Variables related to selection of mental representation and problem-solving strategy during mechanics problem-solving

Park, Yune Bae, Ph.D.
The Ohio State University, 1990
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VARIABLES RELATED TO SELECTION OF MENTAL REPRESENTATION
AND PROBLEM SOLVING STRATEGY DURING
MECHANICS PROBLEM SOLVING

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
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* * * * *

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1990

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To My Mom In Heaven
ACKNOWLEDGEMENTS

As finishing my dissertation, I can not skip mentioning my teachers, friends, and families who have taught, helped, and supported me so much at every score of my life.

My dissertation advisors, Dr. White, Dr. Howe, and Dr. Ploughe, deserve my sincere thanks for tireless encouragement, care, help when I needed, and wisdom in teaching and research.

My wife, Mee Ae, who did her best for serving family; and Jong-Sur and Jong-Yul, who understood their dad's circumstances and endured some playing time, deserve all the honor, love and gratitude. I would like to share my joy of this accomplishment with my family, my wife's family, and my friends for their supports in diverse ways.

I want to thank to my Lord for providing all resources to study and challenges to overcome. I can not express my thanks to the Lord Jesus in words for all he has done to help me. Sola Gratia.
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FIELDS OF STUDY

Major Field: Education
Studies in science education, research methodology,
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- iv -
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>VITA</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Need for study</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Philosophical basis</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Research problem</td>
<td>5</td>
</tr>
<tr>
<td>1.4 Overview of the research design</td>
<td>6</td>
</tr>
<tr>
<td>1.5 Assumptions</td>
<td>6</td>
</tr>
<tr>
<td>1.6 Limitations</td>
<td>7</td>
</tr>
<tr>
<td>1.7 Definition of terms</td>
<td>8</td>
</tr>
<tr>
<td>II. REVIEW OF LITERATURE</td>
<td>10</td>
</tr>
<tr>
<td>2.1 Problem solving</td>
<td>10</td>
</tr>
<tr>
<td>2.1.1 Model</td>
<td>10</td>
</tr>
<tr>
<td>2.1.2 Mental representation</td>
<td>13</td>
</tr>
<tr>
<td>2.1.3 Problem solving strategy</td>
<td>16</td>
</tr>
<tr>
<td>2.1.4 Methodology</td>
<td>18</td>
</tr>
<tr>
<td>2.2 Variables related to problem solving</td>
<td>26</td>
</tr>
<tr>
<td>2.2.1 Role of representational mode</td>
<td>27</td>
</tr>
</tbody>
</table>
V. DISCUSSION .................................................. 120

5.1 Roles of problem solving process variables .................................. 120
  5.1.1 Familiarity ............................................ 122
  5.1.2 Problem representation .................................. 122
  5.1.3 Problem solving strategy ................................ 125
  5.1.4 Confidence .............................................. 126
  5.1.5 Like/dislike ........................................... 128
  5.1.6 Difficulty .............................................. 128

5.2 Roles of knowledge and skills ............................................. 129

5.3 Problem solving model building ............................................ 141

5.4 Conclusions .................................................. 145

5.5 Recommendations ................................................ 150

REFERENCES ..................................................... 153

APPENDICES

A. ANNOUNCEMENT FOR GETTING VOLUNTEERS ............................ 166

B. APPLICATION FORM ............................................. 167

C. QUESTIONS FOR SCREENING SESSION .................................. 168

D. QUESTIONS FOR PRESTUDY SESSIONS .................................. 169

E. QUESTIONS FOR FOLLOW-UP SESSION .................................. 170

F. QUESTIONS FOR ADDITIONAL INTERVIEW SESSION ....................... 172

G. THINK-ALOUD INSTRUCTIONS ....................................... 173

H. MULTIPLE CHOICES OF MPT ITEMS ................................... 174

I. DATA INSTRUMENTS AND DESCRIPTIONS FOR K .......................... 176
  I.1 Learning history ........................................... 176
  I.2 Misconceptions ............................................ 176
  I.3 Prestudy ................................................... 180

- viii -
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I.</strong></td>
<td>Problem representation</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Solving strategy</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>Errors</td>
<td>183</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>Characteristics</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Raw data</td>
<td>191</td>
</tr>
<tr>
<td><strong>J.</strong></td>
<td>DATA INSTRUMENTS AND DESCRIPTIONS FOR P</td>
<td>225</td>
</tr>
<tr>
<td>J.1</td>
<td>Learning history</td>
<td>225</td>
</tr>
<tr>
<td>J.2</td>
<td>Misconceptions</td>
<td>226</td>
</tr>
<tr>
<td>J.3</td>
<td>Prestudy and problem sequence</td>
<td>230</td>
</tr>
<tr>
<td>J.4</td>
<td>Problem representation</td>
<td>231</td>
</tr>
<tr>
<td>J.5</td>
<td>Solving strategy</td>
<td>231</td>
</tr>
<tr>
<td>J.6</td>
<td>Errors</td>
<td>233</td>
</tr>
<tr>
<td>J.7</td>
<td>Confidence</td>
<td>239</td>
</tr>
<tr>
<td>J.8</td>
<td>Characteristics</td>
<td>242</td>
</tr>
<tr>
<td>J.9</td>
<td>Raw data</td>
<td>244</td>
</tr>
<tr>
<td><strong>K.</strong></td>
<td>DATA INSTRUMENTS AND DESCRIPTIONS FOR E</td>
<td>278</td>
</tr>
<tr>
<td>K.1</td>
<td>Learning history</td>
<td>278</td>
</tr>
<tr>
<td>K.2</td>
<td>Test results on related variables</td>
<td>278</td>
</tr>
<tr>
<td>K.3</td>
<td>Misconceptions</td>
<td>279</td>
</tr>
<tr>
<td>K.4</td>
<td>Prestudy and problem sequence</td>
<td>280</td>
</tr>
<tr>
<td>K.5</td>
<td>Problem representation</td>
<td>280</td>
</tr>
<tr>
<td>K.6</td>
<td>Solving strategy</td>
<td>281</td>
</tr>
<tr>
<td>K.7</td>
<td>Errors</td>
<td>283</td>
</tr>
<tr>
<td>K.8</td>
<td>Confidence</td>
<td>286</td>
</tr>
<tr>
<td>K.9</td>
<td>Characteristics</td>
<td>289</td>
</tr>
<tr>
<td>K.10</td>
<td>Raw data</td>
<td>290</td>
</tr>
<tr>
<td><strong>L.</strong></td>
<td>DATA INSTRUMENTS AND DESCRIPTIONS FOR M</td>
<td>328</td>
</tr>
<tr>
<td>L.1</td>
<td>Learning history</td>
<td>328</td>
</tr>
<tr>
<td>L.2</td>
<td>Misconceptions</td>
<td>328</td>
</tr>
<tr>
<td>L.3</td>
<td>Prestudy and problem sequence</td>
<td>330</td>
</tr>
<tr>
<td>L.4</td>
<td>Problem representation</td>
<td>331</td>
</tr>
<tr>
<td>L.5</td>
<td>Solving strategy</td>
<td>332</td>
</tr>
<tr>
<td>L.6</td>
<td>Errors</td>
<td>333</td>
</tr>
<tr>
<td>L.7</td>
<td>Confidence</td>
<td>337</td>
</tr>
<tr>
<td>L.8</td>
<td>Characteristics</td>
<td>341</td>
</tr>
<tr>
<td>L.9</td>
<td>Raw data</td>
<td>342</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Model of problem solving process</td>
<td>12</td>
</tr>
<tr>
<td>2. Mechanics problem solving process model</td>
<td>142</td>
</tr>
</tbody>
</table>
**LIST OF TABLES**

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Comparison of quantitative and qualitative methods</td>
<td>21</td>
</tr>
<tr>
<td>2. Items of the VSP</td>
<td>46</td>
</tr>
<tr>
<td>3. Items of the PKT</td>
<td>48</td>
</tr>
<tr>
<td>4. Problems of the MPT</td>
<td>50</td>
</tr>
<tr>
<td>5. Content and mode of the MPT problems</td>
<td>61</td>
</tr>
<tr>
<td>6. Prerequisite items to solve the MPT problems</td>
<td>68</td>
</tr>
<tr>
<td>7. Summary of K's solving of the MPT problems</td>
<td>83</td>
</tr>
<tr>
<td>8. Summary of P's solving of the MPT problems</td>
<td>94</td>
</tr>
<tr>
<td>9. Summary of E's solving of the MPT problems</td>
<td>107</td>
</tr>
<tr>
<td>10. Summary of M's solving of the MPT problems</td>
<td>117</td>
</tr>
<tr>
<td>11. Problem solving process variables by MPT problems</td>
<td>121</td>
</tr>
<tr>
<td>12. Four subjects' responses on the RLT, CST, PKT items</td>
<td>130</td>
</tr>
<tr>
<td>13. Four subjects' prerequisites</td>
<td>132</td>
</tr>
<tr>
<td>14. Prerequisite knowledge and solving success for solvers on MPT</td>
<td>133</td>
</tr>
<tr>
<td>15. Numbers of problem in each category</td>
<td>135</td>
</tr>
<tr>
<td>16. Solving strategy in terms of results and prerequisites</td>
<td>139</td>
</tr>
<tr>
<td>17. Errors in each category</td>
<td>141</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

In this chapter, the need and philosophical basis of this study are discussed. The research problem is presented followed by an overview of the research design, assumptions, limitations, and definitions of terms used in this study.

1.1 NEED FOR STUDY

Two kinds of problem solving have been viewed as critical to education. First is problem solving within a specific subject discipline. The second kind is of a broader nature and may encompass several subject matter areas (Voss, 1989).

Lester (1980) believes research on problem solving is a chaotic area mainly because of the widely diverse types of tasks used. Various conditions and environments for problem solving are studied during research: group versus individual; routine versus nonroutine; single-step versus multi-step; with or without calculator; paper-and-pencil
Garrett (1986) suggested that all anomalies of problem solving approaches can be thought of as continuity along a single dimension which includes puzzles (situation known or assumed to be solvable within a given paradigm) and problems (situations where existing paradigms may not be applicable and indeed where there may be no solution possible).

Solving problems, including puzzles (Kuhn, 1970), is the heart of the work of a physicist. While solving problems is a long tradition in physics, research into how people solve physics problems is relatively recent. Before the early 1970s, it was thought that physicists knew how to solve physics problems and they knew how to teach other people to solve physics problems (Fuller, 1982).

Explanations of how problem solving takes place typically have been derived from theories that had their bases in phenomena other than the problem itself. Such theoretical viewpoints include Gestalt theory with its perceptual emphasis, learning theories with an associationistic emphasis, and theories of cognitive development in which problem solving is used to monitor mental development. In recent years, problem solving has received increased interest
mainly due to the growth of the research related to information processing (Voss, 1989).

Many problem solving studies are correlational or experimental. In these kinds of studies, researchers generally examine relations or certain cause and effects of preselected variables. In addition, most of these studies have a nomothetic feature; therefore it is almost impossible to determine the impact of variables not included or idiosyncratic variables. Most of these variables are related to personal differences, are considered as error components, and are treated by randomization or assumed to have equal effects between experimental or control groups of the study. Issues on research methodology are discussed in Chapter 2.

Research on problem solving is currently receiving a great deal of attention in areas of psychology (Bransford et al., 1986), mathematics (Charles & Silver, 1988), and science (Camacho & Good, 1989; Garrett, 1986). Problem solving in the area of mechanics is the most frequently studied area in physics. This is because most high school and introductory level college students experience difficulties in mechanics problem solving. They perceive the problems to be difficult when the problems require more than simple knowledge based on memorization. Mechanics is especially difficult to teach and to learn (Kolody, 1977).
Many studies have investigated the basic phenomenon of mental representation and problem solving strategies of successful and unsuccessful students (or novice and expert) (Camacho & Good, 1989; Kinnear & Martin, 1989; Smith, 1986; Whimbey & Lochhead, 1986) and the general variables of selecting the mental representation and problem solving strategy (de Jong & Ferguson-Hessler, 1986; Garrett, 1986). Therefore, there is a need to study a small number of subjects intensively and qualitatively for identifying other variables influencing the problem solving process.

Knowing the variables influencing the selection of a student's mental representation and solving strategy with respect to the specifics of a given problem is expected to give crucial information for finding the mechanism of the physics problem solving process. It should also provide a useful tool for teaching problem solving as well as for writing learning materials and developing test items.

1.2 PHILOSOPHICAL BASIS

The information-processing (IP) model and constructivism are two pillars in research methodology for studying problem solving. This study selected an eclectic approach. The think-aloud method and analyses of declarative knowledge and procedural knowledge are based on IP models.
Analyses of beliefs and descriptive case study approaches are based on constructivist models. The researcher hypothesizes that a stronger model of problem solving can be developed by combining selected strengths of each of the theroretical approaches.

1.3 RESEARCH PROBLEM

In this study, college students' problem solving processes, as applied to mechanics problems, are analyzed to determine what variables are involved in the processes. More specifically, this study, as a qualitative study, aims to identify variables related to students' selection of mental representations and problem solving strategies when solving mechanics problems in physics. The general variables considered include task structures of the problem, declarative knowledge, procedural knowledge, strategic knowledge, and belief system. Based on the problem solving process, a problem solving model is proposed. The model includes stages in problem solving process, influencing variables, and confidence change due to errors which occurred in each stage.
1.4 OVERVIEW OF THE RESEARCH DESIGN

This study examined college students' problem solving processes. Problems used in this study can be characterized as individual, routine, multi-step, with calculator, paper-and-pencil, and college introductory level physics (mechanics) problems. Some problems included superfluous information. To obtain data about the subjects' problem solving processes, think aloud techniques and retrospective interviews were used and the protocol was transcribed from an audiotape record. Each subject was interviewed by the researcher individually. The interview consisted of four sessions. Each session lasted two or two and a half hours.

1.5 ASSUMPTIONS

Students' verbalizations were used as data for analyzing cognitive processes. Therefore, it was assumed that students' verbal behaviors could be observed and analyzed like any other behavior and that the verbal behaviors expressed during the think-aloud method represent their cognitive processes at that time.

To focus this research on problem solving process analyses, students who did not have a predetermined minimum amount of knowledge on linear motion and energy conservation were excluded from this study. It was assumed that
this would be accomplished by selecting students who received at least B- grade in the related physics course.

The interviewer limited the sample to subjects not studying mechanics during the research data gathering period. Therefore, it is assumed that all participating subjects did not learn mechanics during and/or between problem solving sessions.

1.6 LIMITATIONS

By selecting students who received at least B- grade for the related physics course, this study did not gather any data from students who received a grade lower than B- for the course. Therefore, results of this study should be interpreted with this limitation in mind.

