rubber band units. To do this, double click with the mouse pointing to the first box in the **Spring Extension** column, and enter the first value. The return key will then move you down the column.
 The data will be plotted as you enter them. You may wish to change the graph axes when you are done to better display the data.
- We are interested in the nature of the mathematical relationship between force (in rubber band units) and the extension of the spring. This can be determined from the graph by drawing a smooth curve which fits the plotted data points. Some definitions of possible mathematical relationships are shown in the sketches on the top of the next page.
 In these examples, y might be the force in rubber bands and x the extension of the spring.

Note that these *are not all the same*. Y can increase as x increases, and the relationship doesn't have to be *linear* or *proportional*.

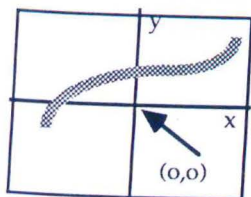
Proportionality refers only to the special linear relationship where the y -intercept is zero, as shown in the example on the right.

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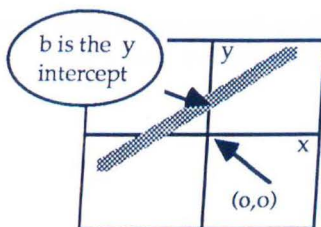
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Supported by National Science Foundation, U.S. Dept. of Education (FIPSE)

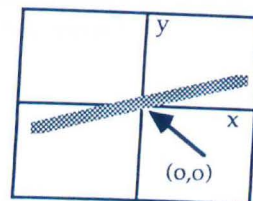
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y is a function of x which increases as x increases



y is a *linear* function of x which increases as x increases according to the mathematical relationship $y = mx + b$ where $b = \text{const.}$



y is *proportional* to x . This is a special case of a linear relationship where $y = mx$, ie. $b=0$

MacMotion allows you to determine the relationship by trying various curves to see which best fits the plotted data. To fit the data on your graph of rubber band forces vs. spring extension, select **Fit...** from the Analyze menu. To try a linear fit, select **Linear** $y = b_0 + b_1 \cdot x$ and then press **Try Fit**.

When you have found a good fit, where the curve goes through or close to all of the data points, print the graph along with the fit equation, and affix it to this report.

Question 1-6: How are the applied force and extension of the spring related? Write down the equation you found and describe the mathematical relationship in words.

Question 1-7: Based on your graph, what spring extension corresponds to a pull of one rubber band unit? How did you determine this?

Question 1-8: Based on your graph, how many rubber band units would it take to stretch your spring one centimeter? Ten centimeters? How did you determine this?

If your spring were large enough to do so without breaking, how many rubber band pulls would it take to stretch your spring one meter?

Comment: The behavior of springs of many kinds was studied by Robert Hooke, a contemporary of Newton. The simple relationship you have just found was also found by Hooke and is called Hooke's law. This is your first example of a *Force Law*, a mathematical description that enables you to describe the behavior of a particular kind of force. The *ratio of force applied to the spring to the resulting extension of the spring* is called the *force constant* or stiffness of the spring, and is usually expressed as the amount of force required for each meter of spring extension.

Question 1-9: What is the force constant of your spring in rubber band units for each meter? How did you find this?

Since a spring extends in a simple linear way as more force is applied to it, it makes sense to use a spring as a new, more convenient standard for measuring force. A spring scale is a spring which has been carefully calibrated to read in standard force units called Newtons.

To get a sense of the size of one Newton of force, take a spring scale and pull on it until it reads 1.0 N. How does this compare to your earlier force standard of one rubber band pull? Stretch a rubber band to your standard length by pulling it with the spring scale. Record your result.

One rubber band pull = _____N

LABORATORY 4 : INVESTIGATION 1

Activity 1-3: Measuring Forces with a Force Probe

With the spring scale, you now have a device to measure forces accurately. Is there a way to measure forces accurately using the computer? Let's explore the utility of the force probe to do this.

1. Set up the force probe by plugging it into Port 1 of the ULI. Turn on the ULI, and open the *MacMotion* software. When the axes appear on the screen, display force by placing the mouse pointer over the distance label, holding down the mouse button, pulling down the menu and pointing to **Force**.
2. Since forces are detected by the MBL system as *changes* in an electronic signal, it is important to have the computer "read" the signal when the force probe has no force pushing or pulling on it. This process is called "zeroing".

Zero the force probe by clicking on the **Zero** button in the lower right-hand corner of the screen while there is nothing pushing or pulling on the hook.

Comment: The electronic signal from the force probe can change slightly as the temperature changes. Thus, it is always a good idea to *zero the force probe (with nothing pushing or pulling it) right before taking measurements.*

3. Attach one end of a 10 Newton spring scale to something which can't move, and the other end to the force probe hook. Pull horizontally on the spring scale with the force probe until the scale reads 1.0 N and **Start** graphing while holding the probe steady for the remainder of the graphing time.

Record a typical force probe reading:

(Use **Analyze Data A** on the Analyze menu to get a precise reading of the force.)

4. You have seen before that pulling the spring scale to a larger extension requires a larger pull. Now you can compare how the force probe readings are related to the spring scale readings.

Although you could continue to take data with spring scale pulls in the same way you did with 1.0 N, the easiest way to take these data is to load the experiment **Lab4 Spring Scale Pulls**. This experiment sets the software in "Event Mode" and allows you to plot the probe force reading against the spring scale force.

After loading, **Zero** the force probe and press **Start**. A **Keep** button will appear and a point representing the force probe reading will be

displayed on the graph above
value on the graph.

0 Newtons. Press **Keep** to record this

The point will then be displayed above 2.0 Newton. Pull the scale with the force probe until it reads 2.0 N, and again press **Keep** to record the value on the graph. Repeat with 4.0, 6.0, 8.0 and then 10.0 Newtons, and then press **Stop**.

5. Record the typical force probe reading for each number of Newtons in the table below (you may use **Analyze** or look at the **Data A Table** window to see the values).

Spring scale reading (N)	0.0	2.0	4.0	6.0	8.0	10.0
Force probe reading (?)						

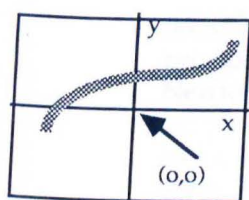
6. We are interested in the mathematical relationship between force probe reading and the force measured by the standard spring scale. To fit the data on your graph of force probe reading vs. spring scale reading, proceed as before.

BEFORE: We are interested in the nature of the mathematical relationship between force (in rubber band units) and the extension of the spring. This can be determined from the graph by drawing a smooth curve which fits the plotted data points. Some definitions of possible mathematical relationships are shown in the sketches on the top of the next page.

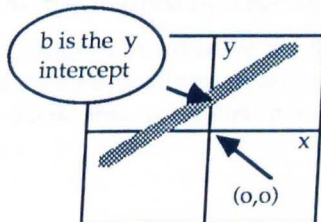
In these examples, y might be the force in rubber bands and x the extension of the spring.

Note that these *are not all the same*. Y can increase as x increases, and the relationship doesn't have to be *linear* or *proportional*.

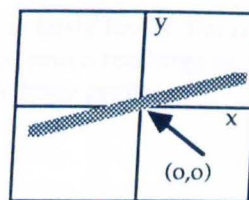
Proportionality refers only to the special linear relationship where the y -intercept is zero, as shown in the example on the right.



y is a function of x which increases as x increases



y is a *linear* function of x which increases as x increases according to the mathematical relationship $y = mx + b$ where $b = \text{const.}$



y is *proportional* to x . This is a special case of a linear relationship where $y = mx$, ie. $b=0$

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MacMotion allows you to determine the relationship by trying various curves to see which best fits the plotted data. To fit the data on your graph of rubber band forces vs. spring extension, select **Fit . . .** from the Analyze menu. To try a linear fit, select **Linear** $y = b_0 + b_1x$ and then press **Try Fit**.

(Select **Fit . . .** from the Analyze menu. To try a linear fit, select **Linear** $y = b_0 + b_1x$ and then press **Try Fit**.)

When you have found a good fit, print the graph along with the fit equation, and affix it to this report.

Question 1-10 How are force probe readings related to the size of the pull exerted by the spring scale? Write down the equation you found and describe the mathematical relationship in words.

Question 1-11: Based on your graph, what force probe reading corresponds to a pull of 1.00 N? To a pull of 5.00 N?

Comment: You now have a graph that relates two different ways of measuring force, one with a standard spring scale, and the other with a force probe. Such a graph is called a *calibration curve* and is used to compare measurements of quantities made with two different measuring instruments. You could use it to convert forces measured in force probe units to standard units of force established by a spring scale.

Since your calibration curve for the force probe is fairly linear, the computer provides a method to automatically convert force probe readings to Newtons. To do this, you must first calibrate the force probe.

LABORATORY 4: INVESTIGATION ONE, CONTINUED

Activity 1-4: Calibrating the Force Probe

1. To calibrate the force probe, select **Calibrate Force** from the **Collect** menu. Hold the force probe still with no force applied to the hook and **Zero** the probe. When the computer asks you to apply a force, pull on the hook with a spring scale holding a steady reading on the scale, for example, 5.0 N. Enter this value in the space, continue to hold a steady reading, and press **return**. The computer will adjust the readings on the Force axis. When the calibration is complete, you may release the spring scale.
2. **Zero** the force probe, **Start** recording data, and pull on the force probe with the spring scale with several different forces. Record the spring scale and force probe readings in the table below.

Spring scale reading (N)						
Force probe reading (N)						

Question 1-12: Do your force probe readings correspond to your spring scale readings? Can you use the force probe to make reasonably accurate force measurements?

Activity 1-5: Measuring Head and Tail pulls

The force probes you have been using are equipped with a "tail hook" that allows you to pull on the force probe in either direction. In this activity you will look at the effect of combining pulls in two directions.

Set up the force probe so that it is clamped to the lab table and the hooks on both ends are free of any forces. Zero the probe. Use a 20 N spring scale to carry out a calibration with 10 N of force pulling on the "head" end of the probe. (Note: Although the force probe is fairly accurate in measuring pulls when calibrated for pulls and pushes when calibrated for pushes, there are still some accuracy problems with measuring pushes when calibrated for pulls and vice-versa. Thus the measurements in this exercise will only be approximately correct. (extra project: make a complete calibration curve for head and tail pulls.)

Now take two 5 N spring scales, and set one to pull on each end of the Force Probe. Have the head end of the probe to the right. Set the time scale to 10 seconds.

Predict what the force probe will read for the following combinations of forces, then test your predictions using the probe. Estimated readings from the graph scale will be accurate enough for this measurement. Record your results to only 1 significant digit. **Remember to zero your probe before each measurement.**

1. 2 N pull on the right hand scale and 0 N pull on the left hand scale.

Prediction:

Measurement:

2. 4 N pull on the right hand scale and 2 N pull on the left hand scale.

Prediction:

Measurement:

3. 5 N pull on the right hand scale and 3 N pull on the left hand scale.

Prediction:

Measurement:

4. 3 N pull on the right hand scale and 3 N pull on the left hand scale.

Prediction:

Measurement:

5. 3 N pull on the right hand scale and 5 N pull on the left hand scale.

Prediction:

Measurement:

Question 1-13. How do the forces combine to give the reading on the Force probe? How can you distinguish a pull to the left from a pull to the right?

Question 1-14. What additional pull would you have to apply to the force probe to achieve each of the following probe readings?

A probe reading of 0 N with a right hand pull of 4 N. Additional pull =

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A probe reading of -3 N with a right hand pull of 2 N. Additional pull =

A probe reading of 2 N with a right hand pull of 3 N. Additional pull =

A probe reading of -2 N with a left hand pull of 4 N. Additional pull =

A probe reading of 1 N with a left hand pull of 2.5 N. Additional pull =

Question 1-15. When more than one force acts on the Force probe, how can you determine the reading of the probe?

Question 1-16. Can you tell from a list of probe readings alone how many forces were acting on it?

Question 1-17. What information do you need to know about the forces applied to a force probe to predict their effect on the reading of the force probe?

Comment. You may know the distinction between "gross income" and "net income." When forces combine in one dimension it is common to use a similar terminology to refer to the result of applying more than one force as the "net Force." In these experiments we will more frequently use the term "combination of forces" or "combined force" as these terms are a better reminder of what "net force" means. Symbolically, we can represent the combination of forces applied to an object by using the notation " ΣF " to mean the algebraic sum or combination of the forces. Σ is the capitol greek letter "sigma" and is used in mathematics to mean "sum of."

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LAB ORATORY 4 : INVESTIGATION 2: MOTION AND FORCE

Now you can use the force probe to apply measured amounts of force to an object. You can also use the motion detector, as in the previous three units, to examine the motion of the object. In this way you will be able to establish the relationship between motion and force.

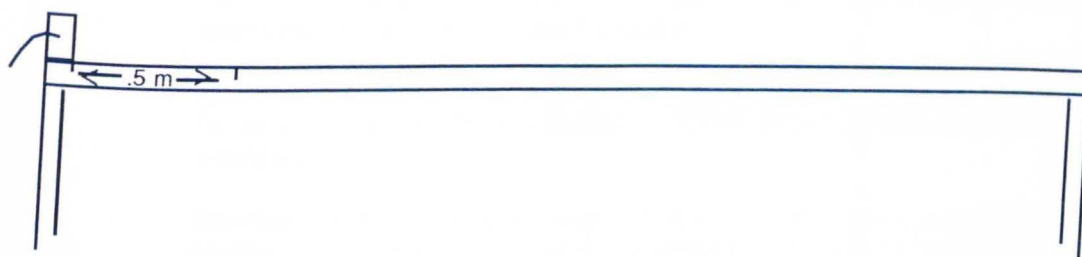
You will need the following materials:

- MacMotion software (PC-Motion)
- Force probe with tail hook attachment
- Motion detector
- Universal Laboratory Interface (ULI)
- Spring scale
- Cart or toy car with very little friction
- Ramp or a smooth board or table top about 2-3 meters long
- springs, rubber bands and strings

Activity 2-1: Force and motion experiment

In this activity you will design an experiment in your class to determine the effect of the combination of forces applied to a cart on the motion of the cart. You will be able to look for relationships between the applied force and the motion quantities, to see which is (are) related to force, and how they are related to force.

1. Briefly describe the experiment your class designs. Include a sketch of the set-up on the diagram below. Set up the experiment, making sure that the force probe and motion detector are properly connected. (Be sure that the cable from the force probe will not be seen by the motion detector.)



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Prediction 2-1: Before you carry out your experiment, do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force, i.e. if you apply a changing force to the cart, will the velocity or acceleration change in the same way as the force?

2. Prepare to test your predictions. First set up the various graph axes you will need, and select **All Graphs Live** from the menu. Use a time scale of about 5 sec. Calibrate the force probe using a 5.0 N pull from a spring scale if you haven't already done this in Activity 1-4. **Zero** the force probe before each run of your experiment. During your experiment *be sure that the cart never gets closer than 0.5 m away from the detector.*
3. Run your experiment, watching the graphs as they are made. Compare the graphs.

Question 2-1: What graphs are similar? What graphs are different? What does this tell you about the relation between the combination of forces and the different motion quantities?

4. Print your graphs and attach them to this report

Question 2-2: Does either graph--velocity or acceleration--resemble the force graph? Which one? Explain.

Question 2-3: Do a detailed comparison of your graphs. Look at the force graph when it has a maximum positive value, a zero value and a maximum negative value. What are the corresponding values of the acceleration graph? the velocity graph?

Question 2-4: Based on your observations, does it appear that either the velocity or acceleration of the cart might be closely related to the applied force? Explain.

5. Repeat your experiment with the cart but this time make a single graph of acceleration versus force. Watch carefully as the graph is being made. When you have a good graph print a copy or sketch a copy and attach it .

Question 2-5: Explain the shape of the graph. What does this tell you about the relation between the combination of forces acting on the cart and the acceleration?

6. Repeat the experiment making a graph of velocity versus force. Watch carefully as the graph is being made. When you have a good graph print a copy or sketch a copy and attach it below.

Question 2-6: Explain the shape of the graph. What does this tell you about the relation between the combination of forces acting on the cart and the acceleration?

Question 2-7: From the force versus velocity and force versus acceleration graphs, does velocity or acceleration most closely match the behavior of the force? How do you know?

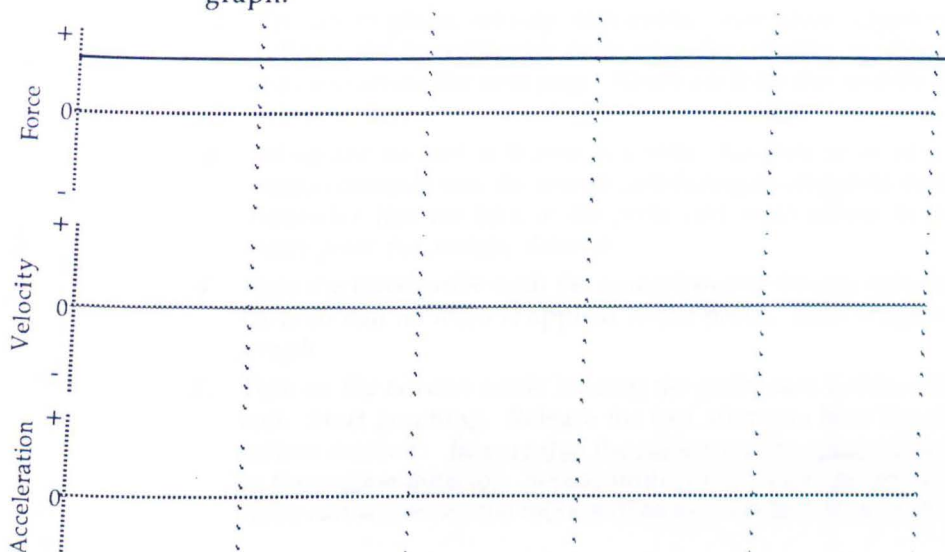
LABORATORY 4 INVESTIGATION TWO :PART TWO

Activity 2-2: Speeding Up

You have seen in the previous activity that force and acceleration seem to be related in an experiment with a varying force. What do you expect would happen if you pull a cart with a constant force?

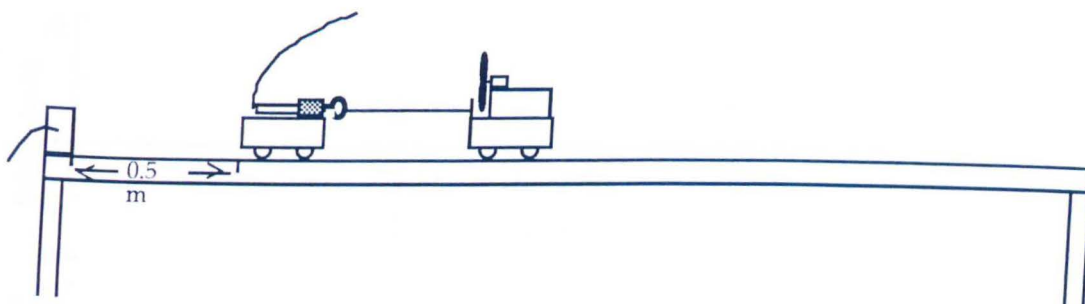
Prediction 2-2: Suppose you have a cart with very little friction. You pull the cart with a constant force.

Sketch on the axes below the velocity-time and acceleration-time graphs of the cart. The cart is pulled with the force which is shown on the force-time graph.