Because data related to the subjects' views on science and physics, tested by the Views on Science and Physics (VSP), was collected at the end of the final interview, the responses may have been influenced by the problem solving activity provided by this study. Or because the Prerequisite Knowledge Test (PKT) was administered after the problem solving sessions, subject's responses on the PKT may have been influenced by the problem solving activity provided by this study.
This study as a qualitative study consisted of a small number of students, so generalizations of the results from this study are limited without stating the specific conditions.

1.7 DEFINITION OF TERMS

1. A problem is a situation in which there is no obvious way of arriving at a goal state from a given state (Mayer, 1985).

2. Problem solving is the process of moving from the given state to the goal state of a problem (Mayer, 1985).

3. A mental representation is a cognitive structure which results in understanding a problem on the basis of his or her domain-related knowledge and its organization.

4. Declarative knowledge is memory which is accessible to conscious awareness (Squire, 1986). It is the ability to recall specific information.

5. Procedural knowledge is memory which is accessible through performance by engaging in the skills or operations in which the knowledge is embedded (Squire, 1986). It is the ability to know how to use the declarative knowledge.

6. Strategic knowledge is a general strategy, independent of subject matter, that helps problem solvers approach, understand, and/or effectively marshall
their resources in solving problems (Schoenfeld, 1979). It is the ability to know when and why to use a procedure.

7. A context refers to a physical situation in which a physics problem is presented (e.g., slope, collision, free fall).

8. A misconception is a student's concept which is conceptually incorrect or deficient in relation to those which scientists have, no matter what reasons or for which circumstances.

9. A reasoning pattern is an identifiable and reproducible thought process directed at a type of task (Karpplus, 1979).

10. A presentational mode is the way a problem is given to the student. A verbal problem is presented in words only; a diagram problem is given in words and with a diagram showing some of the physical variables; and a pictorial problem is given in words and with a photograph.

11. Schemas are organized packets of knowledge gathered together to represent single units of self-contained knowledge (Norman, 1982).
CHAPTER II
REVIEW OF LITERATURE

2.1 PROBLEM SOLVING

2.1.1 Model

Many studies on problem solving have been done from chess games to mathematics and science. Based on the studies' results, problem solving models were proposed.

Polya (1957) suggested four stages for solving mathematical problems: understanding the problem; devising a plan; carrying out the plan; and looking back. Schoenfeld (1979) made a schematic diagram of a mathematical problem solving strategy including analysis, design, exploration, implementation, and verification. Reif, Larkin, and Brackett (1976) also proposed four steps in physics problem solving including describing the problem, planning a solution, implementation, and checking the result. Schoenfeld's diagram and the Reif et al. plan have basically the same features as Polya's (1957).
Hestenes (1987) developed a problem solving model for mechanics: (1) Description stage, including object description and motion and interaction description; (2) Formulation stage, applying the physical laws of motion and interaction to determine definite equations and any subsidiary equations of constraint; (3) Ramification stage, working out the special properties and implications of the model; and (4) Validation stage, concerning the empirical evaluation of the model resulting from the ramification stage. Hestenes stated that the description stage is severely constrained by the content selected because theory specifies what kind of objects and properties that can be modeled.

The strategies and structures that problem solvers are observed to apply in the successful solutions of problems have been identified as important variables in problem solving studies. Understanding physical situations requires both that a relevant schema is present and that the features of the physical situation evoke the schema (Champagne, Klopfer, and Gunstone, 1982). A research model of the problem solving process based on their study is illustrated in Figure 1.

The model shown in Figure 1 agrees with the common observation that details of problem solving depend on the
content and nature of the initial problem representation (Roth & Chaiklin, 1987).

Mayer (1985) has also identified two stages: (1) forming a representation or understanding of the problem, and (2) searching the problem space for a solution. The first stage needs linguistic, factual, and schematic knowledge to encode the problem in relation to other knowledge and other problems. The second stage requires algorithmic knowledge of well-defined procedures and strategic knowledge of useful approaches to problems.
2.1.2 Mental representation

Larkin (1981) has suggested a sequence of four problem representations:

1. literal representation: just a simple statement of the problem as it might be presented.
2. naive representation: sketch of the real-world situation. (e.g., hammer, inclined slope)
3. physical representation: reflecting the physics concepts (e.g., energy loss by friction, initial velocity = 0)
4. algebraic representation: equations are produced.

Comparisons between naive and physical representation were examined by Larkin (1983).

Chi, Feltovich, and Glaser (1981) pointed out that there is a big difference between expert and novice performance in the naive and in the physical stages. Generally a novice solver skips the physical stage, trying to jump directly from a sketch of the situation to a set of equations. However, the expert uses the physical representation to guide his/her problem solving.

Many studies (e.g., Chi et al., 1981 Smith & Watermann, 1987; Veldhuis, 1987) agree that the unsuccessful problem solver (or novice) uses surface structures (explicitly-
stated features in the text of problems) mainly and the successful problem solver (or expert) uses deep structures (principles that determine and control solutions to problems) in the formation of mental representations.

Larkin, McDermott, Simon, and Simon (1980) and Larkin (1983) suggest that there are two kinds of representation styles in mechanics problem solving. First, some subjects understood that the problem could be structured by forces or kinematics principles. Students used the concepts, such as force, acceleration, time, and distance, to understand the problem. This style is referred to as the Force-Kinematics (F-K) representation. On the other hand, other students used concepts of kinetic energy, potential energy, and work to characterize their problems. This style was named the Work-Energy (W-E) representation.

In a study on expert-novice differences in mechanics problem solving, Park (1988) reported that experts seemed to use different representation styles for different problems while novices used one representation for all three problems and that all students who used Work-Energy representation solved the problems correctly. Questions such as the following remained unanswered at the end of the study. Is the W-E representation more effective than the F-K representation? Do other variables of the successful solver
(e.g., nature of problem or previous learning history) relate to the use of the W-E representation?

Roth and Chaiklin (1987) summarized the properties of a novice's mental representation:
1. more than one interpretation of a given concept;
2. the format of these alternative representations may differ;
3. conceptual knowledge may be in the form of declarative facts, procedural rules, or schematic relations;
4. the information contained in each representation may differ; and
5. the conditions under which each concept is invoked may differ.

Schultz and Lochhead (1988) reported that experts probably go through a hierarchical sequence of questions focusing on the relevant physical principles. By contrast, novices tend to use a nonhierarchical "laundry list" of physics terms, problem types, and variable names, and match these to superficial aspects of the problem statement.

Singley (1989) listed factors influencing representation as: 1) task instructions provided by the experimenter; 2) previous experience on similar tasks; and 3) practice on the task.
2.1.3 Problem solving strategy

In the research to develop simulation models for mechanics problems, Larkin et al. (1980) implemented two strategies, means-ends analysis and knowledge-development. They reported that the means-ends model was used by many novice solvers while the experts often used the knowledge-development model.

Problem solving strategies have been classified as follows (Larkin et al., 1980; Park, 1988; Simon & Simon, 1978):

1. Means-Ends (M-E) strategy begins with the desired quantity and looks for equations including that quantity. Then the student works backward until equations containing no unknowns other than the desired subgoal were encountered.

2. Knowledge-Development (K-D) strategy begins with the known quantities in the problem statement and applies appropriate equations to derive new quantities until the desired quantity is reached (forward chaining).

3. Random (RA) strategy looks for discretionary equations or uses equations arbitrarily. A student using this strategy does not have any consistent plan but just hopes to find some clues to arrive at the goal.
Simmons (1988) reported that unsuccessful problem solvers used random approaches while successful problem solvers used complex patterns in the problem solving sequence. Smith and Good (1984) found that successful subjects tended to use the Knowledge-Development and unsuccessful subjects used the Means-Ends approaches. Park (1988) also concluded that the K-D strategy was the most effective strategy to solve mechanics problems, in comparison with the M-E and RA strategies. Nine out of the 14 cases which used the K-D strategy correctly solved their problems, while none of five cases using the RA strategy nor six cases using the M-E strategy solved them at all (Park, 1988).

These results may be integrated with those on memory of problem states. Experts are able to work forward immediately by choosing appropriate equations leading to the goal because they recognize each problem state from previous experience and know which moves are effective. However novices, not possessing appropriate schema, are not able to recognize and memorize problem configurations and are forced to use other problem-solving strategies such as means-ends analysis when faced with a problem. In addition the M-E strategy involves a heavy cognitive load which tends to prevent searching for more diverse aspects of the problem (Sweller, 1988). In less familiar problems, problem solvers, even experts, tend to use Means-Ends strategy (Sweller, 1989) rather than Knowledge-Development strategy.
2.1.4 Methodology

The problem solving research done after the 1960s can be classified into two theoretical perspectives. One is the information-processing (IP) model based on cognitive psychology; the other is constructivism. The information-processing model is the typical example of a rationalist, scientific approach (Hatfield, 1984). The rationalist approach considers the learning system as a cybernetic system involving adaptable but predictable beings, understands problem-solving processes as search for the production systems, and assumes invariance across solvers. Many problem solving studies using IP models focused on cognitive aspects or conscious steps of problem solving (Fuller, 1982). People using the IP model have tried to make computer models to understand human problem solving from a reductionist view, and have attempted to make expert systems from their research results.

On the other hand, the constructivist approach considers the learning system as a complexity of perceptions, goals, and interactions, all constructed by individual learners. The constructivist approach understands problem-solving processes as the search for the varied bases for constructions and reconstructions. The changes of constructions are often predictable only within broad terms (Hatfield,
1984). Studies based on constructivism emphasize the plasticity of cognitive and mental structure and emphasize philosophical understanding of what knowledge is and how new knowledge develops (Fuller, 1982). These studies also focus on noncognitive aspects of problem solving, such as beliefs, motivation, attitudes, values, and emotion. The qualitative method has been dominant in these studies.

Magoon (1977) listed three assumptions of the constructivistic perspective: (1) knowledge possessed has important consequences for the interpretation of the subject's behavior; (2) specific behavior has its meaning and purpose; and (3) humans can develop knowledge by organizing complexity, attend to complex communications, and take on complex social roles. The constructivism and information-processing models have been well analyzed and compared in terms of their definitions, epistemology and research methodology, and implications for education and curriculum (Carter, 1987).

These two theoretical perspectives came from different philosophical aspects and drew upon different research methodologies. The information-processing theory research shares the same philosophical roots with quantitative methodology, and constructivism research usually involves qualitative methodologies.
Table 1 shows the characteristics and emphases of quantitative and qualitative methodologies (Cziko, 1989; Eisner, 1981; Howe, 1988; Jacob, 1987; Magoon, 1977; Smith, 1982; White et al., 1989). As shown in the table, both methods have unique characteristics and advantages in certain aspects and certain circumstances.

Recently many have recommended the increased use of qualitative methodology in educational research. The experimental research from the 1950s to late 1970s, which was summarized by White, Baird, Mitchell, Fensham, & Gunstone (1989), was based on a simple causal model, changing one factor would be followed directly and indirectly by changes in another. They said that the experimentalists found that the mechanisms of teaching and learning are not immutable or easily generalizable and that the relative importance of factors change with time, individuals, and context.

Cziko (1989) argued for the view that complex human behavior is unpredictable if not indeterminate and raised serious questions about the validity of a quantitative, experimental, positivistic approach to educational research. Within a deterministic perspective, two arguments, individual difference and chaos, were presented to be considered for the unpredictability of human behavior.
### Table 1

Comparison of quantitative and qualitative methods

<table>
<thead>
<tr>
<th>QUANTITATIVE METHOD</th>
<th>QUALITATIVE METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>constructs a reality in terms of the metaphor &quot;machine&quot;</td>
<td>a reality in terms of the qualities of situation</td>
</tr>
<tr>
<td>produces machine-based knowledge (e.g., computer)</td>
<td>situation-based knowledge</td>
</tr>
<tr>
<td>displays precision without very much scope</td>
<td>displays scope without very much precision</td>
</tr>
<tr>
<td>scientific research</td>
<td>descriptive or case study</td>
</tr>
<tr>
<td>positivism</td>
<td>interpretism</td>
</tr>
<tr>
<td>reductionist</td>
<td>expansionist or contextualist</td>
</tr>
<tr>
<td>looking for general laws of human functioning</td>
<td>looking for laws of the individual</td>
</tr>
<tr>
<td>discovery of laws of nature</td>
<td>creation of meaningful images</td>
</tr>
<tr>
<td>implies singularity and monopoly</td>
<td>implies relativism and diversity</td>
</tr>
<tr>
<td>attempting to predict and control</td>
<td>attempting to describe, interpret, and explain</td>
</tr>
<tr>
<td>hypothetic-deductive process</td>
<td>inductive process</td>
</tr>
<tr>
<td>seeking context-free laws</td>
<td>describing the variations of causal interactions through different circumstances</td>
</tr>
<tr>
<td>exclude values, beliefs, and intentions</td>
<td>include values, beliefs, and intentions</td>
</tr>
<tr>
<td>ordinal, interval, and ratio scales</td>
<td>nominal scale</td>
</tr>
</tbody>
</table>

He provided three arguments for the view that human behavior is by nature indeterministic and unpredictable: learning as evolutionary processes, free will, and has quantum mechanical characteristics (randomness). Stake (1978) also recommended the case study method in the study of human affairs. Idiographic procedures such as interview and observations are recommended for studying thought processes (Erlwanger, 1974).

Eisner (1981) and Roberts (1982) argued that when both methods (qualitative and quantitative) are used cooperatively a more adequate picture of reality would come out: "Looking through one eye never did provide much depth of field." Smith (1982) argued that naturalistic (e.g., qualitative or ethnographic) methods as used in the social sciences are appropriate for research in science education. Lester (1985) also suggested adopting a naturalistic perspective to problem solving research and listed its emphasizing features: (1) reliance on qualitative methods; (2) eschew rigor for the sake of relevance; (3) reliance on tacit knowledge as theory development; (4) adopt an expansionist view; and (5) discover theory rather than verify.

Lester (1980) and Shavelson, Webb, and Burstein (1986) listed types of verbal report methods that attempted to obtain data on the intellectual processes used by subjects
as they rendered judgments and made decisions or solved problems: (1) think aloud or talk aloud; (2) introspection, requiring subjects to analyze their thinking as they attempt to solve a problem; (3) retrospective interview, recalling thought after having completed a task; (4) stimulated recall thinking aloud while reviewing an audio- or video-tape of performing a task; and (5) written inventories, eliminating the need for audiorecording and protocol coding.

Many researchers suggest that the think aloud approach is the best way to obtain protocols (Bhaskar and Simon, 1977; Finegold and Mass, 1985; Gorodetsky and Hoz, 1980; Larkin and Reif, 1979; Reif, Larkin, and Brackett, 1979; Stewart, 1982; 1983). Think aloud methods can be directed to elicit complex forms of problem solving and to identify the internal symbolic mechanisms that underlie problem solving (Ginsburg et al., 1983). The protocol made from a subject's verbal speaking usually contains information that reveals the subject's control, evaluation process, and goals (Ericsson and Simon, 1984).