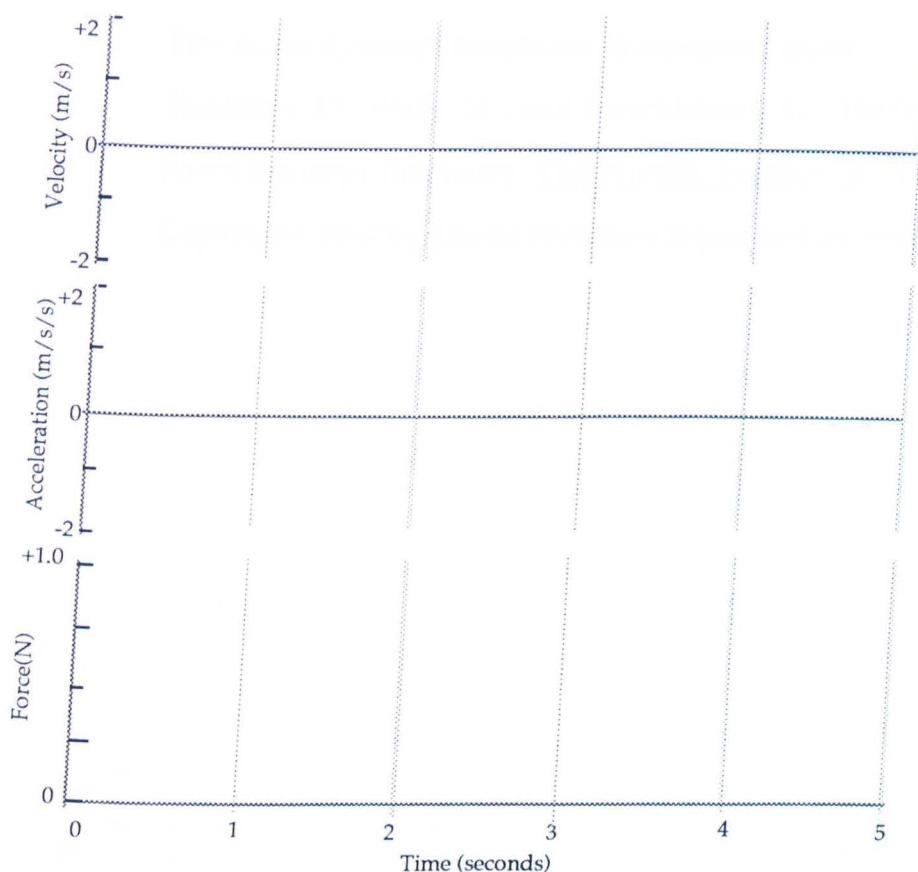
Describe in words the velocity and acceleration of the cart.

1. Test your predictions. Set up the ramp, fan cart, probe cart, string, motion detector and force probe as shown below.



Be sure that the friction is minimum for both carts. (If either cart has a friction pad, it should be raised so it doesn't contact the ramp.)

2. Prepare to graph velocity, acceleration and force. Open the experiment called **Lab4 Speeding Up** to display the velocity, acceleration and force axes shown on the next page. Single click on the velocity graph to graph velocity first.
3. Set up the fan cart with four AA cells. Also test to be sure that the motion detector sees the towed cart during its complete motion. *Remember that the back of the probe cart must always be at least 0.5 meter from the motion detector.*
4. **Zero** the force probe with the string hanging loosely between the two carts so that no force is applied to the probe. Zero it again *before each graph*.
5. Turn on the fan cart while holding the probe cart. Let the string become taut. **Start graphing.** Release the cart after you hear the clicks of the motion detector. Be sure that the cable from the force probe is not seen by the motion detector. Repeat until you get good graphs in which the probe cart is seen by the motion detector over its whole motion.



6. If necessary, adjust the axes to display the graphs more clearly. Sketch the actual velocity, acceleration and force graphs on the axes above, or print the graphs and affix them over the axes. Draw smooth graphs; don't worry about small bumps.

Questions 2-8 Is the force which is applied to the probe cart by the fan cart constant, increasing or decreasing? Explain based on your graph.

Question 2-9 How does the acceleration graph vary in time? Does this agree with your prediction? What kind of acceleration corresponds to a constant applied force?

Question 2-10: How does the velocity graph vary in time? Does this agree with your prediction? What kind of velocity corresponds to a constant applied force?

APPENDIX B: Force Concept Inventory

The Force Concept Inventory is reprinted from

Hestenes, D., Wells, M., and Swackhamer, G. (1992)

Force Concept Inventory. The Physics Teacher, 30, 154-158.

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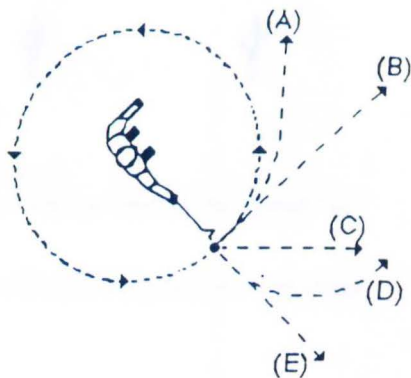
Force Concept Inventory

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
 - (A) about half as long for the heavier ball.
 - (B) about half as long for the lighter ball.
 - (C) about the same time for both balls.
 - (D) considerably less for the heavier ball, but not necessarily half as long.
 - (E) considerably less for the lighter ball, but not necessarily half as long.

2. Imagine a head-on collision between a large truck and a small compact car. During the collision,
 - (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
 - (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
 - (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
 - (D) the truck exerts a force on the car but the car doesn't exert a force on the truck.
 - (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

3. Two steel balls, one of which weighs twice as much as the other, roll off of a horizontal table with the same speeds. In this situation:
 - (A) both balls impact the floor at approximately the same horizontal distance from the base of the table.
 - (B) the heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
 - (C) the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
 - (D) the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
 - (E) the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.

4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram to the right. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.

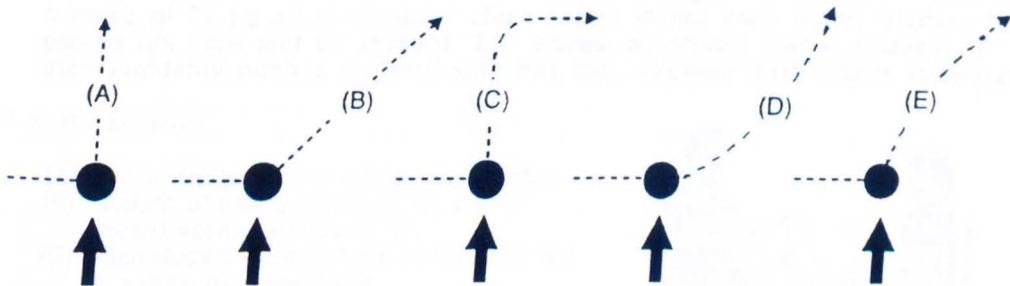


5. A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):
- (A) its weight vertically downward along with a steadily decreasing upward force.
 - (B) a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
 - (C) a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.
 - (D) a constant downward force of gravity only.
 - (E) none of the above, the ball falls back down to the earth simply because that is its natural action.

- Use the statement and diagram below to answer the next four questions:
- The diagram depicts a hockey puck sliding, with a constant velocity, from point "a" to point "b" along a frictionless horizontal surface. When the puck reaches point "b", it receives an instantaneous horizontal "kick" in the direction of the heavy print arrow.



6. Along which of the paths below will the hockey puck move after receiving the "kick" ?



7. The speed of the puck just after it receives the "kick"?

- (A) Equal to the speed " v_0 " it had before it received the "kick".
- (B) Equal to the speed " v " it acquires from the "kick", and independent of the speed " v_0 ".
- (C) Equal to the arithmetic sum of speeds " v_0 " and " v ".
- (D) Smaller than either of speeds " v_0 " or " v ".
- (E) Greater than either of speeds " v_0 " or " v ", but smaller than the arithmetic sum of these two speeds.

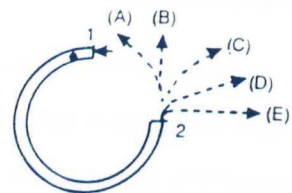
8. Along the frictionless path you have chosen, now does the speed of the puck vary after receiving the "kick"?

- (A) No change.
- (B) Continuously increasing.
- (C) Continuously decreasing.
- (D) Increasing for a while, and decreasing thereafter.
- (E) Constant for a while, and decreasing thereafter.

9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

- (A) the downward force due to gravity and the effect of air pressure.
- (B) the downward force of gravity and the horizontal force of momentum in the direction of motion.
- (C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck in the direction of motion.
- (D) the downward force of gravity and an upward force exerted on the puck by the table.
- (E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at "1" and exits at "2". Which of the path representations would most nearly correspond to the path of the ball as it exits the channel at "2" and rolls across the table top.



11. Two students, student "a" who has a mass of 95 kg and student "b" who has a mass of 77 kg sit in identical office chairs facing each other. Student "a" places his bare feet on student "b's" knees, as shown below. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

In this situation,

- (A) neither student exerts a force on the other.
- (B) student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
- (C) each student exerts a force on the other but "b" exerts the larger force.
- (D) each student exerts a force on the other but "a" exerts the larger force.
- (E) each student exerts the same amount of force on the other.



12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

1. A downward force due to gravity.
2. The upward force by the table.
3. A net downward force due to air pressure.
4. A net upward force due to air pressure.

- (A) 1 only
 (B) 1 and 2
 (C) 1, 2, and 3
 (D) 1, 2, and 4

(E) none of these, since the book is at rest there are no forces acting on it.

* Refer to the following statement and diagram while answering the next two questions.

A large truck breaks down out on the road and receives a push back into town by a small compact car.



13. While the car, still pushing the truck, is speeding up to get up to cruising speed;

- (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
 (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
 (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
 (D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
 (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

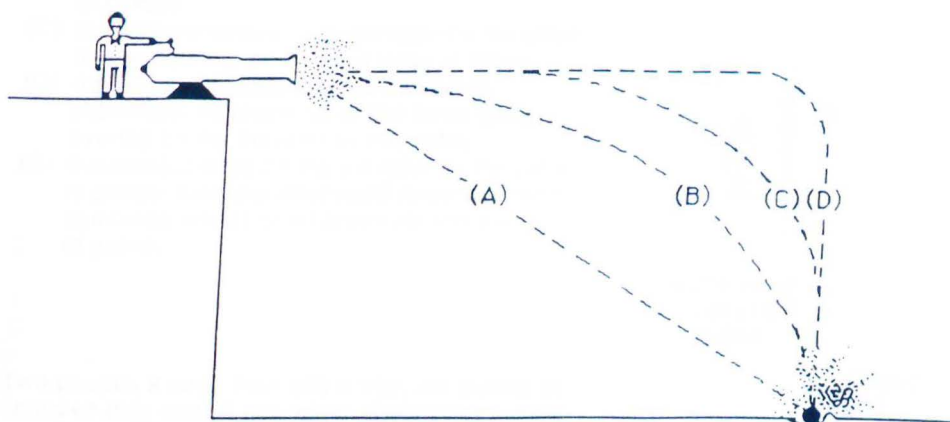
14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed;

- (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
 (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
 (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
 (D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
 (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because;

(A) energy of the ball is conserved.
 (B) momentum of the ball is conserved.
 (C) the floor exerts a force on the ball that stops its fall and then drives it upward.
 (D) the floor is in the way and the ball has to keep moving.
 (E) none of the above.

16. Which of the paths in the diagram to the right best represents the path of the cannon ball?



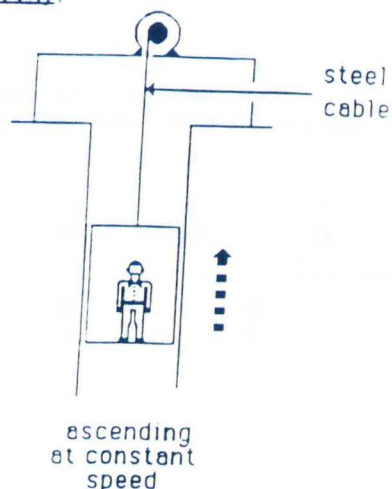
17. A stone falling from the roof of a single story building to the surface of the earth;

(A) reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
 (B) speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
 (C) speeds up because of the constant gravitational force acting on it.
 (D) falls because of the intrinsic tendency of all objects to fall toward the earth.
 (E) falls because of a combination of the force of gravity and the air pressure pushing it downward.

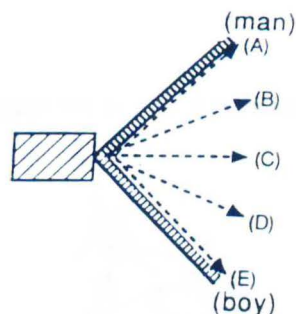
- * When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at a constant velocity:

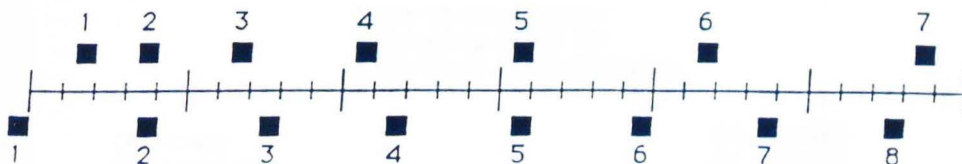
- (A) the upward force on the elevator by the cable is greater than the downward force of gravity.
- (B) the amount of upward force on the elevator by the cables equal to that of the downward force of gravity
- (C) the upward force on the elevator by the cable is less than the downward force of gravity.
- (D) it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
- (E) the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



19. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as illustrated in the diagram to the right. Which of the indicated paths (A-E) would most likely correspond to the path of the crate as they pull it along?



- * The positions of two blocks at successive 0.20 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.

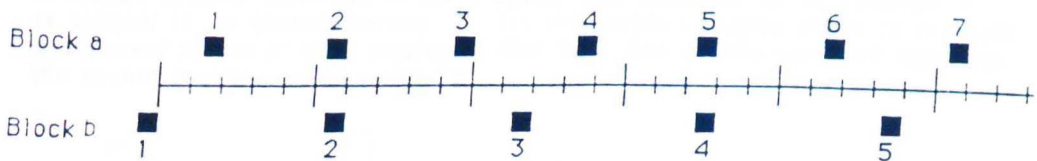


(continued on the next page)

20. Do the blocks ever have the same speed?

- (A) No
- (B) Yes, at instant 2.
- (C) Yes, at instant 5.
- (D) Yes, at instant 2 and 5.
- (E) Yes, at some time during interval 3 to 4.

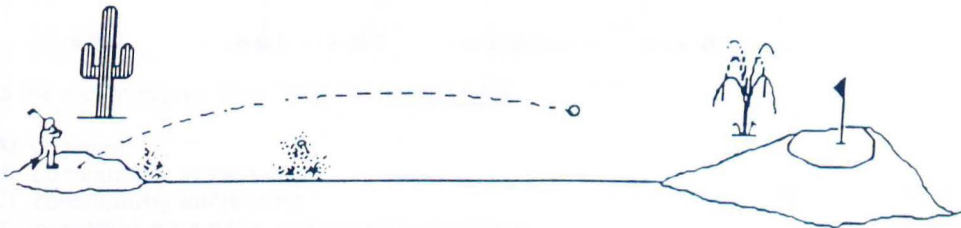
* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



21. The acceleration of the blocks are related as follows:

- (A) acceleration of "a" > acceleration of "b"
- (B) acceleration of "a" = acceleration "b" > 0
- (C) acceleration of "b" > acceleration "a"
- (D) acceleration of "a" = acceleration of "b" = 0
- (E) not enough information to answer.

22. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.



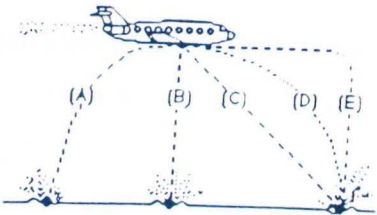
Which following force(s) is(are) acting on the golf ball during its entire flight?

1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

- (A) 1 only
- (B) 1 and 2
- (C) 1, 2, and 3

- (D) 1 and 3
- (E) 2 and 3

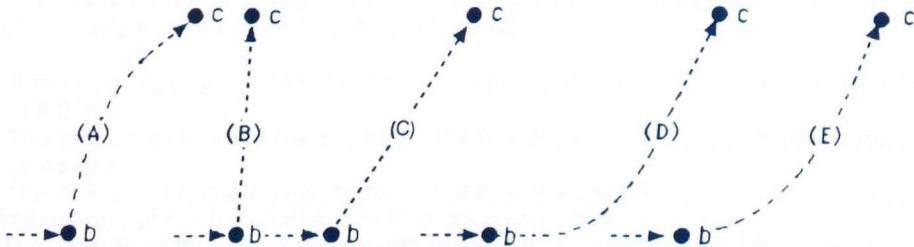
23. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground, which path would the bowling ball most closely follow after leaving the airplane?



- When answering the next four questions, refer to the following statement and diagram.
- A rocket, drifting sideways in outer space from position "a" to position "b", is subject to no outside forces. At "b", the rocket's engine starts to produce a constant thrust at right angles to line "ab". The engine turns off again as the rocket reaches some point "c".



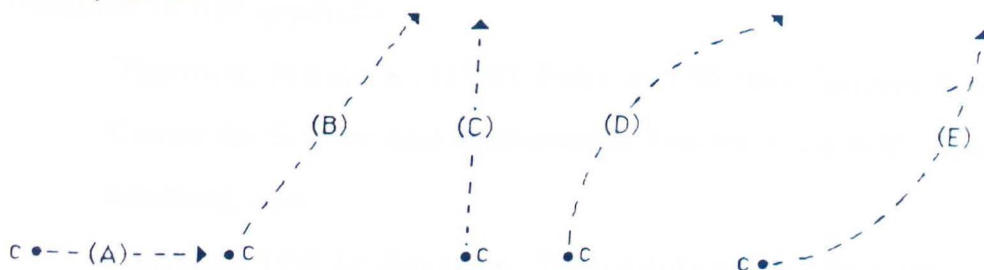
24. Which path below best represents the path of the rocket between "b" and "c"?



25. As the rocket moves from "b" to "c", its speed is

- (A) constant.
- (B) continuously increasing.
- (C) continuously decreasing.
- (D) increasing for a while and constant thereafter.
- (E) constant for a while and decreasing thereafter.

26. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?



27. Beyond "c", the speed of the rocket is;
- constant.
 - continuously increasing.
 - continuously decreasing.
 - increasing for a while and constant thereafter.
 - constant for a while and decreasing thereafter.
28. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box
- If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
 - The amount of force applied to move the box at a constant speed must be more than its weight.
 - The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
 - The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
 - There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces they just resist motion.
29. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will;
- stop immediately.
 - continue at a constant speed for a very short period of time and then slow to a stop.
 - immediately start slowing to a stop.
 - continue at a constant velocity.
 - increase its speed for a very short period of time, then start slowing to a stop.

APPENDIX C: Thornton Force And Motion Test

Question 1-21 from the Force and Motion Concept Test are reprinted in this appendix.

Thornton, Ronald K., (1992), Force and Motion Concept Test, Center for Science and Mathematics Teaching, Tufts Univesity, Medford, MA.

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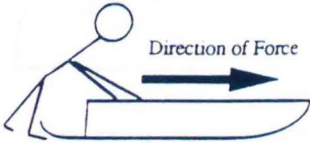
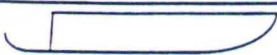
QUESTIONS ON FORCE AND MOTION

Directions: Answer questions 1-45 in spaces on the answer sheet.

Answer questions 34 and 35 also on the answer sheet.

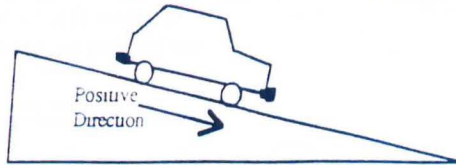
A sled on ice moves in the ways described in questions 1-7 below. Friction is so small that it can be ignored. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would keep the sled moving as described in each statement below.