The advantage of a think aloud method includes its immediacy compared with recall techniques. To discover the subject's thinking process, as little interference as possible is necessary in the think-aloud method (Ginsburg et
However, there are many issues and shortcomings related to verbal protocols (Ericsson & Simon, 1984; Eylon & Linn, 1988; Ginsburg et al., 1983; Lester, 1980; Singley & Anderson, 1989). These include:

1. Objectivity and reliability of verbal data;
2. Difficulty in deriving a rule from a protocol statement;
3. Difficulty in using verbal protocols for young students;
4. Theoretical presupposition in encoding;
5. Inferring thought processes from behavior;
6. Difficulty in articulating all, or even the most important, thought processes;
7. Deleterious effect on performance;
8. Tendency for subjects to talk only about moves they believe to be safe or correct;
9. Not working with all kinds of tasks, such as highly automated tasks or very complex problems;
10. Difficulty in knowing the exact meaning of a word or sentence;
11. Danger of taking statements too literally.

To cover the limitations of the think aloud method, a retrospective interview may be used (Ericsson and Simon, 1984; Ginsburg et al., 1983; Lester, 1982). The interview is designed to elicit intellectual activities in a variety of contexts, to specify the nature and organization of the cognitive processes, and to evaluate cognitive competence. Think aloud and clinical interview methods may be used in combination. The mixing of these methods involves the generation of spontaneous accounts of problem solving and the checking of hypotheses suggested by these accounts.
The interview method also has limitations: (1) limited numbers of subjects; (2) informally obtained data; (3) relationship between interviewer and subject; (4) quality of questions; and (5) adequate sources (Erlwanger, 1974).

Although the expert-novice paradigm has given much insightful information about problem solving, it has some limitations. According to Chi, Glaser, and Rees (1982), when experts are asked to solve a problem in which their experience has been limited, their solving process looks like that of the novice, and when a novice is familiar with a particular type of problem, the novice is able to develop a representation that cannot be distinguished from that of the expert. Therefore, the expert-novice classification appears to be oversimplified. There is a need to examine the kind of variables which influence the problem solving process and performance. On the other hand, expert-novice approaches have severe limitations when applied to classroom studies directly. Experts may have enough background experience which permits them to use methods that are not effective for novices, who cannot gain the experience in a short time (Eylon and Linn, 1988).
2.2 VARIABLES RELATED TO PROBLEM SOLVING

Many studies report variables influencing the process of problem solving. Kilpatrick (1978) categorized independent variables on mathematical problem solving; subject, task, and situation variables. de Jong and Ferguson-Hessler (1986) identified four kinds of knowledge factors; declarative knowledge (principles, formulas, concepts), procedural knowledge (knowledge about actions that are necessary for solving that particular type of problem), problem knowledge (characteristics of problem situations), and strategic knowledge (knowledge that tells the problem solver the stages that he or she has to follow in the problem solving process). Schoenfeld (1985) reported four major variables related to problem solving performance: resources (mathematical knowledge possessed by the individual), heuristics (strategies and techniques for making progress on unfamiliar or nonstandard problems), control (global decisions regarding the selection and implementation of resources and strategies), and belief systems (the set of determinants of an individual's behavior). Lester, Garofalo, and Kroll (1989) categorized five factors in mathematical problem solving: knowledge, control (metacognition), affects (emotion and attitudes), beliefs, and contextual (socio-cultural) factors. The specific variables included in this study are discussed in the next section.
2.2.1 Role of representational mode

In a study on secondary school students' problem solving in mathematical and real settings, Jurdak (1986) concluded that structural equivalence of problems did not guarantee consistency in solving strategy. Eylon and Linn (1988) reported that novice students may be confused in differentiating critical features and trivial features of a given problem.

Larkin and Simon (1987) listed the characteristics of the diagrammatic representation comparing it with the verbal mode: 1) localization of information; 2) minimal labeling; and 3) perceptual enhancement. This means diagrams can group all information that is used together, thus avoiding large amounts of time searching for the elements needed to make a problem-solving inference; use location to group information about a single element, avoiding the need to match symbolic labels; and support a large number of perceptual inferences which are extremely easy for human beings. They found that the advantages of the diagram are computational, and suggested that the diagrams may be better representations when the indexing of the information supports useful and efficient computational processes.
2.2.2 Knowledge structure

Many problem-solving deficiencies may be attributed to lack of knowledge or to unstable conceptual systems (Lesh, 1985). Physics problem solving requires knowledge for understanding and representing problems; knowledge of basic concepts and principles; and repertoires of familiar patterns and known procedures (Heller and Hungate, 1985).

Greenbowe (1983), in research on college level chemistry students, reported that good problem solvers had:

(1) knowledge of specific subject matter facts and skills;
(2) knowledge of supporting subject matter and skills;
(3) understanding of subject matter concepts;
(4) appropriate representations of the problem; and
(5) chunking of information, skills, and processes to reduce overload on working memory. (p. 49)

In a table comparing characteristics of novices' and experts' schemata, Champagne, Klopfer, and Gunstone (1982) reported that principles applied by novices to problem solving are expressed as formulas or rules, whereas experts' applied physical laws. Eylon and Linn (1988), in a review of studies on categorizing physics terms and problems, concluded that the knowledge structure of experts was different qualitatively from the novice's structure. Experts linked salient information around physics principl-
pies while novices linked ideas around surface features. Larkin (1983) reported that experts solve: (1) easy problems through filling slots in a single schema for a physical representation; (2) harder problems by coordination of two or more schemas; and (3) very difficult problems by successive attempts to validate schemas, with computation occurring only when a completed schema can guide it. In contrast, novice solutions do not show these features and are often incorrect. Sweller (1989) concluded that rule automation and schema acquisition are the most important characteristics of skilled problem solving performance.

After reviewing physics problem solving studies, Voss (1989) summarized the difference of knowledge structures of experts and novices as follows. Experts tended to sort problems in relation to abstract laws and principles; novices sorted in relation to surface structure. Experts sorted into reasonable subcategories because their knowledge was classified according to higher level principles. Experts were able to follow inference paths relating high level laws and principles to other concepts.

2.2.3 Misconceptions in mechanics

Many misconception studies have involved mechanics. It may be because of its basic status in physics. Pfundt and Duit (1988) made comprehensive bibliographies on alterna-
tive frameworks in science education. Of a total of 926 studies on investigations of students' notions, 602 were on physics; among them were 259 on mechanics or energy.


Voss (1989) concluded that the sources of the misconceptions include both real-world experience and an inadequate understanding of physics concepts. Larkin (1983) reported that misconceptions were a block to forming effective representations for problem solving. Murray, Schultz, Brown, and Clement (1988) said that misconceptions were often deep-seated and interfere with problem solving. A sub-
ject's misconceptions related to mechanics should be examined to study his/her problem solving process.

The sources of misconceptions on force and motion may be three types: real-world experience, partial understanding of instruction, and considering some concepts as scalar rather than vector (White, 1983). In addition, the evolution of knowledge development and the presentation of physics primarily in a formal mathematical language were listed as causes of misconceptions (Voss, 1989).

2.2.4 Reasoning skill

Sternberg (1986) defined reasoning as controlled and mediated application of three processes—selective encoding, comparison, and combination—to inferential rules. He further stated "No task requires only reasoning, and few tasks require no reasoning at all." Citing several studies on the reasoning abilities of college students, Nummedal (1987) reported that a majority of college students were unable to use the strategies and processes of formal reasoning consistently and reliably. There are many studies specifically reporting reasoning skills as one of the important factors for solving problems.

Greenbowe (1983) found that successful chemical problem solvers exhibited more formal operations than unsuccessful
problem solvers. Champagne, Klopfer, and Anderson (1980) reported that the mechanics achievement scores in an introductory college level course were correlated with mathematics skills \((r = .55)\) and reasoning scores \((r = .38)\). Later, Champagne and Klopfer (1982) proposed a causal model for mechanics achievement using reasoning skill and mathematics skill as major components.

Bitner (1989) found that five formal operational modes of reasoning (i.e., proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial logic) have been identified as essential for success in science and mathematics at the high school and college levels. Logan and Bailey (1989) reported that probability, ratio and proportion, equilibrium, and conservation are difficult reasoning skills for Australian high school physics students. Lawson and Thompson (1988) found a negative correlation \((r = -.41)\) between formal reasoning and misconceptions. They concluded that students who had acquired higher order reasoning patterns held fewer misconceptions because higher order reasoning patterns are necessary to overcome prior misconceptions. Lavoie (1989) also concluded that subjects who could make successful predictions were formal operational and exhibited fewer misconceptions than unsuccessful subjects.
Karplus (1979) and Staver and Bay (1989) developed concepts of reasoning pattern and analyzed many patterns in concrete and formal reasoning.

2.2.5 Strategic knowledge

Most of the current models of problem solving have their origin in Dewey's (1933) reflective thought phases: (1) getting an idea for a possible solution; (2) recognition of the potential difficulty of a problem; (3) hypothesising or devising a plan; (4) mental elaboration or reasoning; (5) testing the hypothesis; and (6) looking back to assess or looking ahead to generalize. Dewey's model is very similar to the Polya's (1957) heuristics.

Krulik and Rudnick (1989) have also stated a set of heuristics for a mathematics problem solving:

(1) Read the problem;
(2) Explore;
(3) Select a strategy;
(4) Solve; and
(5) Look back. (p. 24)

Clement and Konold (1989) derived basic mathematical problem-solving skills as stage-specific skills, general skills, and attitudes. The two skill categories include comprehending and representing; planning, assembling, and
implementing a solution; and verifying the solution. The attitudes include alternately generating and evaluating ideas; striving for precision in the use; and monitoring progress.

Lester, Garofalo, and Kroll (1989) listed a cognitive-metacognitive framework for studying mathematical performance:

1. orientation (strategic behavior to assess and understand a problem);
2. organization (planning of behavior and choice of actions);
3. execution (regulation of behavior to conform to plans); and
4. verification (evaluation of decisions made and outcomes of executed plans). (p. 11)

Larkin et al. (1980) suggested that poor problem solvers in the relevant content domain use general-but-weak strategies; good problem solvers in the domain tend to use powerful content-related processes. There is evidence that students who know enough domain-specific subject matter fail to solve problems because they do not use their knowledge wisely (Lochhead, 1988). Metacognition helps students to know how and when to use such knowledge (Narode, 1987). Narode identified many metacognition skills, such as
"interpretation of the problem and the relationships within, selection of heuristics, re-examination of previous work, resolution of conflicting ideas, further qualitative assessment of the problem to check the solution, and an explanations of the errors." (p. 20) He reported that in simple problems there may be little evidence of metacognition because of the speed of the process.

Good problem solvers had different strategic knowledge compared to poor solvers as follows (Greenbowe, 1983; Whimby and Lochhead, 1986): (1) read carefully; (2) break problem into small steps; (3) organize their work; (4) evaluate and check intermediate and final results; (5) try different approaches; and (6) possess several cognitive strategies and use various problem-solving heuristics.

On the other hand, poor problem solvers tend to jump to conclusions, guess answers, make intuitive judgements without checking because they do not believe in persistent analysis, are careless in their reasoning, and have not learned to break a problem into parts (Whimby and Lochhead, 1986). For mechanics problem solving, novices typically lack strategic knowledge. Experts usually possesses such knowledge in tacit form (Heller and Hungate, 1985).

Experts do more planning and evaluating before implementing than novices do. Novices usually start to calcu-
late using formulas rather than planning because they lack both a repertoire of algorithms and the necessary skills of organization. In addition, experts engage in more monitoring concerning their own cognitive processes than do novices. Average students may rarely evaluate their problem solving because they lack evaluation techniques, and problem solving requires most of the student's processing capacity (Eylon & Linn, 1988).

2.2.6 Belief system

Many studies have investigated problem solvers' belief systems. Lederman (1990) examined high school students' views on science and classified their responses using four items. He checked conclusive or tentative, realist or instrumentalist, induction or invention, and subjective or objective.

Good problem solvers had different belief systems compared with poor solvers. Good solvers believe they can solve any problem and are more likely to improve accuracy (e.g., talk to himself or herself to clarify own thoughts), and they have persistence. Poor solvers lack both confidence and experience in dealing with problem solving through gradual analysis (Greenbowe, 1983; Whimby and Lochhead, 1986).
After interviewing two college physics students, Hammer (1989) found that one student had incoherent, fragmented conceptions but did well on course problems, and the other student tried to make sense of all the given information but was not successful in solving course problems.

In chemistry problem solving using traditional and non-traditional problems, Carter (1987) reported that beliefs influence:

1. the selection of algorithms;
2. the degree to which students rely upon algorithms;
3. willingness to examine concepts and to attempt alternate solutions when solving problems;
4. decisions as to when a problem is solved;
5. the degree of evaluation;
6. confidence in one's solution;
7. perceptions of what tasks and problems are fair or solvable; and
8. basic approaches to learning and studying chemistry.

(p. 317)

2.3 ERRORS IN PROBLEM SOLVING

Many studies have investigated students' errors in problem solving. Most of them tried to find some common errors and develop treatment or instructional programs. Lester,
Garofalo, and Kroll (1989) proposed a scoring scheme for measuring the stages of understanding the problem, of planning a solution, and of answering the question individually. In a mathematics problem solving study, Whimby and Lochhead (1986) listed errors in problem solving as follows: inaccuracy in reading and thinking; weakness in problem analysis; and lack of perseverance. In a chemistry problem solving study, Greenbowe (1983) listed ten areas of difficulty: (1) constructing an appropriate representation; (2) applying concepts to unfamiliar tasks; (3) applying a familiar rule to unfamiliar tasks; (4) checking the results; (5) applying knowledge of real world events; (6) use of a variety of heuristics; (7) use of formal reasoning; (8) reaching final result by reporting intermediate result as final; (9) availability of basic facts; and (10) recognizing computational errors.

From experience in an introductory physics course, van Ausdal (1988) listed general difficulties to diverse topics: hard to start; searching for equation or technique for solution; failing to make sketches; recognizing the need for more information; and isolating the source of difficulties. Some specific difficulties in constant acceleration problems are also discussed: confusing acceleration with velocity; use of constant acceleration methods in cases where the acceleration is not constant; confusion with
signs; choices of initial and final states; and choice of a coordinate system. Procedural difficulties in physics problem solving include confusion of related physics terms and overgeneralization from a specific case (Eylin & Linn, 1988).

Some students could perform calculations using formulas, but they might have misconceptions and use the formulas in an inappropriate context. In a physics problem solving study by Clement (1981), he called the knowledge possessed by these students as formula-centered knowledge. They are relying on matching variables instead of thinking of the given problem in terms of its qualitative physics features.