You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice J.

	A. The force is toward the right and is increasing in strength (magnitude). B. The force is toward the right and is of constant strength (magnitude). C. The force is toward the right and is decreasing in strength (magnitude).
	D. No applied force is needed
	E. The force is toward the left and is decreasing in strength (magnitude). F. The force is toward the left and is of constant strength (magnitude). G. The force is toward the left and is increasing in strength (magnitude).

- _____ 1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?
- _____ 2. Which force would keep the sled the sled moving toward the right at a steady (constant) velocity?
- _____ 3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
- _____ 4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
- _____ 5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?
- _____ 6. The sled is slowing down at a steady rate and has an acceleration in the positive direction. (The positive direction is to the right.) Which force would account for this motion?
- _____ 7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

Questions 8-10 refer to a toy car which is given a push up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again.



Use one of the following choices (A through C) to indicate the net force acting on the car for each of the cases described below. Answer choice J if you think that none is correct.

(A) Net force down ramp



(B) Net force zero



(C) Net force up ramp



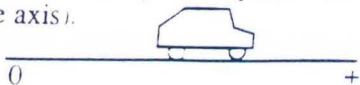
- ____ 8. The car is moving up the ramp after it is released.
 ____ 9. The car is at its highest point.
 ____ 10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through C) to indicate the force acting on the coin for each of the cases described below. Answer choice J if you think that none is correct.

- A. The force is downward.
 B. The force is zero.
 C. The force is upward.

- ____ 11. The coin is moving upward after it is released.
 ____ 12. The coin is at its highest point.
 ____ 13. The coin is moving downward.

Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).

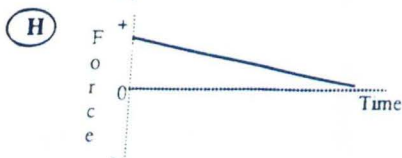
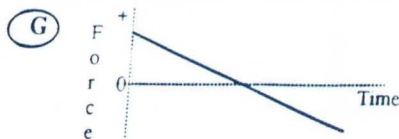
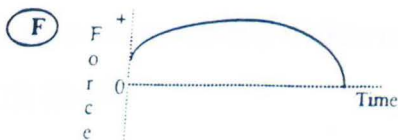
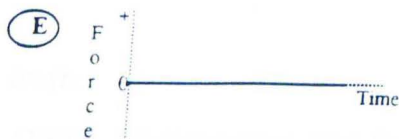
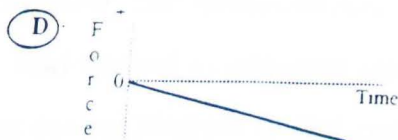
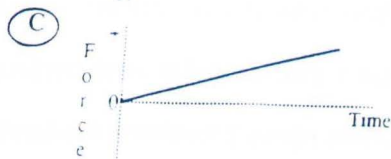
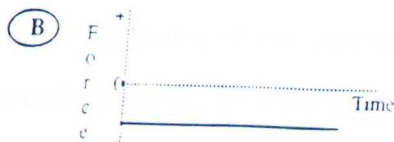
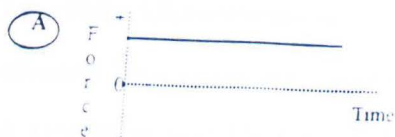


Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (A through H) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice J.

- ___ 14. The car moves toward the right (away from the origin) with a steady (constant) velocity.
- ___ 15. The car is at rest.
- ___ 16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).
- ___ 17. The car moves toward the left (toward the origin) with a steady (constant) velocity.
- ___ 18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).
- ___ 19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).
- ___ 20. The car moves toward the right, speeds up and then slows down.
- ___ 21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.



(J) None of these graphs is correct.

APPENDIX D: Motivated Strategies for Learning Questionnaire

Motivated Strategies for Learning Questionnaire

This appendix contains the Motivated Strategies for Learning Questionnaire designed by Pintrich et al. (Pintrich and De Groot, 1990). The questionnaire was taken by students at the beginning of the course, before any MBL based instruction and was administered again after instruction was complete to assess changes in students' motivational and self-regulated learning beliefs. The questionnaire was administered so that the teacher was blind to the identity of individual student's responses until after the instructional sequence was complete. The questionnaire is shown in two forms, first as given to students, and second as grouped into the five motivational and self-regulated learning scales.(Pintrich & DeGroot, 1990)

The questions below are taken from:

Pintrich, P. R., & DeGroot, E.V. (1990). Motivational and Self-Regulated Learning Components of Classroom Academic Performance. Journal of Educational Psychology, 82,(1), 33-40.

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Questionnaire as given to students.

Learning Questionnaire for Physics teaching research study.

The following questionnaire will help me understand how you think about learning and about this course, to help me with my research project. This will have no effect upon your grade in the Physics course. When you are done with the questionnaire, please write your name on it and turn it in.

Answer the questions on the basis of your experience in this physics course. Please be very honest in your responses, as that will help me to improve the way we teach physics.

Please answer the questions on a 7 point scale, by circling the answer that best describes how true the statement is about you, where 1= not at all true of me and 7 = very true of me. Thus if you felt that a statement was only slightly true of you, you would choose 2. If you were not sure whether a statement was true of you or not, or if you thought it was true of you about half of the time, you would choose 4.

Not at all true of me								very true of me
	1	2	3	4	5	6	7	

(In the questionnaire, the scale above was reprinted for each question.)

NOTE: you will find that some question numbers are missing. These questions were selected from a larger survey, and have their original numbers for my convenience. Thank you for your help.

- 1. I prefer class work that is challenging so I can learn new things.
- 2. Compared with other students in this class I expect to do well.
- 3. I am so nervous during a test that I cannot remember facts I have learned.
- 5. It is important for me to learn what is being taught in this class.

6. I like what I am learning in this class.
7. I'm certain I can understand the ideas taught in this course.
9. I think I will be able to use what I learn in this class in other classes.
10. I expect to do very well in this class.
11. Compared with others in this class, I think I'm a good student.
12. I often choose paper topics I will learn something from even if they require more work.
13. I am sure I can do an excellent job on the problems and tasks assigned for this class.
14. I have an uneasy, upset feeling when I take a test.
15. I think I will receive a good grade in this class.
17. Even when I do poorly on a test I try to learn from my mistakes.
18. I think that what I am learning in this class is useful for me to know.
20. My study skills are excellent compared with others in this class.
21. I think that what we are learning in this class is interesting.
22. Compared with other students in this class I think I know a great deal about the subject.
23. I know that I will be able to learn the material for this class.
24. I worry a great deal about tests.
25. Understanding this subject is important to me.
27. when I take a test I think about how poorly I am doing.
30. When I study for a test, I try to put together the information from class and from the book.
31. when I do homework, I try to remember what the teacher said in class so I can answer the questions correctly.
32. I ask myself questions to make sure I know the material I have been studying.
33. It is hard for me to decide what the main ideas are in what I read.
34. When work is hard I either give up or study only the easy parts.
35. when I study I put important ideas into my own words.

36. I always try to understand what the teacher is saying even if it doesn't make sense.
38. When I study for a test I try to remember as many facts as I can.
39. When studying , I copy my notes over to help me remember material.
40. I work on practice exercises and answer end of the chapter questions even when I don't have to.
41. Even when study materials are dull and uninteresting, I keep working until I finish.
42. When I study for a test I practice saying the important facts over and over to myself.
43. Before I begin studying I think about the things I will need to do to learn.
44. I use what I have learned from old homework assignments and the textbook to do new assignments.
45. I often find that I have been reading for class but don't know what it is all about.
46. I find that when the teacher is talking I think of other things and don't really listen to what is being said.
47. When I am studying a topic, I try to make everything fit together.
52. When I'm reading I stop once in a while and go over what I have read.
53. When I read material for this class, I say the words over and over to myself to help me remember.
54. I outline the chapters in my book to help me study.
55. I work hard to get a good grade even when I don't like a class.
56. When reading I try to connect the things I am reading about with what I already know.

Questionnaire items grouped by scales.

Motivational beliefs

A. Self-Efficacy

2. Compared with other students in this class I expect to do well.
7. I'm certain I can understand the ideas taught in this course.
10. I expect to do very well in this class.
11. Compared with others in this class, I think I'm a good student.
13. I am sure I can do an excellent job on the problems and tasks assigned for this class.
15. I think I will receive a good grade in this class.
20. My study skills are excellent compared with others in this class.
22. Compared with other students in this class I think I know a great deal about the subject.
23. I know that I will be able to learn the material for this class.

B. Intrinsic Value

1. I prefer class work that is challenging so I can learn new things.
5. It is important for me to learn what is being taught in this class.
6. I like what I am learning in this class.
9. I think I will be able to use what I learn in this class in other classes.
12. I often choose paper topics I will learn something from even if they require more work.
17. Even when I do poorly on a test I try to learn from my mistakes.
18. I think that what I am learning in this class is useful for me to know.
21. I think that what we are learning in this class is interesting.
25. Understanding this subject is important to me.

C. Test Anxiety

3. I am so nervous during a test that I cannot remember facts I have learned.
14. I have an uneasy, upset feeling when I take a test.
24. I worry a great deal about tests.
27. when I take a test I think about how poorly I am doing.

Self-Regulated Learning Strategies

D. Cognitive Strategy Use

30. When I study for a test, I try to put together the information from class and from the book.
31. when I do homework, I try to remember what the teacher said in class so I can answer the questions correctly.
33. It is hard for me to decide what the main ideas are in what I read.
35. when I study I put important ideas into my own words.
36. I always try to understand what the teacher is saying even if it doesn't make sense.
38. When I study for a test I try to remember as many facts as I can.
39. When studying , I copy my notes over to help me remember material.
42. When I study for a test I practice saying the important facts over and over to myself.
44. I use what I have learned from old homework assignments and the textbook to do new assignments.
47. When I am studying a topic, I try to make everything fit together.
53. When I read material for this class, I say the words over and over to myself to help me remember.
54. I outline the chapters in my book to help me study.
56. When reading I try to connect the things I am reading about with what I already know.