2.4 SUMMARY

Several problem solving models were reviewed from the general domain to physics content. The two problem solving process variables, problem solving strategy and mental representation, were defined, and examined in terms of their differences between expert and novice and between good problem solvers and poor problem solvers. Some important characteristics of both the quantitative method and qualitative method were described. To backup the shortcomings of the think-aloud approach and the retrospective interview used separately, the methods should be combined.
Some categories of variables related to problem solving were reviewed. Some research results on the variables to be used in this study were reviewed and discussed. These variables included: the role of problem representational mode, knowledge structure of the subject, misconceptions on mechanics, relationship to reasoning skills, heuristics, and belief system. Lastly errors in problem solving were discussed to help the data analysis of this research. The actual variables examined in this research will be described in the next chapter.
CHAPTER III
METHOD

This chapter includes the description of the population and the sample, selection procedures, the data collection instruments including the Views on Science and Physics (VSP), Reasoning Level Test (RLT), Computational Skill Test (CST), Prerequisite Knowledge Test (PKT), and Mechanics Problem Test (MPT), data collection procedures, and data analysis methods.

3.1 GENERAL METHOD AND SAMPLE

During late autumn quarter of 1989 and early winter quarter of 1990, announcements (Appendix A) asking for participation as a volunteer and application forms (Appendix B) were distributed in the second of a three course physics sequence. Four students among the nine students who submitted their application forms were interviewed. The five students who were not interviewed had irresolvable schedule conflicts. Among the four interviewed, three (K, P, and E) finished all sessions. The one dropout student did not come to the appointed place at the appointed time after the
screening session. During the spring quarter of 1990, the announcements were again distributed in the second course of the physics sequence. From the four students who submitted their application forms, one student (M) who submitted his application the earliest, was contacted; he completed all interviews. Because of time limitations of the interviewer, the other three were not used in this study.

The four subjects selected had taken high school physics and had completed the first quarter course in an introductory-level physics sequence for science and engineering majors at a large midwestern university. They were volunteers who had finished the mechanics part of the series and had earned grades of B- or higher. Starting autumn quarter of 1989, the textbook of the physics sequence was changed from Sears, Zemansky, and Young's "University Physics" (1987) to Halliday and Resnick's "Fundamentals of Physics" (1988). Some of the problems of the Mechanics Problem Test (MPT) were taken from the latter book. However, no problems of the MPT were included as assigned problems in the course syllabus.

After making an appointment by telephone, the interviewer met with the applicants at one of the laboratories in the physics building. After explaining the purpose of this study, students' background information was collected
through questions (Appendix C) based on Greenbowe's study (1983). The questions were related to their high school and college physics course background, attitude toward physics courses, and their physics self concept.

After checking that the applicant was qualified on the criteria described above and that the applicant was sufficiently motivated to be involved in this study, additional meetings were arranged. Four time blocks were scheduled; each of them lasting from two to two and a half hours.

### 3.2 SELECTION OF VARIABLES

For this research, variables influencing the selection of the mental representation and solving strategy are classified in the following five categories based on the literature review. Of course, these five categories interact in a variety of ways.

1. **Task structures (nature, features, demands) of the problem are:** content (linear motion or energy conservation), context (inclined plane, car, or falling), variables included, algorithm, and mode represented (verbal, diagram, or pictorial).

2. **Declarative knowledge including:** definitions, facts, principles, formulas, and concepts (misconceptions).
3. Procedural knowledge including: reasoning skill (proportional reasoning, functional reasoning, and conservation) and mathematical skill.

4. Strategic knowledge including: metacognition (Flavell, 1979; Narode, 1987), heuristics (Polya, 1957), control strategy, cognitive strategy, conditional knowledge, and managerial strategy.

5. Belief system including: belief, worldview, confidence, attitude, motivation, affects, anxiety, preference, emotion, and personality.

The above five categories subsume most of the categories suggested by previous studies. Affective and socio-cultural factors are rarely seen in physics problem solving studies. That's why they are combined in the same category here.

3.3 INSTRUMENTATION

This section includes the descriptions of the instruments used in this study. The order of description chosen for the variables measured by these instruments is from broad, general, or those less directly influencing physics problem solving to those more specific or directly related to physics problem solving.
3.3.1 Questionnaire of Views on Science and Physics (VSP)

The purpose of this questionnaire was to identify the subject's views on the nature of science and physics, views on the science-technology-society (STS) issues, and attitude toward school physics. Items of the VSP were collected and modified from Aikenhead (1985), Brickhouse (1988), Durkee (1975), and Schoenfeld (1989).

The VSP contained 24 questions distributed in three parts according to format. In part I (7 questions), the subjects were asked whether they agreed or disagreed with the given statements and were required to explain why they agreed or disagreed. Part II (11 questions) was a multiple-choice format. Subjects were asked to choose two or more responses if they seemed equally good. One blank was provided for every question so subject's could add their own response if they did not like any of the given options. Six open-ended questions were included in part III.

Questions are classified into three subscales as follows: (1) nature of science/physics (I 1-3, II 3-5,7, III 1-8); (2) STS (II 1,2,6); and (3) views on school physics (I 4-6, III 9-11). Topic and question number of each question are listed in Table 2 by subscales.
Table 2

**Items of the VSP**

<table>
<thead>
<tr>
<th>Subscale Part No.</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>definition of science</td>
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<tr>
<td>1</td>
<td>definition of physics</td>
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<tr>
<td>1</td>
<td>nature of science</td>
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<tr>
<td>1</td>
<td>tentativeness of scientific knowledge</td>
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<tr>
<td>1</td>
<td>nature of scientific models</td>
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<tr>
<td>1</td>
<td>nature of scientific approach</td>
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<td>social nature of scientific knowledge</td>
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<td>aims of science</td>
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<tr>
<td>1</td>
<td>nature of scientific laws</td>
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<td>1</td>
<td>objectivity of scientists</td>
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<tr>
<td>1</td>
<td>nature of scientific theories</td>
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<tr>
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<td>verification/falsification</td>
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<td>scientific terms</td>
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<td>science versus other discipline</td>
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<td>social responsibility of scientists</td>
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<td>2</td>
<td>role in resolving social problems</td>
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<tr>
<td>2</td>
<td>public influence on science</td>
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<tr>
<td>3</td>
<td>view of school physics</td>
</tr>
<tr>
<td>3</td>
<td>problem solving behavior at impasse</td>
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<td>view of school physics</td>
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<td>3</td>
<td>attribution of school physics</td>
</tr>
<tr>
<td>3</td>
<td>view of school physics</td>
</tr>
<tr>
<td>3</td>
<td>motivation to learn physics</td>
</tr>
</tbody>
</table>

3.3.2 *Reasoning Level Test (RLT)*

To develop the RLT, all of the MPT problems were solved by the researcher and checked by at least one other faculty member. From the results of the solving, it was determined that two reasoning patterns are required for responding to the MPT problems: functional reasoning and proportional...
reasoning. The four questions of item #1, representing functional reasoning, came from Clement (1982) and Niaz (1989). Four items (#2 to #5) representing the proportional reasoning were selected from Lawson (1978), Ronning, McCurdy, and Ballinger (1984), and Thornton and Fuller (1981). It took about 30 minutes to solve all items.

3.3.3 Computational Skill Test (CST)

This test deals with the mathematical skills required to solve the problems on the MPT. For example, they require the use of quadratic equations, square root calculations, use of trigonometric functions, and basic arithmetic operations (Champagne et al., 1980; Hudson, 1986; Linder & Hudson, 1989; Wollman & Lawrentz, 1984). Unit conversion questions were tested in item #1. Item #2 provided arithmetic questions; item #3 asked to solve equations. General trigonometric knowledge was tested in item #4.

3.3.4 Prerequisite Knowledge Test (PKT)

This test is a 17 item achievement measure on linear motion and energy conservation. Specifically it focuses on the recognition/recall of the prerequisite concepts, mathematical definitions, and principles and the identification of misconceptions related to linear motion and energy conservation (Brown & Clement, 1987; Clement, 1982; Ivowi,
1984, 1986; McDermott, 1984; Trowbridge & McDermott, 1980, 1981; Viennot, 1979). The prerequisites were determined by using the results of structure analysis done by Griffiths (1987). The source material and topic area for each item are listed at Table 3.

Items from #1 to #11 tested for subjects' misconceptions on diverse mechanics concepts. Because there was a need to know the subjects' specific declarative knowledge on mathematical definitions and conservation principles, items #12 to #17 were prepared by the researcher.

Table 3

<table>
<thead>
<tr>
<th>item</th>
<th>source</th>
<th>area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Viennot (1979)</td>
<td>force, potential energy</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>&quot;</td>
<td>friction</td>
</tr>
<tr>
<td>5</td>
<td>Clement (1982)</td>
<td>friction</td>
</tr>
<tr>
<td>6</td>
<td>Ivowi (1986)</td>
<td>force in motion</td>
</tr>
<tr>
<td>7</td>
<td>Ivowi (1984)</td>
<td>energy conservation</td>
</tr>
<tr>
<td>8</td>
<td>Trowbridge &amp; McDermott (1984)</td>
<td>velocity</td>
</tr>
<tr>
<td>9</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>(1981) acceleration</td>
</tr>
<tr>
<td>11</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>12</td>
<td>Park (this study, 1990)</td>
<td>dimensions</td>
</tr>
<tr>
<td>13</td>
<td>&quot;</td>
<td>mathematical definitions</td>
</tr>
<tr>
<td>14</td>
<td>&quot;</td>
<td>speed, velocity, and acceleration</td>
</tr>
<tr>
<td>15</td>
<td>&quot;</td>
<td>energy conservation</td>
</tr>
<tr>
<td>16</td>
<td>&quot;</td>
<td>momentum conservation</td>
</tr>
<tr>
<td>17</td>
<td>&quot;</td>
<td>inclined plane</td>
</tr>
</tbody>
</table>
Items #1 and #6 of the PKT tested for knowledge about exerting forces and about potential energies of bodies in motion. Items #2 and #3 ask about the application of Newton's third law. Items #4 and #5 dealt with friction. Energy conservation was the content of item #7. Items #8 and #9 tested the concept of velocity, and items #10 and #11 tested the concept of acceleration. The units of basic concepts used in linear motion and work-energy were asked in items #12 and #14. Item #13 asked the respondent to recall ten mathematical definitions on mechanics concepts. The energy and momentum conservation principles were the content of item #15 and #16 respectively. Item #17 dealt with energy and frictional force on a slope.

3.3.5 Mechanics Problem Test (MPT)

The Mechanics Problem Test consisted of eight problems on linear motion and energy conservation. The problems were collected from Clement (1981), Finegold and Mass (1985), Haber-Schaim, Dodge, and Walter (1986), Halliday and Resnick (1988), and Mandinach (1988). The problems were selected and modified to span diverse structures of the problem situations such as algorithm, variables, and presentational mode (verbal, diagram, or pictorial). The problems required the use of more than a single formula or simple recall for solution and involved functional and proportional reasoning.
The content, presentational mode, and context of each problem, identified by this researcher and validated by two faculty members, are summarized in Table 4.

Table 4

Problems of the MPT

<table>
<thead>
<tr>
<th>problem</th>
<th>content</th>
<th>mode</th>
<th>context</th>
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<tbody>
<tr>
<td>1</td>
<td>linear motion</td>
<td>verbal</td>
<td>falling rock</td>
</tr>
<tr>
<td>2</td>
<td>energy conserve</td>
<td>diagram</td>
<td>bullet collision</td>
</tr>
<tr>
<td>3</td>
<td>linear motion</td>
<td>pictorial</td>
<td>basketball player jump</td>
</tr>
<tr>
<td>4</td>
<td>linear motion</td>
<td>verbal</td>
<td>train motion</td>
</tr>
<tr>
<td>5</td>
<td>energy conserve</td>
<td>verbal</td>
<td>slingshot projectile</td>
</tr>
<tr>
<td>6</td>
<td>both*</td>
<td>diagram</td>
<td>block on inclined plane</td>
</tr>
<tr>
<td>7</td>
<td>either**</td>
<td>diagram</td>
<td>vertical throw</td>
</tr>
<tr>
<td>8</td>
<td>linear motion</td>
<td>pictorial</td>
<td>jump from bridge</td>
</tr>
</tbody>
</table>

* The "both" means that the problem must be solved using both the Force-Kinematics representation and the Work-Energy representation.
** The "either" means that one or the other of the Force-Kinematics representation and the Work-Energy representation can be used.

Problems #1, #3, and #8 required the same algorithm on linear motion to solve them, but the problem context varied. Problem #1 was a free fall from a cliff and presented as a word problem. Problems #3 and #8 were both presented as a pictorial problem, but one involved a basketball players jump, and the other a jump from a bridge. Problem #2 requesting the use of energy conservation principle was given in a collision context. Problem #5 also requesting the energy conservation principle was a slingshot projec-
tile problem. Problem #6 gave a block in motion on an inclined plane and could be solved using both the linear motion and energy conservation principles. Problem #7, a vertical motion problem, could be solved using either linear motion or energy conservation principles.

All eight problems are given in the following section in terms of their algorithms and characteristics with actual problem statements.

3.3.5.1 Problem #1

1. A rock is dropped from a 100-m high cliff. How long does it take to fall from the mid-point (50-m high point) to the bottom?

This problem requires the solver to compute the travel time to two points. To do that, the solver would need a mathematical definition involving time and distance, and would need to subtract the two travel times computed from the top of the cliff to the mid-point and to the bottom.

3.3.5.2 Problem #2

2. A 5-g bullet horizontally penetrates a 1 kg block suspended at rest from a 1 m long thread of negligible mass. The bullet leaves the block from its far side with velocity 200 m/s. How much energy was transformed into heat if the block rose through a height of 0.3 m? (You may assume that the block did not rise while the bullet was inside it.)
This problem requires the solver to use multiple steps to solve the problem. First, the solver should apply the energy conservation principle to this system. To get the initial velocity of the coming bullet, the solver should apply momentum conservation and energy conservation principles to the movement of the block. This is one of the most difficult problems in the MPT.

3.3.5.3 Problem #3

3. A basketball player, standing near the basket to grab a rebound, jumps 76 cm vertically. During falling from top, 0.175 second is measured in the top 15 cm of this jump. How much time does the player spend in the bottom 15 cm during the falling? Does this help explain why such players seem to hang in the air at the tops of their jumps?
This problem requires the calculation of travel time from two points. In order to do that, the solver must use a mathematical definition including time and distance, and subtract time of travel from the top to each relevant point. This involves the same algorithm as problems #1 and #8.

3.3.5.4 Problem #4

4. A late passenger, sprinting at 8 m/s, is 30 m away from the rear end of a train when it starts out of the station from rest with an acceleration of 1 m/s$^2$. Can the passenger catch the train if the platform is long enough?