E. Self-Regulation

32. I ask myself questions to make sure I know the material I have been studying.
34. When work is hard I either give up or study only the easy parts.
40. I work on practice exercises and answer end of the chapter questions even when I don't have to.
41. Even when study materials are dull and uninteresting, I keep working until I finish.
43. Before I begin studying I think about the things I will need to do to learn.
45. I often find that I have been reading for class but don't know what it is all about.
46. I find that when the teacher is talking I think of other things and don't really listen to what is being said.
52. When I'm reading I stop once in a while and go over what I have read.
55. I work hard to get a good grade even when I don't like a class.

APPENDIX E: Tape Interview Questions

This appendix contains the questions used in the tape interviews for each day. The first question each day asked the student to give his name, the period and the day (1 through 7).

The questions are numbered by day and question number, thus Q103 is Question 3 on day 1.

Questions Day 1

Q102 From your previous studies and knowledge, when you think of the word “force”, what thoughts come to mind? What does the word “force” usually mean to you?

Q103 What effect do you think a force or forces would have on the motion of an object? Give an example to illustrate your ideas.

Q104 Briefly describe what you did in the lab today, including the measurements you made.

Q105 What do you think was the main learning purpose or goal of the lab work today?

Q106 Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

Q107 What did you learn about the physicist’s meaning of force today, in particular what did you learn that was new to you , and what did you learn that confirmed or extended things you already knew?

Q108 Did you learn anything today that surprised you?

Q109 What parts of today’s lab work do you think were most effective or helpful to you in learning about force?

Questions Day 2

Q202 Describe what you believe would be the force or forces needed to have an object move with a steady speed.....to move with an increasing speed. Give any examples you can think of.

Q203 Suppose you arranged to apply a steady force to an object, how do you think it would move? give any examples you can think of.

Q204 Briefly describe what you did in the lab today, including the measurements you made.

Q205 What do you think was the main learning purpose or goal of the lab work today?

Q206 Sketch the graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

Q207 When you think about the word "Force" in physics, what thoughts come to mind? What does the word "Force" mean to you?

Q208 What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q209 Did you learn anything today that surprised you? What was the most memorable thing you saw or learned about in the lab today?

Q210 What parts of today's lab work do you think were most effective or helpful to you in learning about force?

Questions Day 3

Q302 Briefly describe what you did in the lab today, including measurements you made.

Q303 What do you think was the main learning purpose or goal of the lab work today?

Q304 Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

Q305 What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q306 What properties of a spring do you think make a spring scale a good standard of force? What is the evidence for your answer?

Q307 Suppose you had two 10 N spring scales and wanted to apply an 18 N force to another object. Describe how you could use the scales to be sure you were applying an 18 N force.

Q308 Compare the spring scale and force probe-what would be the advantages and disadvantages of using each device to measure force?

Q309 What was the most memorable thing you saw or learned about in the lab today?

Q310 What parts of today's lab work do you think were most effective or helpful to you in learning about force?

Questions Day 4

Q402 Briefly describe what you did in the lab today, including measurements you made.

Q403 What do you think was the main learning purpose or goal of the lab work today?

Q404 Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

Q405 What did you learn about force and combining forces today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q406 What is the effect of combining two forces in opposite directions on the reading on a force probe? What do you expect would be the effect of combining two forces in the same direction?

Q407 What parts of today's lab work do you think were most effective or helpful to you in learning about force?

Questions Day 5

Q502 Briefly describe what you did in lab today, including the measurements you made.

Q503 What do you think was the main learning purpose or goal of the lab work today?,

Q504 Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab,

Q505 Which of the graphs you made were most closely related to each other?

Q506 What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q507 On the basis of what you learned today, how would you describe the effect of forces on an object on the motion of that object?

Q508 Did you learn anything today that was unexpected or that surprised you? Did you see anything that contradicted what you would have predicted to happen.

Q509 What was the most memorable thing you saw or learned about in the lab today?

Q510 What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

Questions Day 6

Q602 Briefly describe what you did in lab today, including the measurements you made.

Q603 What do you think was the main learning purpose or goal of the lab work today?

Q604 Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

Q605 What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q606 From your work in the last few days, which of the motion variables is most directly affected by the forces acting on an object? What is the evidence for your answer?

describe the experiment that most clearly showed the relationship of forces to acceleration and velocity.

Q607 Did you learn anything today that was unexpected or that surprised you? What was the most memorable thing you saw or learned about in the lab today?

Q608 What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

Q609 Suppose an object were acted on by a steady force. What do you think the acceleration of the object would be like? Sketch an acceleration-time graph.

What do you think the velocity of the object would do? sketch a velocity-time graph.

Q610 What is the effect of adding more “stuff” to a moving object when the same combination of forces act on it?

Questions Day 7

Q702 Briefly describe what you did in lab today, including the measurements you made.

Q703 What do you think was the main learning purpose or goal of the lab work today?

Q704 Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

Q705 What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

Q706 From your work in the last few days, which of the motion variable is most directly affected by the forces acting on an object? What is the evidence for your answer?

Q707 What happens to the acceleration of a cart when the same forces are used but more “stuff” is added to the cart?

Q708 When a constant force is applied to a cart, describe what happens to the velocity and the acceleration of the cart.

Q709 Suppose a steadily increasing force were applied to the cart, what do you think would happen to the velocity and the acceleration?

Q710 What parts of today’s lab work do you think were most effective or helpful to you in learning about force and motion?

APPENDIX F: Sample Transcripts

This section includes two complete transcripts, one for student 309 and one for student 315. Both the questions and the responses are given for each student, but only the responses are numbered.

Transcript for student 309

From your previous studies and knowledge, when you think of the word "force", what thoughts come to mind? What does the word "force" usually mean to you?

A102: I guess the word force, force what does force mean. force iswhat gets me to school every morning. I never really think about the word because it's kind of a useless word. but it says it's something that I'd say moves something. (slightly supercilious tone in these answers).

What effect do you think a force or forces would have on the motion of an object? Give an example to illustrate your ideas.

A103: I think that forces can severely affect the motion of an object, either creating motion or stopping, altering it. like if you kick a ball, your foot imparts a force to the ball and the ball goes in that direction.

Briefly describe what you did in the lab today, including the measurements you made.

A104: Today in the lab we analyzed the stretch of different amounts of rubber bands, establishing a standard and then adding on multiple like rubber bands to see what difference it would make.

What do you think was the main learning purpose or goal of the lab work today?

A105: The main purpose of the lab work today was to get us used to measuring force by using graphs and paper

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A106: Well, we didn't get the chance to make any graphs today, I'm sure they'll be very useful

What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A107: My meaning of force was not severely altered as I had some small understanding of it anyway.

Did you learn anything today that surprised you?

A108: No, I didn't learn anything today that surprised me.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A109:

Describe what you believe would be the force or forces needed to have an object move with a steady speed.....to move with an increasing speed. Give any examples you can think of.

A202: (in exaggerated tone of voice) To move with a steady speed I think an object would have to have a force acting on it that is a constant force, not changing. to move with an increasing speed you would need an ever harder force. for example to go at a constant speed in your car, you press the gas down a given way and that gives a given force to this car. to increase, you keep pressing down and you increase your force by pressing down on the gas pedal, and well in a magic carpet, you have to signal the carpet to increase speed and then it increases the force acting upon it.

Suppose you arranged to apply a steady force to an object, how do you think it would move? give any examples you can think of.

A203: Actually, I arrange to apply a steady force to an object every day when I drive to school, and my car moves with a steady, constant velocity. when I wish to slow down, I apply the brake and that is applying a force in the opposite direction. when I wish to accelerate, I press the accelerator and that is applying a force, is increasing the force in the given direction.

Briefly describe what you did in the lab today, including the measurements you made.

A204: Actually we made no measurements today. Today we made a graph relating force of the rubber band force and extension of the spring. then we had to , using our graph and our equations that we used to derive the graph, we had to uh , hypothesize what different extensions, uh how many rubber bands it would take to give the spring a given extension.

What do you think was the main learning purpose or goal of the lab work today?

A205: The main purpose of the lab was to learn how force relates to the extension of the spring, using standard rubber band units.

Sketch the graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A206: The graph related to the purpose of the lab as it was the graph of the equation that relates force in rubber band units to extension of the spring in centimeters.

When you think about the word “Force” in physics, what thoughts come to mind? What does the word “Force” mean to you?

A207: When I think about the word force in physics, I think about power acting on an object. to me force means the all embodying invisible energy that flows through all things and can be used to do work through the harnessing it with the mind...

What did you learn about the physicist’s meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A208: ...and I really didn’t learn anything new today, just analyzed old data. Did you learn anything today that surprised you? What was the most memorable thing you saw or learned about in the lab today?

A209: I didn’t learn anything that surprised me, either. What parts of today’s lab work do you think were most effective or helpful to you in learning about force?

A210: As always, I like the graph the most, although the equation was the most useful for answering questions.

Briefly describe what you did in the lab today, including measurements you made.

A302:

What do you think was the main learning purpose or goal of the lab work today?

A303: I think the main purpose of the lab work today was to find out, whatever the unit the force probe uses on the computer, find out how many Newtons its equal to, so that we could use it in other experiments.

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A304: The graph that we made in the lab today clearly shows the relationship to the unit the computer uses and the Newton.

What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A305: What I learned about the physicist's meaning of force today was mainly the unit that they use to describe it, the Newton. and I discovered that the Newton is actually a very weak force. you know, many people don't know this but its actually named after Sir Isaac Newton and it was discovered when he bought a standard box of rubber bands and decided that one rubber band's standard length should be a Newton.

What properties of a spring do you think make a spring scale a good standard of force?

What is the evidence for your answer?

A306: I think the fact that a spring can be stretched, and has the same tension in it over and over again, can be stretched to that same tension without losing it, makes a spring scale a good standard for force. the evidence for my answer is that we actually had to do the lab twice, because we messed up the first time, not recording a zero Newton, and we discovered that the line was the same both times, meaning that the spring was pulled to the same length, the same tension, both times.