This problem asks whether the passenger could catch the train. The solver could obtain the answer, yes or no, by
determining the time at which the passenger and the train meet. In order to do that, the solver should use an equation involving the relationships of time, distance, and velocity, and another equation involving time, acceleration, and distance. These expressions can then be equated and a solution obtained from the resulting quadratic equation.

3.3.5.5 Problem #5

5. A 100-g projectile is placed in a slingshot, and a band is pulled back 0.5 m and held with a force of 50 N before being released. The slingshot takes 0.05 sec to accelerate the projectile to its final speed. What is the final speed of the projectile?

This problem requires the solver to get the final speed when the projectile is released from a slingshot. First of all, the solver should notice that this is similar to a spring problem. The energy making the projectile fly comes from the stored energy of the slingshot. Then the solver should select an energy equation involving force and distance, and apply the energy conservation principle to get the final speed. Superfluous information regarding time is included in this problem.
3.3.5.6 Problem #6

6. A block is moving up a 40 degree incline. At a point 1.8 m from the bottom of the incline (measured along the incline), it has a speed of 4.5 m/s. The coefficient of kinetic friction between block and incline is 0.15. How fast will it be going after it slides back to the bottom of the incline?

This is a very complicated problem. The block is moving up and stops at some point and then slides back down the incline all the way to the bottom. Throughout all these movements, the frictional force is acting. The solver may represent this problem as a Force-Kinematics problem, as a Work-Energy problem, or both. In any case, the solver should compute the actual acceleration of the block as influenced by gravitational acceleration, angle of the slope, and the coefficient of kinetic friction. This problem strongly suggests that the solver should use the K-D strategy because the block moves from a given position to the top and slides back down to the final position at the bottom. If the solver follows these procedures through the block movement, it would be a forward chaining strategy.
3.3.5.7 Problem #7

7. A stone is thrown vertically upward. On its way up it passes point A with speed $v$, and point B, 3.0 m higher than A, with speed $\frac{1}{2}v$. Calculate the maximum height reached by the stone above point B.

This problem can be solved using Force-Kinematics principles or Work-Energy principles. In the first case, mathematical definitions involving distance, velocity, and acceleration are needed. In the second case, the energy conservation principle could be applied in this system. In both cases, the solver would have sufficient information from the two given points and the expected maximum point.

3.3.5.8 Problem #8

8. As the figure shows, Clara jumps from a bridge, followed closely by Jim. How long did Jim wait after Clara jumped? Assume that Jim is 170 cm tall and that the jumping-off level is at the top of the figure. Make scale measurements directly on the figure.
This problem required the student to compute the time of travel to two points. In order to do that, solvers should measure correct distances from the photograph. Then the solver should use an equation involving time and distance, and subtract time traveled from top (bridge) to each point. This has the same algorithm as problem #1 and #3.

3.4 DATA COLLECTION PROCEDURES

Each subject in this study was interviewed individually by the author. All interviews were tape-recorded. The interviews were designed for gathering additional information beyond what solvers wrote on their answer sheets and scratch sheets. Data were collected using the following instruments listed in the order which they were obtained.
3.4.1 Computational Skill Test

A calculator was permitted during the Computational Skill Test. To practice the think-aloud method, each subject was asked to read the instructions on the think-aloud method (Appendix G) and solve the problems of the CST with the think-aloud method. It took about 30 minutes.

After finishing this test, the interviewer asked the subject to identify the most difficult item. By analyzing the unsolved item(s) and providing some additional specific, simple problems, the interviewer tried to determine the subject's specific computational capabilities and difficulties.

3.4.2 Mechanics Problem Test

In order to refresh the subject's declarative knowledge on linear motion and energy conservation, a self-study session was given before the Mechanics Problem Test. Since some students had finished their first quarter physics courses a year in the past, the refresher activity seemed to be necessary. The study material was excerpted from the "Study guide to accompany Sears, Zemansky, and Young's University Physics (1987)" written by Gaines and Palmer (1987). Students were told that the test areas were limited to linear motion and energy conservation. The 15-pages
of study material contained pages 2-2, 4-2, 3, 5-2, 3, 4, 5, 7-1, 2, 3, 4, 5, 6, 7, and 8-2, 3, 4 of the study guide (Gaines & Palmer, 1987). It covered the topics, such as linear motion, Newton's third law, motion on slope with friction, work and energy, conservation of energy, elastic forces, conservation of momentum, and collisions. About 15 minutes was given for this prestudy session. Blank sheets were given so the student could make notes if needed.

The instructions to the subject were:

"This is study material for the coming test. The test will be a closed book test. Therefore you may memorize anything if you need to. Study these materials as though you were preparing for an examination. About 15 minutes is allowed for your study. Blank sheets are given for writing whatever you need."

The subjects' prestudy sessions were observed by the interviewer. In order to analyze learning strategies, the subjects were asked questions on their perceptions of importance of specific topics and information, confidence in their understanding, and of explanations and mathematical definitions (Appendix D).

After rereading the instructions on think-aloud method (Appendix G), an additional practice session for the method was given to the subject. The subject received feedback and directions based on his/her performance. Additional practice was given if needed. Whenever subjects would
think about so many things, so rapidly that they did not speak out about all of their thoughts, they were advised that they should describe their intentions or summarize what they were thinking about.

Subjects were then asked to

"choose the order in which you wish to solve the eight problems after reading through all eight problems within five minutes. Each problem was numbered randomly."

Each problem was numbered by using a random digit table. The sequence for solving the problems was determined by each subject. The subject was asked why they decided on the order selected (e.g., difficulty, category, preference, or random).

If the subject had no preference on any specific sequence, the researcher provided a sequence. The sequence could be one of the following: 1) difficulty (easiest to hardest or hardest to easiest), 2) content (both-linear motion-energy conservation), 3) mode (verbal-diagram-pictorial), and 4) combination of content and mode (content within mode or mode within content).

The content and mode of each MPT problem are illustrated in Table 5.

The Mechanics Problems Test was presented in the order selected by the problem solver. The interviewer asked the solvers to
Table 5

Content and mode of the MPT problems

<table>
<thead>
<tr>
<th>mode</th>
<th>linear motion</th>
<th>both</th>
<th>either</th>
<th>energy conserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>verbal</td>
<td>1*, 4</td>
<td>6</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>diagram</td>
<td></td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>pictorial</td>
<td>3, 8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* number means the problem number in MPT

"Think aloud as much as possible while solving the problem. When your thinking is so fast or you can not speak your thinking in detail, just say the plan that you are going to follow. You can not return to a problem to solve it once you finish it. There is no time limit in this study."

As soon as the subject started to solve the problems, an audio-tape recorder was started. When the subject kept silent longer than 20 seconds, the experimenter said "speak out about what you are thinking." A calculator and a slide ruler were permitted for solving the problems and the value of gravitational acceleration was given. There was no time limit for solving these problems, but the solving time of each problem was recorded.

After the completion of each problem, a follow-up interview focused on the parts where the solvers thought processes were not apparent to the interviewer (e.g., illogical development or mental leaps in solving process) and the nonverbalized portions (e.g., sudden change of solving method after silence) of the solving process. In addition,
information from the subject regarding confidence level of their solutions, like/dislike of problem, and familiarity with the problem was obtained. This follow-up interview, a retrospective probing, helps to cover the shortcomings of the think-aloud method (Lester, 1982). All interviews were audiotaped and transcribed.

During the follow-up interview, care was taken to avoid giving the solver a learning experience for solving the remaining problems. Interview protocols mainly followed Greenbowe's (1983).

Usually the first day (2 to 2.5 hours) provided enough time for solving 3 or 4 problems. Before finishing the first day's session, the interviewer requested that the solver not study mechanics during this research. The remaining problems were solved the second day.

After solving all problems, solvers were requested again to select the order in which they would solve the problems and, where the sequence differed they were asked the reason for the change.

3.4.3 Prerequisite Knowledge Test

The Prerequisite Knowledge Test (PKT) was conducted in an interview situation. Subjects were asked their answers without any multiple choices. The multiple choices provid-
ed in Appendix H were used only as reference information before or after asking for subjects' responses in items #2 through #5, and #7. When finishing each item, the subjects was asked about their reasons for their answers. It took about one hour to finish the test and the follow-up questions.

3.4.4 Questionnaire of Views on Science and Physics

The Questionnaire of Views on Science and Physics (VSP) was given to students after completing the MPT problems and the PKT items, and they were requested to write their views and reasons for these views. After they finished the written portion, some supplemental questions were asked to clarify unclear points. The discussions were recorded. It took about 45 minutes to finish this questionnaire and follow-up discussion. Normally the PKT and VSP were done at the third interview session.

3.4.5 Additional interview

After all problems and tests were finished, usually at the fourth session, the interviewer asked for more details related to the problems for which the subject's reasons were obscure or for which the reasons were in contradiction with others (Appendix F). The interviewer tried to determine why subjects used particular representations and solv-
ing strategies. Some isomorphic problems, such as simple energy conservation, were given and subject's responses were observed.

3.5 SCORING AND DATA ORGANIZATION

3.5.1 Reasoning Level Test

Only when both the answer and the reason for the answer were correct was the question counted as correct. The correct reasoning skill should produce both the correct answers and the correct reason (process) for each question.

3.5.2 Prestudy protocols

The solvers' prestudy protocols from the notes and the solvers' responses to the questions were analyzed. For example, areas of content on which the solvers focused, instances where solvers chose to memorize formulas as opposed to understanding explanations were examined. These data were helpful for interpreting the students' think-aloud protocols.

3.5.3 Problem solving sequence

The solvers' reasons for choosing one of the two solving sequences were analyzed. If there was any change between the two sequences, the reason for the change was explored.
3.5.4 Think-aloud protocols

The audio tape contained verbal statements of principles, algebraic combinations, and statements of numerical values. Solver's notes provided additional information about the solving process. The transcribed protocol was made by combining the taped transcript and the solver's notes.

In the analysis of the transcripts, Erlwanger's (1974) terminology was used. Of the pages of transcripts, only portions of the data were analyzed and discussed in detail. In the transcriptions of data, "I" refers to the interviewer/researcher. The following abbreviations are used in the data:

- ... short pause
- ... long pause
- .... very long pause
- ( ) word in parenthesis inserted by interviewer
- : indicates some of the responses are omitted
- : because it is considered to be irrelevant here
- :

From the protocol, two basic analyses were done. First, the sequence of problem representations from solver's statements about the understanding of the problem were
identified. Secondarily a sequential list of each physics principle mentioned or implied in a protocol was constructed. The problem solving strategy was characterized and classified from the order of principles applied by each subject.

Errors were then checked and categorized by type. Some of the variables which might be related to the cause of the errors were identified. Some computational errors, including unit conversion errors, and wrong substitutions were considered as minor errors. When the solver committed only a minor error in a problem, the researcher said the problem solution was "almost correct."

The stages in which the most errors occurred were identified for each solver and between solvers. Problem solving behaviors of different solvers on the structurally equivalent problems and the same person's solving processes in various problems were analyzed. The behaviors of solvers when they were at an impasse in the problem solving process were also observed and noted.

Sometimes solvers had difficulty when they could not recall an appropriate formula. In this case the solver's behavior was examined in relation to how they detoured and solved the problem without getting direct help from their declarative knowledge.
3.5.5 Overall analysis

After categorizing the solver's representation and solving strategy, the researcher looked for possible relationships between these categories and other related variables, such as reasoning levels, various types of knowledge, computational skills, and views on science and physics.

The required and related declarative knowledge and procedural knowledge (items of RLT, CST, and PKT) needed to solve each problem of the MPT were identified and are displayed in Table 6.

Problem #7 of the MPT could be solved two ways. One is using the Force-Kinematics principles; the other using the Work-Energy principles. Therefore, prerequisites for each way were identified separately. PKT item #13 had 10 mathematical equations, so each MPT problem had different equation for prerequisites.
<table>
<thead>
<tr>
<th>item</th>
<th>1</th>
<th>2</th>
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<th>5</th>
<th>6</th>
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<th>7</th>
<th>8</th>
<th>(F-K)</th>
<th>(W-E)</th>
</tr>
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<tbody>
<tr>
<td>PKT 1</td>
<td>*</td>
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<td>RLT 1</td>
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<td>CST 1</td>
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** required item to solve the MPT problem
* related item to solve the MPT problem
CHAPTER IV
CASE STUDIES

In this chapter, the data for the four subjects are presented in part and described. The following four subjects are listed in the order which they were interviewed. A brief learning history, beliefs on science and physics assessed by the Questionnaire of Views on Science and Physics (VSP), the results of the Reasoning Level Test (RLT) and the Computational Skill Test (CST), and misconceptions based on the Prerequisite Knowledge Test (PKT) are described in each case. Then the problem representation, solving strategy, errors, confidence, and characteristics of each subject's problem solving process are identified and discussed. The variables influencing the problem solving process for each subject are discussed in terms of the problems in the order which they were solved.

In most cases, problem representation and solving strategy were hard to separate because they were expressed together on the subject's transcript. In the confidence section, the solvers' like/dislike, difficulty, and confidence ratings are discussed. Each subject's similarities
and differences across the eight problems from the MPT are discussed in a summary section with a summary table for each case. Following the data description and discussion, similarities and differences between subjects' problem solving processes are compared. All time intervals stated in this chapter have been rounded to the nearest minute. The linear motion formula used throughout this chapter refers to the equation, \( x = v_0 t + \frac{1}{2} at^2 \). The subject's are referred to as K, P, E, or M. The more detailed transcripts and original data instruments for each solver can be found in Appendices I, J, K, and L respectively.

4.1 CASE K

4.1.1 Learning history

Subject K was a junior female student majoring in zoology. She graduated from a large suburban high school. K studied high school physics in the 11th grade and said she liked physics a lot because she had a woman teacher. She also remembered a lot of the demonstrations and video presentations.

For college level physics, K studied the first course of the physics series during the spring quarter of 1989 and received a grade of A-, and the second course during autumn quarter of 1989 and received a grade of B-. At the time
of this interview, winter quarter of 1990, K was in the third quarter of this physics series.

K does not need any more physics in terms of her college curriculum, however she likes physics and keeps taking physics courses. K liked to do physics problem solving and enjoyed being involved in this study. When this researcher talked about money offered as payment for participating as a subject, K said, "money does not really matter. I like physics and your research." K rated herself above average on the amount of physics and liked hands-on activity rather than abstract things.

4.1.2 Test results on related variables

K viewed science as created in terms of scientific technologies, and as discovered in terms of natural phenomena. She respected the neutrality of scientific knowledge. Subject K's responses on the VSP items are in Appendix I.

During the Reasoning Level Test, K showed some confusion. For the first four items requiring functioning reasoning, K wrote the expression incorrectly. For example, at item #1 a), she wrote the expression 5G = B, although she understood the sentence correctly.

After showing her the statement about 30 boys and 6 girls, K changed it to "G = 5B" then read "For every girl,
there are 5 boys." At item c), K also wrote "S = P/6" then read "For every student, there is 1/6 professor." K seemed to interprete the equation directly and confuse the nature of variable and proportionality. On the CST, K did not remember the quadratic formula. Other than that, there were only minor computational errors. Summaries of K's responses on the CST and RLT items are in Table 12, page 130.

4.1.3 Misconceptions

In summary K did not have a correct concept of exerting forces and potential energies for moving bodies. She did not apply Newton's third law in the collision case, confused velocity with acceleration, did not remember most of the necessary mathematical definitions, and had a weak understanding of the slope context. Summaries of K's responses on the PKT items are in Table 12, page 130. Discussions of her misconceptions and responses on the PKT are in Appendix I.

4.1.4 Prestudy and problem sequence

During 20 minutes of reading, K kept reading the study material through for the entire time and finally read through quickly from beginning to the end once more.
After studying the given material, K said force parts are more logical and are simple to her; she felt more confident about them. K selected the problem sequence, after looking at the eight problems for two minutes, as 8-3-1-6-4-7-5-2, based on problem difficulty from the easiest to the hardest. K liked photographs in problems because they looked easier to her and gave her more information.

There seemed to be no relationship between K's problem sequence selection to her confidence or familiarity with the problems. It might indicate K's selection was not based on deep structures of the problems. Later, after solving all the MPT problems, K said she would choose the problem solving sequence using the same principle and the same order if she were to solve the problems again.

K looked like she was having trouble thinking about the energy conservation (EC) principle. To K, a typical EC problem was a two-body collision, and she was not familiar enough with the principle to apply it to #7 and #2. According to the PKT, K forgot the potential energy equation. This may be the reason why K did not use the W-E representation.

According to additional interview responses, K got a hint from the problem phrase "force and mass" for using the $F = ma$ equation to solve problem #2.
Additional data from #2 on how K understood the problem includes: K tried to use $F = ma$ equation but could not, because there was no value for $F$ and $a$, so she got the answer using the kinetic energy equation.

On the familiarity of given problems, K said she had not seen problem #8 before, felt familiar with #3, and remembered how to solve problem #1. All three problems involve the same algorithm in the solution. She solved the three problems in a row, but after solving #8, she knew it was similar with #3. After solving #3, she remembered that she had seen that kind of problem, but could not remember it specifically. It might be concluded that K seemed to have a surface structure understanding of the problems, instead of deep structure understanding.

4.1.4.1 Solving strategy

K used the Knowledge-Development (K-D) strategy three times, the Means-Ends (M-E) strategy once, and the Random (RA) strategy three times. In one problem, her strategy could not be identified as one of the three strategies.

4.1.4.2 Errors

K's errors were identified and described in this section. The errors were analyzed as to whether they related to problem familiarity, prestudy, and/or misconceptions.
In some cases, additional interview data were used in the analysis.

In problem #8, K did not recall the equation to get time from distance and acceleration. She just matched the units of an equation known from linear motion, \( x = vt \), got \( a = \frac{x}{t^2} \) because the unit of acceleration is \( \text{m/s}^2 \), and used it to solve for the travel time. K measured the distance from the feet of Jim to the top of Clara instead of distances from top of the bridge to each person's feet. When K was faced the problem again at the additional interview, K measured the distance in exactly the same way.

K knew that times to travel the same distance at different heights are different. However K did not apply that fact to solve this problem. It looked like she interpreted the question "How long did Jim wait after Clara jumped?" as the time to travel the distance between the separation for Jim and Clara. This could be another example of K's surface processing. K identified three difficult things in this problem: remembering the formula; converting everything; and making the ratio. At the additional interview, K had all the mathematical equations on notes that might be needed to solve this problem but failed to solve it successfully because of the wrong interpretation of the interval between Jim and Clara. This might be an example when
even having two equations available is not enough to solve a physics problem.

In problem #3, K relied on given information rather than her calculated information. In problem #6, K did not have enough prerequisite knowledge to solve the problem, so K just tried to use some mathematical equations which she knew related to linear motion; then she multiplied some related variables to make the velocity smaller. For problem #4, K seemed not to understand the problem fully. K correctly drew a diagram based on the problem sentences. K compared velocities of passenger and train and then reached her conclusions.

In problem #7, K used an estimation method to solve it because she did not have enough prerequisite knowledge. Later at an additional interview, K tried again to solve #7. Following a prompt about using the EC principle she tried an equation taken from a note made during the pre-study session. K did not spend enough time to find the appropriate equations needed from the note. She got 1 m as an answer. K rated her confidence as a 5 even though she got a correct answer. With the equation note, K had solved the problem correctly; however, her confidence was low. Once more a prompt was given by the interviewer. K wrote a mathematical definition of the EC principle at the bottom
point and the maximum height point, but she could not apply the equation to any other points. K was not able to find a frame of reference for the evaluation of the potential energy. K looked uncomfortable using the EC principle.

K misrepresented problem #5 as F-K, and chose a reasonable value rather than a calculated result. K understood problem #2 as F-K. In an additional interview, using formula notes, K tried to solve this problem using energy concepts. K calculated the final kinetic energy of the bullet and the final potential energy of the block, then added the two energies. K appeared to be trying to get a correct answer rather than following the physical principles involved. K could explain the principle of momentum conservation in the PKT, but she could not apply it to this situation. Again, K went back to the F-K representation.

4.1.4.3 Confidence

In this section K's confidence in her answers, her likes/dislikes, and her difficulties in solving the problems are discussed. K's confidence ranged from 1 to 8.5. She liked five problems among the eight and rated three problems as easy, one as medium, three as hard, and one as very hard.
In problem #8, K said 6 on confidence because of trouble with the equation. K liked this problem because "it is logical and fun to figure out." In problem #3, both not knowing the equation needed and getting two answers resulted in her confidence rating of lower than that of #8.

For problem #1, K still did not know the equation, but she used her own equation again for the third time and perhaps was a little more confident about using it.

K had a very high level of confidence concerning her conclusion that the two persons in problem #4 can meet. Even though she made a wrong substitution, which she did not recognize, it did not affect her level of confidence in her solution of the problem.

In summary, when a problem was hard to figure out and understand, confidence was generally very low: when the given variables were easy to use with equation(s), confidence was high. Wrong substitution did not seem to affect her confidence at all. When K's confidence in her answer was very low, K did not like the problem and rated it as a hard problem. In cases where problems were rated as hard, the confidence ratings were low even though K liked the problem. In this case, K liked the problem more because enough time was given, than because of the problem itself.
4.1.4.4 Characteristics

K believes that a problem should have enough information given (e.g., #5 and 6). She tried to find the value of certain physical quantities that she thought it needed; when these were not given, she turned to another equation to solve the problem.

When K forgot the equation needed to solve a problem, she sometimes (1) made up her own equation by matching the units of the given information and the units of the required answer (e.g., #8, #3, #1); (2) chose operations to make sense (e.g., #6); and (3) made an estimate of the relationship (e.g., #7).

K just kept going on with her calculations even though she knew she was wrong in problem #7.

I: Why did you keep trying to calculate instead of thinking again to get a new understanding?

K: I like to get an answer.

I: Even if it's the wrong answer?

K: Sure.

I: Why?

K: Because some teachers may give partial credit (if you) get an answer. So better I get one at least, even if it might not be right, better than just to leave no answer. By some chance you might (just get) a right answer.
K knew how to play the game named "schooling" through her school experience.

K wrote down some information or drew diagrams while reading the problem (e.g., #8, #3, #4, #5, #2). Her reasons for doing this were as follows; (1) not to forget some of the given information, (2) to help in understanding the problem, and (3) to help herself figure out what equation would be selected.

4.1.5 Summary

K seemed not to have enough declarative knowledge to solve the MPT problems and had the largest number of misconceptions among the four subjects. K could not recall the linear motion formula and did not derive it correctly. This hurt her problem solving results for relatively easy problems, like #1, #3, and #8. If the appropriate formulas were given, she may have been able to solve the problems. In problem #4, she seemed not to understand the problem correctly. K was able to solve problem #7 in an additional interview session with the help of formula notes by using the F-K representation. Although she got an A-grade in the first course of the physics series, it was one year ago, and perhaps because her major is Zoology and the role of physics is not directly perceived, she had not retained
the knowledge. She had a problem with functional reasoning in the RLT, and said she did not like abstract things. The data showed K used surface processing frequently when trying to understand the problems. K rated herself as not very good at mathematics, even though her grade in the physics course was good. K was the only solver in the sample who was not an engineering major. The others would more likely have had continuous experience with mechanics-related problem solving; whereas, she did not.

To obtain the linear motion formula, K used the unit matching method. It was unsuccessful. During her solution to problem #3, K had an opportunity to discover that her own formula was incorrect, but she missed the chance because she used her result even though it did not seem right to her. When K did not remember an exact equation, she would try to use relationships to get a number close to the expected one by choosing an appropriate operation (e.g., #6). Using an estimation method as in problem #7 was one of her unique characteristics of problem solving.

Table 7 is the summary of K's MPT problem solving processes. For each problem in the Mechanics Problem Test (MPT), K's familiarity, representation, solving strategy, errors during problem solving, her characteristics in problem solving, solving result, confidence in her answer,
like/dislike, difficulty of the problem, and time spent to solve it are summarized.

K's errors could be classified as following: (1) not understanding the problem (e.g., #6, #4, #7, #2, #5); (2) not understanding the equation or concepts (e.g., #6, #7); (3) not recalling mathematical equation needed (e.g., #8, #3, #1, #6, #2); (4) wrong substitution (e.g., #4); (5) wrong measure (e.g., #8); and (6) unit conversion error (e.g., #5).

If a problem was hard to figure out and understand, confidence scores were low. In these cases, a random strategy was usually observed.

K tried to determine what would be a reasonable range for her answer (e.g., #1 and #5). She prepared a range of acceptable answer values before she got an answer and compared her result to this range. The comparison affected her confidence rating on the answers.

K did not have enough declarative knowledge. She used two ways to avoid the knowledge deficiency: (1) making an equation using a unit matching method and (2) estimation. During problem solving, K complained about not being able to recall equations and criticized the problem presentation for not providing the needed equation(s). She even said
Table 7

Summary of K's solving of the MPT problems

<table>
<thead>
<tr>
<th># familiarity</th>
<th>problem representation</th>
<th>solving strategy*</th>
<th>errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 new</td>
<td>F-K</td>
<td>M-E</td>
<td>wrong measure not recall equation</td>
</tr>
<tr>
<td>3 familiar</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
</tr>
<tr>
<td>1 know</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
</tr>
<tr>
<td>6 new</td>
<td>F-K</td>
<td>RA</td>
<td>not understand concepts use linear motion not recall equation not understand</td>
</tr>
<tr>
<td>4 familiar</td>
<td>F-K</td>
<td>RA</td>
<td></td>
</tr>
<tr>
<td>7 familiar</td>
<td>F-K</td>
<td></td>
<td>wrong equation can not use EC principle@</td>
</tr>
<tr>
<td>5 new</td>
<td>F-K</td>
<td>K-D</td>
<td>not same force unit conversion</td>
</tr>
<tr>
<td>2 familiar</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation not understand not use momentum</td>
</tr>
</tbody>
</table>

# problem number
* blank in solving strategy means it could not be identified among the Knowledge-Development (K-D), Means-Ends (M-E), and Random (RA) strategies.
@ information obtained from additional interview session
Table 7 (continued)

<table>
<thead>
<tr>
<th># characteristics</th>
<th>result</th>
<th>confidence</th>
<th>dis/like</th>
<th>time difficulty (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 make equation</td>
<td>wrong</td>
<td>6</td>
<td>like</td>
<td>easy</td>
</tr>
<tr>
<td>just matching unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3 make equation</td>
<td>wrong</td>
<td>4</td>
<td>like</td>
<td>hard</td>
</tr>
<tr>
<td>just matching unit</td>
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<td>follow given number</td>
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<td>wrong</td>
<td>8</td>
<td>like</td>
<td>easy</td>
</tr>
<tr>
<td>just matching unit</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6 choose smaller operations</td>
<td>wrong</td>
<td>1</td>
<td>not like</td>
<td>very hard</td>
</tr>
<tr>
<td>partial credit</td>
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<tr>
<td>4</td>
<td>wrong</td>
<td>8.5</td>
<td>like</td>
<td>easy</td>
</tr>
<tr>
<td>7 estimation</td>
<td>wrong</td>
<td>3</td>
<td>don't mind</td>
<td>hard</td>
</tr>
<tr>
<td>right@</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 try to make sense</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>medium</td>
</tr>
<tr>
<td>2</td>
<td>wrong</td>
<td>2</td>
<td>don't like</td>
<td>hard</td>
</tr>
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</table>

that if the formulas were given the problem would be easy. However, the second time she was faced with the same problem with the appropriate equation, her problem solving success was not that much improved. Even though K received a
grade of A- in the first course of the physics series, throughout this problem solving session, a lack of declarative knowledge including mathematical equations, basic concepts, and principles was observed.

4.2 CASE P

4.2.1 Learning history

Subject P is a sophomore student majoring in Mechanical Engineering. He studied "Physics with Calculus" in 12th grade in a city high school located in small town in rural Ohio. The school also offered physics which was a lower mathematics level. He liked the fun experiments in high school physics and remembered having a fun experience with an individual project for which he visited an Air Force Base.

P studied the first course of the series during spring quarter of 1989 and received a grade of B-; the second course during autumn quarter of 1989 and received a C+ grade. At the time of this interview, P was in the third course and later he said he received a grade of C+. P liked basic conceptual problems rather than formula-centered problems. Later P said he does not like to memorize formulas. Although P thought of himself as good in mathematics, he sometimes felt that it was hard to visualize or figure out some physics problems.
4.2.2 Test results on related variables

P knew diverse sources, such as informal meetings, could affect the scientist's work. He thought physics is everywhere in terms of its natural law. P's responses on the VSP questionnaires are given at Appendix J.

On item #1 d) of the RLT, P understood more strudels are ordered than cheesecake. But P wrote \(4/5C = S\). After the contradiction was pointed out by the interviewer, P changed it to \(C/S = 4/5\). He could not solve item #4 because he thought it was too complicated. For the CST, there was no major error except minor calculation mistakes.

4.2.3 Misconceptions

P did not have correct concepts for exerting forces and potential energies in moving bodies, could not apply Newton's third law in the collision case, could not remember six equations, and had a weak understanding of the slope context. A summary of P's misconceptions is in Table 12, p130.

4.2.4 Prestudy and problem sequence

P took about 17 minutes to study the given material. During the prestudy session, P kept reading the material through but occasionally came back and then went forward
again. He stated that the areas where he has the most confidence were motion with equations, force, and free-body diagram; and less confident in realizing and recognizing the conservation of energy.