Suppose you had two 10 N spring scales and wanted to apply an 18 N force to another object.

Describe how you could use the scales to be sure you were applying an 18 N force.

A307: Well, you could hook them both up to the object and then pull them until they both register 9 Newtons of force then you could be sure you were applying a total of 18 Newtons of force to the object.

Compare the spring scale and force probe-what would be the advantages and disadvantages of using each device to measure force?

A308: Well, the advantage of using a force probe instead of just a spring scale was because the force probe can put it right into the computer whereas the spring scale you have to have a human element, which can occasionally make mistakes.

What was the most memorable thing you saw or learned about in the lab today?

A309: Again, as always I like.....the graphs. its that simple presentation of data that conveys so much, surely, a genius invention.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A310:

Briefly describe what you did in the lab today, including measurements you made.

A402: Today we learned how to calibrate the force probe, we also we looked at opposing..how opposing forces will affect the total force.

What do you think was the main learning purpose or goal of the lab work today?

A403: I think this was to teach us how to calibrate a probe and also how the effects of the opposite forces.

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A404: The first graph we made was just another graph like yesterday where we pull one Newton and then two Newtons and then three Newtons and then we'd fit the information. the other three graphs were all ...(inaudible.). graphs where we'd have 5 Newtons on one side, 2 Newtons on the other and things like that. they all averaged out to 2 though.

What did you learn about force and combining forces today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A405: I kind of already knew that opposing forces would uh subtract from each other and so that really didn't confirm or extend..it kind of confirmed it I guess, it didn't really extend anything I knew.

What is the effect of combining two forces in opposite directions on the reading on a force probe? What do you expect would be the effect of combining two forces in the same direction?

A406: The effect of combining two forces in opposite directions is that they're opposite to each other, so you take one force and subtract the other force from it, and that's your total force. and then uh, if it's negative its in the force..it's in the direction of the force ..it's a net force in the direction of the force that you subtracted and if it's positive, then it's a net force in the force.. in the one that you added. the effect of combining two forces in the same direction would be to add, you'd have to add the two forces and that would be the total force in that direction that they were pulling.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A407: As always I like the graphs. because they're so pretty.

Briefly describe what you did in lab today, including the measurements you made.

A502: In the lab today, we played with rubber bands and springs. making the carts go back and forth, back and forth, back and forth. well we took an analysis of them through the force probes and also through a motion detector so that we could look at the relationships between velocity, acceleration and force.

What do you think was the main learning purpose or goal of the lab work today?,

A503: I think the main purpose of the lab work today was to uh to look at the uh relationship between force and acceleration and force and velocity.

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab,

A504: The graphs that describe the relationship ...uh ...inaudible...

Which of the graphs you made were most closely related to each other?

A505: The graphs of force and time and acceleration and time were the most closely related to each other.

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A506: I wouldn't have thought that force and acceleration were similar, I would have thought that force and velocity but , I was wrong! it's the first time, I don't think I'll do it again.

On the basis of what you learned today, how would you describe the effect of forces on an object on the motion of that object?

A507: I would say that forces affect the acceleration of an object, which then affects the velocity.

Did you learn anything today that was unexpected or that surprised you? Did you see anything that contradicted what you would have predicted to happen.

A508: The thing that contradicted what I expected, I would suspect force and velocity to be similar but it wasn't , it was force and acceleration which was new and contradicted things that I thought I would have known.

What was the most memorable thing you saw or learned about in the lab today?

A509: The acceleration force graphs and the velocity force graphs were the most memorable thing I saw or learned today...

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A510: ... and the graphs again were the most helpful part in learning about force and motion.

Briefly describe what you did in lab today, including the measurements you made.

A602: Today we looked at how uh how force responds, how a constant force affects acceleration and velocity.

What do you think was the main learning purpose or goal of the lab work today?

A603: I think it was the main purpose and learning purpose of this goal was to learn how constant force affects velocity and acceleration.

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

A604: The graphs we used in the lab today are the graphs of velocity time, acceleration time and force and time and they show, they illustrate for us how acceleration and velocity respond to a constant force...

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A605: ... and I confirmed, what I already knew , was that constant force produced constant acceleration and steadily increasing velocity which would correspond to the constant acceleration.

From your work in the last few days, which of the motion variables is most directly affected by the forces acting on an object? What is the evidence for your answer?

describe the experiment that most clearly showed the relationship of forces to acceleration and velocity.

A606: I'd say acceleration is most directly affected by forces acting on an object. my evidence is the apparent similarity between force graphs and acceleration graphs. I would say that the experiment in which we had the uh cart go back and and, where we applied a force to it and let it go back and forth, working off the force, that one showed me, because the graphs, the acceleration and force graphs were almost identical with just some small variations.

Did you learn anything today that was unexpected or that surprised you? What was the most memorable thing you saw or learned about in the lab today?

A607:

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A608: Again I think the graphs were the most effective and helpful in helping me learn about force, acceleration and velocity.

Suppose an object were acted on by a steady force. What do you think the acceleration of the object would be like? Sketch an acceleration-time graph.

What do you think the velocity of the object would do? sketch a velocity-time graph.

A609: I think a steady force would produce a steady acceleration or a constant acceleration. I think the velocity of the object would go up steadily and constantly just like the uh the uh acceleration graph would predict.

What is the effect of adding more "stuff" to a moving object when the same combination of forces act on it?

A610: The effect of adding more stuff to a moving object when the combination of forces is the same is to reduce the acceleration.

Briefly describe what you did in lab today, including the measurements you made.

A702: Since I finished the lab yesterday, I didn't do anything in the lab today. What do you think was the main learning purpose or goal of the lab work today?

A703:

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

A704:

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A705:

From your work in the last few days, which of the motion variable is most directly affected by the forces acting on an object? What is the evidence for your answer?

A706: Acceleration is most directly affected by the forces acting on an object. my evidence for this is that their graphs are the most similar.

What happens to the acceleration of a cart when the same forces are used but more "stuff" is added to the cart?

A707: The acceleration of the cart decreases when the same forces are used but more stuff is added.

When a constant force is applied to a cart, describe what happens to the velocity and the acceleration of the cart.

A708: When a constant force is applied to a cart, the velocity steadily increases and the acceleration is constant.

Suppose a steadily increasing force were applied to the cart, what do you think would happen to the velocity and the acceleration?

A709: If a steadily increasing force were applied to a cart, you get steadily increasing acceleration and you get velocity increasing in a curved pattern I guess, I'd hypothesize a parabolic.

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A710: Again I didn't do the lab today, so I couldn't tell you which were helpful, but traditionally I found the graphs to be the most helpful.

Transcript for student 315

From your previous studies and knowledge, when you think of the word "force", what thoughts come to mind? What does the word "force" usually mean to you?

A102: From previous studies and knowledge, I generally think of the word force to mean the pressure that is exerted from a certain object as a result of uh energy from something else.

What effect do you think a force or forces would have on the motion of an object? Give an example to illustrate your ideas.

A103: And forces have the the effect on the other object. the force given to a certain object is the same as the energy given out by one object.

Briefly describe what you did in the lab today, including the measurements you made.

A104: Today in the lab we determined what the standard , for our rubber band length would be and then using that standard, determined how much the uh the spring would extend using certain, using different numbers of rub..integer numbers of rubber bands and extending them to the same length every time, which was 8 cm.

What do you think was the main learning purpose or goal of the lab work today?

A105: The main learning purpose or goal of the lab today was to become more familiar with how certain forces act on other things, what you know , when different forces are given.

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A106: We didn't get to any graphs today, we'll do that in day 2 .

What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you , and what did you learn that confirmed or extended things you already knew?

A107: Um the physics..today we learned that the physicist's meaning of force is not only just the pressure that's exerted, but...uh.. we learned today that...the number of rubber bands will increase the amount of force given on a certain thing. that confirmed knowledge that I already had before class.

Did you learn anything today that surprised you?

A108:

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A109: And to see that..we saw that easily by putting different numbers of rubber bands on the spring and measuring out to the eight cm and that was very helpful in in seeing the different amount of force for each number of rubber bands and how it increased when the number of rubber bands increased.

Describe what you believe would be the force or forces needed to have an object move with a steady speed.....to move with an increasing speed. Give any examples you can think of.

A202: Today we learned about forces and how they act on different objects and we did the graphing of these of these forces as opposed to uh in relation to a spring and rubber bands. um.

Suppose you arranged to apply a steady force to an object, how do you think it would move? give any examples you can think of.

A203: Um for an object to move at a steady speed it would have to have a steady force behind it, either pulling it or pushing it, and an increasing force would result in an increasing speed. to have a steady force of an object, it would obviously move at a steady speed, such as holding down the accelerator of a car with the same force would have the car move at the same speed, you know saying that it was on flat ground.

Briefly describe what you did in the lab today, including the measurements you made.

A204: Today in the lab we plotted our points on the graph in MacMotion and came up with a graph and then came up with an equation for the graph which was $y = .13x$ with the y intercept being zero.

What do you think was the main learning purpose or goal of the lab work today?

A205: The main learning purpose of the work today was uh to see that , that all of the.. that as the number of rubber bands go up it steadily increases the force applied to the spring.

Sketch the graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A206: The graphs that we made was a straight line graph of the form $y = mx + b$, and it went through the origin of the graph at 0,0.

When you think about the word "Force" in physics, what thoughts come to mind? What does the word "Force" mean to you?

A207: When I think about the word force in physics it means the energy applied or the pressure applied to a certain thing to make it move or stop moving for that matter, depending on which way the uh the force is acted on.

What did you learn about the physicist's meaning of force today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A208: Today we learned that force is proportional as whatever is applying the force is increased proportionally . um that confirmed what I already knew. we saw

that in day one of the lab and saw that again today by graphing it and seeing that it was a straight line graph.

Did you learn anything today that surprised you? What was the most memorable thing you saw or learned about in the lab today?

A209: Nothing, nothing seemed to surprise me in today's work, but uh um the parts that were most effective were plottin.. entering the points into the computer program and seeing it graph a straight line and then seeing the graph printed. um it was effective and helped me to see the proportion..the proportional um force to uh to spring extension. then because it was a straight line it was easier to see that it is proportional.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A210:

Briefly describe what you did in the lab today, including measurements you made.

A302: Um in the lab today we used the force probe in exercise 3 of the lab to see how ,
how Newtons of force can be can be graphed in comparison to the uh the spring
units and the uh spring scale that we had.

What do you think was the main learning purpose or goal of the lab work today?

A303:

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate
to the purpose of the lab.

A304: The graph that we came up with was a linear graph of $y = 25.175 x$. um the
graph that we had was obviously a linear graph that shows proportional uh
proportional relationship between the force and the spring scale.

What did you learn about the physicist's meaning of force today, in particular what did you
learn that was new to you, and what did you learn that confirmed or extended things you
already knew?

A305: Today I learned that the physicist's meaning of force is in units called
Newtons. the most common unit of force, but yet the physicists meaning of force
compared to any other meaning of force is still a little bit confusing to me.

What properties of a spring do you think make a spring scale a good standard of force?

What is the evidence for your answer?

A306: The properties of a spring that make a spring scale a good standard of force ,
one is that uh the more force you exert on a spring, the more force it will exert
back on whatever is giving it the force, and so that helped us use it because we
hooked the spring scale to uh the spring scale to the force probe and could judge
with Newtons how many what effect it had on the force probe.

Suppose you had two 10 N spring scales and wanted to apply an 18 N force to another object.

Describe how you could use the scales to be sure you were applying an 18 N force.

A307: Um we had two 10 Newton spring scales and wanted to apply 18 Newtons of
force, we'd do one uh pull all the way to 10 Newtons and one to 8 Newtons and
that would make, and adding the two would make a force of 18 Newtons.

Compare the spring scale and force probe-what would be the advantages and disadvantages
of using each device to measure force?

A308: For the force probe, uh the advantage of using the spring scale over the force
probe is that you can measure exactly in Newtons, while the force probe doesn't
.. it measures just a .. suppose it uses a question mark for units of force, so you can
relate them to each other, you can't relate it to Newtons.

What was the most memorable thing you saw or learned about in the lab today?

A309: The most memorable thing I saw was the spring scale and how we used the force probe and the spring scale together to uh get the linear graph.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A310: Seeing the linear graph and the proportional relationship helped ...was the most helpful thing to me.

Briefly describe what you did in the lab today, including measurements you made.

A402: Um in the lab today we first calibrated the force probe and then we observed what certain forces would be when two forces are acting on the probe, one a positive force and one a negative force.

What do you think was the main learning purpose or goal of the lab work today?

A403: The main learning purpose for this was to first uh understand how to calibrate the force probe, which was a very quick exercise, and then in activity 1-4 or 1-5 I'm sorry, to uh to uh see how two forces acting on a probe, when they were combined together what, what the end ..end force would be on ..on a graph. we did this using the computer of course.

Sketch any graphs you made in the lab today, and describe how the graph or graphs relate to the purpose of the lab.

A404:

What did you learn about force and combining forces today, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A405: We learned that combining.. when you combine forces that one force is a negative force, today it was a force to the left and one force, the positive force and when they're combined, you add the two together and whatever you're..the sum of the two is , is the final force. Uh we ..that .. by seeing it on the graph , it uh it confirmed what we what we thought would happen. all of our predictions were correct.

What is the effect of combining two forces in opposite directions on the reading on a force probe? What do you expect would be the effect of combining two forces in the same direction?

A406: The effect of combining two forces in opposite direction is they uh .. one is negative and one is positive, so they they contradict each other so that if there's a force to the left in the the negative direction of 5 and a force to the right of 6 u it being uh you combine the two, 5 plus a negative oh 6 plus a negative 5 um would be a force of uh a combined force of 1 . if two forces were pulling in the same direction you would just add the two both being positive..in the positive direction.

What parts of today's lab work do you think were most effective or helpful to you in learning about force?

A407: Seeing thisfirst doing it...making predictions and then seeing it on the graph is the was the most helpful thing for me today in the lab.

Briefly describe what you did in lab today, including the measurements you made.

A502: Today in the lab we made graphs, well first we.. the experiment was setup with the fan cart and a rubber band on one side and a spring on the other and we diagrammed the experiment on the lab and uh then saw how motion compares to force and we we graphed motion force and velo.. I mean velocity acceleration and force and saw how they all related.

What do you think was the main learning purpose or goal of the lab work today?,

A503: Learning purpose was to see how these related, uh to see how these related and by doing graphs to make it easier for us to observe that.

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab,

A504: The graphs relate to the purpose of the lab because you can see how uh when how the force relates to motion which is the velocity and the acceleration.

Which of the graphs you made were most closely related to each other?

A505: But uh the when when the uh we saw when the force was highest, then then the uh acceleration is at its highest also because those two graphs are very similar and then when uh when the force is at its lowest, acceleration is at its lowest and at both of these peaks , uh the velocity is zero.

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A506: What I learned today was that force and acceleration are similar when graphed, yet the velocity is not similar although one may think that force and velocity are similar.

On the basis of what you learned today, how would you describe the effect of forces on an object on the motion of that object?

A507: The acceleration is similar with it because when the springs extended all the way, the acceleration is at its highest along with the force, yet the velocity is zero because its at a standstill for a second then its coming back.

Did you learn anything today that was unexpected or that surprised you? Did you see anything that contradicted what you would have predicted to happen.

A508: This relationship between acceleration and force was unexpected . I would think that the velocity and the force were related.

What was the most memorable thing you saw or learned about in the lab today?

A509: The most memorable thing was seeing the graph and then in the graph, acceleration versus force to see.. (TAPED OVER BY NEXT STUDENT)

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A510: (NO DATA-TAPED OVER BY NEXT STUDENT)

Briefly describe what you did in lab today, including the measurements you made.

A602: Today we um made different graphs on the computer. First using one graph we compared velocity and force and saw that it was a uh enlarging circle, which showed that when the force was greater, then the velocity was zero uh uh force was at its maximum when velocity was zero, and that's why it appeared to be a circle on just the one axes. um then using three graphs, force, velocity and acceleration versus time we put more stuff on the cart and saw how the graphs compared to that, those when there was no stuff on the cart.

What do you think was the main learning purpose or goal of the lab work today?

A603: The main learning purpose of the lab was to see how this extra weight changed the graphs that we made.

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

A604:

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A605: The relationship of forces to the motion of an object, uh there wasn't much that I learned that was new today, um most of that knowledge I had before class uh was just extended by observing the graphs after doing the experiments.

From your work in the last few days, which of the motion variables is most directly affected by the forces acting on an object? What is the evidence for your answer?

describe the experiment that most clearly showed the relationship of forces to acceleration and velocity.

A606: From my work in the last few days uh um I've seen which of the motion variables is most directly affected by the force acting on an object. the motion variable that is most directly affected by the force acting on an object is acceleration because its identical or its its proportional to the force. um the experiment that most clearly showed the relationship of forces to acceleration and velocity was when we er we uh any of the experiments using three graphs, when they were lined up on the computer screen we could observe them easily.

Did you learn anything today that was unexpected or that surprised you? What was the most memorable thing you saw or learned about in the lab today?

A607: Nothing really surprised me today about the uh looking at the graphs or any of the experiments. uh nothing was really unexpected.

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A608: The parts that were most effective to me were like I said before, when three graphs are together you can observe all three at the same time and compare them that way.

Suppose an object were acted on by a steady force. What do you think the acceleration of the object would be like? Sketch an acceleration-time graph.

What do you think the velocity of the object would do? sketch a velocity-time graph.

A609: If an object were acted on by a steady force, um the acceleration would be steady also. um the velocity ...the velocity would also be steady.

What is the effect of adding more "stuff" to a moving object when the same combination of forces act on it?

A610: The effect of adding more stuff to a moving object when the same combination of forces act on it is to see how the acceleration and the velocity are affected.

Briefly describe what you did in lab today, including the measurements you made.

A702: In the lab today we used the fan cart to pull the uh force probe with a constant force and we saw how, what how the velocity and acceleration were graphed with uh with a constant force.

What do you think was the main learning purpose or goal of the lab work today?

A703: The main learning purpose was to see how these three, the acceleration and velocity and a constant applied force related to each other.

Sketch the graphs you made in the lab today and describe how the graphs relate to the purpose of the lab

A704:

What did you learn about the relationship of forces to the motion of an object, in particular what did you learn that was new to you, and what did you learn that confirmed or extended things you already knew?

A705: We learned the relationship between the forces and motion of an object uh what we learned was that um for a constant applied force, there's a constant acceleration and therefore a steadily increasing velocity um that confirmed things we had already learned earlier in the lab.

From your work in the last few days, which of the motion variable is most directly affected by the forces acting on an object? What is the evidence for your answer?

A706: The ..uh.. of the motion variables, it's acceleration which is most directly affected by the forces acting on an object um because they're proportional, force and acceleration are proportional.

What happens to the acceleration of a cart when the same forces are used but more "stuff" is added to the cart?

A707: When more stuff is added to the cart with the same force, the acceleration is slowed down.

When a constant force is applied to a cart, describe what happens to the velocity and the acceleration of the cart.

A708: When a constant force is applied to the cart uh the uh the acceleration, there's a steady acceleration and therefore a steady increasing velocity.

Suppose a steadily increasing force were applied to the cart, what do you think would happen to the velocity and the acceleration?

A709: If a steadily increasing force were applied to the cart, then there would be an increasing acceleration and the velocity would increase, would not have a

steady increase, but more of an increase at every time for more time that passed.

What parts of today's lab work do you think were most effective or helpful to you in learning about force and motion?

A710: Seeing the graphs altogether on the computer screen was the the ..and comparing them that way was the most helpful thing that we did in the lab today.

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