After three minutes of reviewing the problems, P decided his solving sequence as 6-2-1-5-4-3-7-8 from the easiest to the hardest.

4.2.5 Problem solving

4.2.5.1 Problem representation

Problems #2, #5, and #6 could be solved correctly if understood as Work-Energy problems. However, P represented only one problem, #2, as the W-E problem. The remaining seven problems were initially interpreted as Force-Kinematics problems.

P used the W-E representation only when the term "energy" appeared in the problem sentences (e.g., #2 and an additional problem). P thought that using the energy conservation principle was not so easy for him.

P drew diagrams for word problems (e.g., #1, #4, and #5). Even for problem #3, for which a picture was provided in the presentation, P drew a diagram to figure it out. In most problems, P could identify some physics principles and
4.2.5.2 Solving strategy

P used the K-D strategy in four problems and the M-E strategy in one problem (#7). In problems #6 and #4, P started with the RA strategy then solved with K-D strategy. In one problem (#2), his solving strategy could not be classified as any one of the three strategies.

4.2.5.3 Errors

In problem #6, P thought that the actual acceleration was the same at the same point, which was gc\cos 40^\circ; whether the block moved up or down the slope surface. The acceleration of gravity alone along the slope should be g\sin 40^\circ. In addition, P did not use the frictional coefficient to calculate the acceleration. He could not derive the acceleration along the slope. P complained a lot about needing the mathematical equation to solve this problem. During an additional interview he had a second chance to solve the problem. Although a note including the equation for frictional force, written as frictional coefficient times normal force was provided, P did not use it and did not recognize that it was relevant. P could not develop the
equation needed from the given information. He might have been looking for the precise equation equipped with all the appropriate variables. P could understand what the problem meant, but could not solve the problem because he needed a more detailed equation.

P did not think to get the initial velocity of the bullet using the momentum conservation principle in problem #2. In an additional interview session, P seemed to be unsure about the momentum conservation principle for this system. He said "if friction is involved, momentum is not conserved. In this case energy is conserved but momentum is not." The additional assumption given in the last sentence of the problem also confused him.

The biggest error in problem #5 was understanding the problem as a Force-Kinematics one. After reading the problem, P wrote the linear motion formula and the F = ma equation. P did not notice that the 50 N of force does not continue to be exerted on the projectile. Rather it appeared that he just kept substituting the given numbers into any mathematical equations he could recall. That may be why P used the time, given as superfluous information, to calculate the final speed. In problem #4, P used an incorrect equation and made a couple of computational errors. Interestingly, the second error returned him to
the correct result. In problem #3, he did not pay attention to each unit when checking his answer. He mistook instantaneous velocity as average velocity and confused non-constant velocity with constant velocity in problem #7. This may be another example of using dimensions to develop a new equation. After spending 8 minutes, P got an expression for the maximum height involving the variable v. Later P really became confused and mixed up; he tried to rearrange the whole thing, but could not. P gave up on solving this problem after spending an additional 20 minutes.

4.2.5.4 Confidence

P showed very diverse range of confidence ratings and his confidence ratings were matched relatively well with his solving results. When he felt very confident that the problem was solved correctly (e.g., #4) or almost correctly (#3), he placed his confidence level at 10. In addition, for two problems which he solved correctly, P rated his confidence at 6. P liked 5 problems and did not mind 3 others. If a problem was hard, he did not say he liked it. His confidence level and the problem difficulties were positively related. He spent relatively longer time to solve each succeeding problem.
4.2.5.5 Characteristics

In the last part of problem #1, P just matched signs to get an answer having a reasonable value, even though it was mathematically incorrect.

Although P made a mistake in the unit conversion on problem #3, he did not recognize it. In addition, he did not notice that the travel time at the bottom 15 cm is greater than the time at the top 15 cm. Even after P had a chance to read the question and think about it, he could not find his mistake. P said the picture given in problem #3 did not give him any help for solving that problem.

In problem #7, P created an equation for velocity change by getting a hint from the dimensions. The equation, which was wrong, made this problem extremely difficult for P. He did not check it because at this point he was very sure of his approach. After spending 28 minutes, P had to give up trying to solve it because too many things were confused. P could not derive the necessary equation from the pairs of points. Among three possible equations showing the relationship of two points from the given three points, he just wrote one equation for the bottom two points.

For problem #8, P made a scale factor for converting a measured number to an actual number. It seemed an
engineer-like behavior. In this problem P sometimes showed his endeavor to make sense of the problem.

4.2.6 Summary

P was a slow problem solver. Except for problem #5, he spent more than 10 minutes each to solve the problems. He recalled a formula to solve problems #1, #3, and #8. And he checked his answer after solving some problems (e.g., #4 and #8). He was able to solve problem #4 even though the RA strategy was used. His schema related to Work-Energy was too weak to solve problem #5, #2, and even #7. For example, in problem #5 P rated it as an easy problem, but all other solvers rated it as hard or medium. P did not understand the problem fully, so he thought it was easy. To P, there were no new problems among the eight MPT problems. When more time was spent in the problem solving procedure, P tended to lose his pattern of thought (e.g., #1 and #7). Even though P got a relatively low grade in the physics course, his problem solving results in the MPT were relatively good. That was because he could solve some of the relatively easy problems correctly. P's confidence was matched well with the solving result and very diverse from 1 through 10.

Table 8 is the summary of P's solving of the MPT problems. For each problem in the Mechanics Problem Test
MPT), P's familiarity, representation, solving strategy, errors during problem solving, characteristics of problem solving, solving result, confidence on the answer, like/dislike, difficulty of the problem, and time spent to solve it are summarized.

P's errors could be classified as following: (1) not understanding the problem (e.g., #6, #2, #5); (2) not understanding the concepts (e.g., #7, #6); (3) not recalling equation needed (e.g., #7, #6); and (4) unit conversion error (e.g., #3, #8).

During problem solving, P often said that if formulas were given, he could solve the problems. However his problem was not formula recall, rather understanding the mechanics principles and concepts were real problems for him.

P did not receive good grades through the physics series. This may be because he spent too much time trying to solve the problems; he was not a quick problem solver. In tests like the MPT, P might get a better score.

By comparing P's chosen problem sequence and the results of his problem solving, P's choice, which was the easiest to the most difficult, did not match. That contradiction may be related to his surface processing during the prestudy session for deciding his problem solving sequence.
Table 8

Summary of P's solving of the MPT problems

<table>
<thead>
<tr>
<th># familiarity</th>
<th>problem representation</th>
<th>solving strategy</th>
<th>errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 familiar</td>
<td>F-K</td>
<td>RA</td>
<td>not deal with friction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K-D</td>
<td>use linear motion</td>
</tr>
<tr>
<td>2 know</td>
<td>W-E</td>
<td></td>
<td>not consider whole system</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>not understand assumption</td>
</tr>
<tr>
<td>1 know</td>
<td>F-K</td>
<td>K-D</td>
<td></td>
</tr>
<tr>
<td>5 know</td>
<td>F-K</td>
<td>K-D</td>
<td>understand as F-K not keep forcing</td>
</tr>
<tr>
<td>4 familiar</td>
<td>F-K</td>
<td>RA</td>
<td>incorrect equation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K-D</td>
<td>computational error</td>
</tr>
<tr>
<td>3 familiar</td>
<td>F-K</td>
<td>K-D</td>
<td>unit conversion</td>
</tr>
<tr>
<td>7 familiar</td>
<td>F-K</td>
<td>M-E</td>
<td>not understand concepts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>not recall equation</td>
</tr>
<tr>
<td>8 know</td>
<td>F-K</td>
<td>K-D</td>
<td>unit conversion</td>
</tr>
</tbody>
</table>

# problem number
* blank in solving strategy means it could not be identified among the K-D, M-E and RA strategies.
Table 8 (continued)

<table>
<thead>
<tr>
<th># characteristics</th>
<th>result</th>
<th>confidence</th>
<th>dis/like</th>
<th>time difficulty (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>wrong</td>
<td>1</td>
<td>don't mind hard</td>
<td>26</td>
</tr>
<tr>
<td>2 misunderstood last sentence</td>
<td>wrong</td>
<td>6</td>
<td>like medium</td>
<td>10</td>
</tr>
<tr>
<td>1 change signs lost track did twice almost</td>
<td>right</td>
<td>6</td>
<td>like medium</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>wrong</td>
<td>7</td>
<td>like easy</td>
<td>5</td>
</tr>
<tr>
<td>4 check answer use one from two answers</td>
<td>right</td>
<td>10</td>
<td>like easy</td>
<td>10</td>
</tr>
<tr>
<td>3 not realize error almost correct</td>
<td>10</td>
<td>like easy</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>7 make equation gave up to solve</td>
<td>wrong</td>
<td>1</td>
<td>don't mind hard</td>
<td>28</td>
</tr>
<tr>
<td>8 calculate scale factor check answer try to make sense</td>
<td>right</td>
<td>6</td>
<td>don't mind medium</td>
<td>11</td>
</tr>
</tbody>
</table>

Among the three problems having the same algorithm, P did not solve problem #3 correctly. For problem #8 he also did not convert the unit to m, but he checked his solution
and found the mistake whereas for problem #3 he did not check. That check made a difference.

4.3 CASE E

4.3.1 Learning history

E is a sophomore student in pre-civil engineering. He studied physics in the 12th grade at a suburban high school. The course was the more math, not calculus, based course of the two courses offered at the high school.

E said he liked high school physics very much because of problem solving. E said he enjoyed reading the problem, picking out information, organizing, and getting the answers.

At this university, E studied the first course of the physics series during autumn quarter of 1988 and received a grade of A, and the second course during winter quarter of 1989 and received a grade of A. At the time of this interview, spring of 1990, E was taking the third course. E was highly confident about his physics knowledge and very proud of his good grades in the physics courses.
4.3.2 Test results on related variables

E believed scientific theories are created and relationships are discovered. He thought that the concept 'demon' can be a part of science because it can be observable. Because physics tests are based on mathematics, and facts, and since all are memorized, not much of physics ability is measured. He thought an old theory is erroneous and the new theory is a correction of former mistakes. E's responses on the VSP questionnaires are given in Appendix K.

In item #1 a) of the RLT, when the interviewer asked him to explain his answer, he drew a diagram. While saying "five times as many boys," E made a dot on the girl side and five dots on the boy side and said "that wouldn't give equations, multiplying 5 times G makes the same. For one girl, there are five boys." In item #1 c), E was confused and did not understand the sentence.

E reversed the ratio of the radii of the two cylinders in item #2. However, E was confident in his answer because making a mistake twice always makes a correct answer. He admitted that part of his problem solving difficulty was related to his quickness. It looks like E likes to rush into the problems and misses some of the small things.
4.3.3 Misconceptions

E did not apply Newton's third law in the collision context, did not calculate the acceleration with time and distance in the slope and plane, and remembered eight equations. He had a pretty good understanding of energy conservation and momentum conservation, and could write the equations for kinetic energy, potential energy, and frictional force on the slope. Summaries of E's misconceptions by items are in Table 12, p131.

4.3.4 Prestudy and problem sequence

E read quickly through the prestudy material until he reached the "slope" material. He paid particular attention to the pages on frictional force on a slope, on work and kinetic energy, and on elastic forces, and especially on the equation on elastic collision between two bodies. E tried to memorize it, but he did not use it later. That was the only equation written in his notes.

After seeing the eight problems for four minutes, E chose the sequence as 1-7-3-4-8-6-5-2. He classified them in two parts: motion (1,7,3,4,8) and energy (6,5,2). Then he arranged them from easier to harder within the two parts.
4.3.5 Problem solving

4.3.5.1 Problem representation

Among three problems which need the W-E representation, E used the correct representation for two problems (#2 and #5). For problem #5, as soon as his reading was finished, E understood that the problem seemed similar to a spring problem and that potential energy is converted to kinetic energy. The problem context might have given him a hint about using the W-E representation based on his previous experiences. In problem #2, he tried to use the momentum conservation principle, but could not find the initial velocity. He changed his thought to energy conservation because the word "How much energy" was included in the problem. For all other problems except #2 and #5, the F-K representation was used.

At the prestudy session, E classified problem #6 as an energy problem, but at the problem solving session he understood it as an F-K one.

I: You put this problem in energy category originally.

E: I didn't use energy anywhere at all. That's why . . . Maybe I forgot (that) I set this problem. Before this problem, I solved all problems using this way. So I just started to solve this problem with the same way.
This was one example of 'Einstellung,' (Sweller, 1989) which is an incorrect classification because of former experience. In addition he seemed to be affected by having to determine equations for acceleration, distance, and velocity. So he kept using equations on linear motion. For him, the W-E representation was a little bit easier than the F-K one.

E understood that problem #4 was similar to #7 because they both used the linear motion formula and made two equations equal. He thought that #4 was the horizontal version of #7.

While reading the problem, E usually drew a diagram showing the physical representation or talked about it, such as the initial velocity being zero.

For the picture problems like #8, E got a lot more information by looking at the picture and spent less time reading the problem. To him, a diagram as part of a problem was very helpful. Pictures or word problems did not help much in the solving but the picture helps him to understand the problem.
4.3.5.2 Solving strategy

E used K-D strategy in four problems and RA strategy in one problem. In one problem (#6), he started with RA strategy then changed to K-D strategies. In two problems (#1 and #5), his solving strategy could not be identified as any one of the three strategies.

4.3.5.3 Errors

E did not understand what the problem asked for in problem #1. He only perceived the need to calculate the time from the top to the 50-m point. Half-way through reading the problem, he made a decision on what the problem requested even though it was not correct.

In problem #7, E incorrectly recalled the linear motion formula as the correct one, which was in the PKT. He forgot that it used the initial velocity instead of the final velocity. E's second error was making the two equations equal because they had different time variables. In addition, E did not make use of an additional equation here.

In problem #3, E understood correctly what the problem meant, but he did not convert units, and made computational errors. During the solving of this problem, E questioned himself two times about the fact that his answer was much greater than he expected. But he did not check why it
occurred because the calculated number was smaller than the given number, which was reasonable. In problem #8, E measured a distance from bottom of Jim to head of Clara. He also seemed to be affected too much by the word given in the problem sentence.

Again E used the incorrect equation for the linear motion in problem #6. In addition E assumed that the given upward speed was the same as the downward speed when the block went back to the same point, which was not correct.

E understood problem #5 as a W-E one so he equated the potential energy of the slingshot and the kinetic energy of projectile. He could not remember how to compute the potential energy when the force varied with the distance.

E understood that the EC principle could be used in problem #2. At first he thought about momentum conservation, but gave up quickly because there was no initial velocity of the bullet. He could not get the initial velocity of the bullet using the momentum conservation principle because he felt that the initial velocity was required.
4.3.5.4 Confidence

When E did not recognize his error, it did not influence his confidence level (e.g., #1 and #8). E sacrificed his confidence to solve problem #7. During the velocity calculation, which turned out to be useless, he struggled with all signs. These things made his confidence rating lower (6). He was confident in his answer that the final velocity was zero, because a lot of problems had simple answers like that and friction was great enough. He believed that the people who designed the problem made it zero. In many cases, E expected his answer to be in a certain range and compared his calculated answer with it.

If a problem was challenging to him, E liked it. E stated that if a problem was too difficult and confusing, he would not like it.

4.3.5.5 Characteristics

E was a predictor. He often predicted what the order or range of his answer should be before he got it. For example, when he got 31 as the t value for problem #1, he recognized something was wrong because the value did not match with his expected value of 1 or 2 seconds. In problem #3, E expected the answer would be ten times smaller than the given number before starting to write down any equations or
calculate anything. In other problems, like #4, #6, and 7, E predicted a range for the answer and checked it with his calculated number. When he got 16 seconds as his answer for problem #4, E said that there must be another solution.

E was a quick but not thorough reader. In problem #1, he misunderstood the problem. Later he explained his error. When he read "from 50-m high point," he decided he knew what this problem meant and interpreted "from" as "to."

As seen in the previous section, E sacrificed his confidence to get an answer for problem #7. Even though he was not sure about it, he assumed the two times were the same to solve the simultaneous equations.

In problem #5, E tried to relate the dimension of force and spring constant to substitute force for the constant. He could not, because it was too complicated for him at that time. He believed that:

(The) problem is always perfect, that means all necessary information is in there. When a problem seems not to have enough information to solve it, the fault is always on me. Based on my previous experiences, there is no way that problem does not have enough information.
4.3.6 Summary

E was a quick problem solver. He seemed to be overconfident in some relatively simple problems. He spent less than eight minutes for each of five problems. During his problem solving, E made some mistakes related to his quickness and/or carelessness. In problem #8, he measured the wrong distances; in #4, he forgot to consider the initial 30 m displacement; in #1, he did not finish reading the whole problem sentence; and in #3 and #7, he made computational errors. He commented that quickness was a chronic problem for him.

E had fewer misconceptions and a better memory for mathematical definitions related to the MPT than did P or K. For example, calculating the acceleration of the moving block on a slope, E was better than P. E used the W-E representation when it should be used, such as for problems #2 and #5. However, the result of problem solving was not directly related to the student's amount of declarative knowledge. Some confounding variables, such as his careless attitude, computational errors, and disorganized procedures contributed to his poor results. He classified the eight MPT problems in terms of content (force and energy) at the prestudy session. This reflected a deep processing in his understanding of the problems (Voss, 1989).
expected a certain range for his answers in many cases (e.g., #1, #7, #3, #4, and #6). In problem #5, E used the matching unit method to develop a formula he could not remember. The attempt was not successful.

Table 9 is the summary of E's solving of the MPT problems. For each problem in the Mechanics Problem Test (MPT), E's familiarity, representation, solving strategy, errors during problem solving, characteristics of problem solving, solving result, confidence on the answer, like/dislike, difficulty of the problem, and time spent to solve it are summarized.

E's errors could be classified as following: (1) misreading the problem statement (e.g., #1, #6); (2) misunderstanding the problem (e.g., #4, #6); (3) not understanding physics concepts or principles (e.g., #7, #6, #5, #2); (4) computational errors (e.g., #3, #7); (5) unit conversion error (e.g., #3); and (6) wrong measurement (e.g., #8).

According to the results of the PKT and the problem solving process of the MPT, E had a lot of physics knowledge and had a high level of confidence in himself. But he got very poor results on the MPT because of trivial mistakes, such as misunderstanding of problem sentence, computational errors, and unit conversion errors.
Table 9

Summary of E's solving of the MPT problems

<table>
<thead>
<tr>
<th># familiarity</th>
<th>problem representation</th>
<th>solving strategy*</th>
<th>errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 know</td>
<td>F-K</td>
<td></td>
<td>misunderstand sentence</td>
</tr>
<tr>
<td>7 familiar</td>
<td>F-K</td>
<td>RA</td>
<td>use same time not understand equation signs in order unit conversion computation</td>
</tr>
<tr>
<td>3 new</td>
<td>F-K</td>
<td>K-D</td>
<td>not considering displacement</td>
</tr>
<tr>
<td>4 know</td>
<td>F-K</td>
<td>K-D</td>
<td></td>
</tr>
<tr>
<td>8 familiar</td>
<td>F-K</td>
<td>K-D</td>
<td>wrong measure</td>
</tr>
<tr>
<td>6 new</td>
<td>F-K</td>
<td>RA</td>
<td>incorrect equation same acceleration up and down</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K-D@</td>
<td></td>
</tr>
<tr>
<td>5 new</td>
<td>W-E</td>
<td></td>
<td>not make equation</td>
</tr>
<tr>
<td>2 familiar</td>
<td>W-E</td>
<td>K-D</td>
<td>initial velocity of bullet</td>
</tr>
</tbody>
</table>

* blank in solving strategy means it could not be identified among the K-D, M-E, and RA strategies.
@ obtained the information from the second trial
The three problems (#1, #3, #8), having the same algorithm, were perceived differently to E as know, new, and familiar respectively. E could not solve any of them correctly, although he had confidence ratings of 9 or 10 on his answers.
Simple computations might not compel him to check his computational procedure because he thought there was no way he could make an error (e.g., #3).

4.4 CASE M

4.4.1 Learning history

Subject M is a freshman who hopes to major in engineering. He has completed the first course of the physics series and received a grade of A. He came from Tunisia. He studied most of the mechanics part of physics with simple equations in a math and physics track in a French high school in Tunisia. After graduating from high school in 1987, he studied at a Tunisian college for two years. In college, he studied 4 semesters of physics for engineers, covering most of the first course content with a greater depth and sophistication of math than commonly taught in the U.S. It was impressive that M thought of himself as an engineer.

4.4.2 Test results of related variables

M said science is a game in which scientists look at a group of objects, determine the rules for them, and predict their behaviors. He believed that scientific knowledge is always changing and that the scientific method is the best
method. Appendix L contains M's responses on the VSP questionnaires.

In item #1 of the RLT, M was confused and did not understand some of the sentences; for example, he interpreted item #1 as there being more professors than students. This might be related to his reading comprehension. In the CST, he remembered and used the quadratic formula. He made some minor calculation errors. M's responses of the RLT and CST by items are summarized in Table 12, p131.

4.4.3 Misconceptions

M did not have a clear definition of acceleration, remembered nine equations except one on the stored energy in a spring, and had a misconception about the kinetic coefficient of friction. Except for these, M had a very fluent knowledge of mechanics. A summary table of M's misconceptions by item is provided in Table 12.

4.4.4 Prestudy and problem sequence

During the prestudy session, M read quickly and continually commented "I know." He paid attention to the page on conservation of mechanical energy, wrote down only unfamiliar mathematical definitions, and read thoroughly the pages on momentum conservation and collision. Finally he looked briefly from the beginning to the end one more time, read-
ing the information on momentum conservation and collision parts over again.

M did not care about the sequence because he was very confident about his problem solving ability. The sequence was selected by the interviewer based on content (linear motion-both-EC) within problem representation (word-diagram-pictorial); so the other was 4-1-5-7-6-2-3-8.

4.4.5 Problem solving

4.4.5.1 Problem representation

M used the W-E representation in all four problems which required its use or could use it (see Table 5).

M explained his method for his selection of the problem representations at an additional interview session:

In #5, there are forces pulled back .5 cm, that's work and you have mass, it can be expressed (as) \( \frac{1}{2}mv^2 \), kinetic energy, at that time I neglected the time (.05 sec). In #7, there are speed and height. When you have the height, I think of energy of the weight as the same. Once you have height, it implicitly has a force. Height implies potential energy; speed implies kinetic energy. In #6, at first I didn't think it as W-E problem. (I) thought about Newton's law. When I see a diagram like this, I think about Newton's law because usually these kinds of problems can be solved using Newton's law (from a textbook), \( F = ma \). With \( x \) and \( y \), I can solve the final speed by differentiating them by time, but that way seemed too (be) longer (took 2 pages) and too difficult to get through it. But I aware (knew) the speed that's why I chose W-E. So I chose W-E, \( KE = \frac{1}{2} W \). This way is easier. You can do it both. In #1, (I) maybe not solve this problem
using W-E. If they ask time, (it is) not W-E problem. #6 requires velocity, it could be W-E. #7 can be solved (using) linear motion but it'll be hard. If there is only one velocity, (I'll) think about linear motion. If there are two velocities, it's W-E. #3,4,1,8 ask time, so linear motion (will be used). #5 asks speed, it's W-E problem.

To M, pictorial problems were the same as the word problems. A diagram in a problem was of great help for him.

4.4.5.2 Solving strategy

In all 8 problems, M used the K-D strategy. M is the only solvers who used the K-D strategy consistently. It shows his fluent declarative knowledge and strategic knowledge.

4.4.5.3 Errors

M made an error in solving a quadratic equation in problem #4 which he solved successfully in the Computational Skill Test. In problem #5, M considered that the 50 N of force worked through .5 m distance, which was incorrect. In an additional interview session, M explained it as "I know it's not reasonable." But he remembered sometimes there were physics problems in which rough assumptions had to be made to solve the problem. He did not realize that this problem used stored energy or that he should use the stored energy concept with the spring case. He thought
that the equation, \( U = \frac{1}{2}kx \), can be used only with the spring. Even though M got a velocity, he said it was the final velocity. Then he doubted the velocity in his procedure because the time variable was not used in his calculation. He made an error in reading the problem sentence (e.g., #7 and #6). Misconceptions about the coefficient of kinetic friction and about the speed at the same point when moving in the upward and downward directions on the slope made his problem solving result in #6 incorrect.

To find the missing velocity of the bullet, M used the equation for an elastic collision. The situation of problem #2 was not an elastic collision. In problem #8, M set his frame of reference incorrectly in his mathematical equation.

4.4.5.4 Confidence

His self-confidence on his problem solving ability was very high. During problem solving, M frequently said "most of the students will not solve this problem" or "this problem is medium to me but hard to average students." In summary, M's criteria on likeliness was:

If I can find answer, I'll like it. Unless, it depends on, if I learned something from that problem, I'll like that.
He never said his confidence was 10 no matter how confident he was of his answer, and never said that his confidence was lower than 6. He rated problem #8 easier than #3, and problem #3 easier than #4.

4.4.5.5 Characteristics

As seen in the solving strategy section, M used the K-D strategy consistently. This indicates he was a good planner. Usually after reading a problem, he set up a plan to solve the problem. He also tried to make sense of the problem. M thought that all variables given in the problem sentence would have to be used to solve the problem (e.g., #5). In a regular test, he would go out of his way to get half credit. When M saw -9521.6 J as the heat energy during the second try of the problem, he doubted his answer. But he understood that some numbers in physics problems are not simple. M said problem #8 was not a physics problem, because:

We have to convert something like that, that's not nice. That's not physics because after spending half the time to know this 100 (mm) (could be) how much meters. But I can do (it) if you want.

M believed that students have to use all given numbers because they did not give too many numbers in the problem. When a number is given in the last part of the problem, it looks more important than numbers given in the front part of the problem.
4.4.6 Summary

M was an expert-like student. He used the W-E representation when it should be used (e.g., #5 and #2). In addition he was the only solver who used the W-E representation in problems when either of the two representations could be used (e.g., #6 and #7). This reveals fluency in his schemata on mechanics and various problem-solving heuristics (Greenbowe, 1983; Whimby & Lochhead, 1986). That kind of flexibility was observed from expert's problem solving in studies by Park (1988) and Sweller (1989). M used the K-D strategy in all eight problems. This indicates a well-structured knowledge system which he used for applying effective problem solving strategies.

M had the smallest number of misconceptions among the four solvers. During problem solving, he usually set a detailed plan for solving problems before writing down any equations. This shows his organization skill is similar to one of expert's characteristics in metacognitive behavior (Eylon & Linn, 1980; Lester et al., 1989). However the misconceptions on the kinetic frictional coefficient hurt his solving of problem #6. Unrecognized mistakes, sometimes careless mistakes, such as misunderstanding the problem (#7), equation solving (#4), and reference frame (#8) also hurt his problem solving results. M tried to make
sense or get a reasonable answer (e.g., #4 and #2). He also had the wisdom to do what he could do as if he were trying for half credit for a physics test. His confidence ratings were high and consistent, ranging from 7 to 9. He did not express a preference for the problem sequence at the prestudy session due to his high level of confidence. This was consistent with Greenbowe's (1983) result on good problem solvers' confidence ratings. M did not check his answer in a simple problem (#7), not because of his solving speed (Narode, 1987), but because of its easiness.

Table 10 is the summary of M's solving of the MPT problems. For each problem in the Mechanics Problem Test (MPT), K's familiarity, representation, solving strategy, errors during problem solving, characteristics of problem solving, solving result, confidence on the answer, like/dislike, difficulty of the problem, and time spent to solve them are summarized.

M's errors could be classified as following: (1) misunderstanding the sentence (e.g., #7, #6); (2) not understanding the problem (e.g., #2, #5, #6); (3) not understanding physics concepts (e.g., #6, #8); and (4) computational error (e.g., #4).

M used diverse representation to solve the problems. For example in problems #5 and #6, he tried to use princi-
Table 10

Summary of M's solving of the MPT problems

<table>
<thead>
<tr>
<th># familiarity</th>
<th>problem representation</th>
<th>solving strategy</th>
<th>errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>know</td>
<td>F-K</td>
<td>K-D</td>
</tr>
<tr>
<td>1</td>
<td>know</td>
<td>F-K</td>
<td>K-D</td>
</tr>
<tr>
<td>5</td>
<td>new</td>
<td>W-E</td>
<td>K-D</td>
</tr>
<tr>
<td>7</td>
<td>new</td>
<td>W-E</td>
<td>K-D</td>
</tr>
<tr>
<td>6</td>
<td>know</td>
<td>F-K</td>
<td>K-D</td>
</tr>
<tr>
<td>2</td>
<td>new</td>
<td>W-E</td>
<td>K-D</td>
</tr>
<tr>
<td>3</td>
<td>know</td>
<td>F-K</td>
<td>K-D</td>
</tr>
<tr>
<td>8</td>
<td>know</td>
<td>F-K</td>
<td>K-D</td>
</tr>
</tbody>
</table>

# problem number
Table 10 (continued)

<table>
<thead>
<tr>
<th># characteristics</th>
<th>result</th>
<th>confidence</th>
<th>dis/like</th>
<th>difficulty</th>
<th>time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 check answer</td>
<td>almost</td>
<td>9</td>
<td>like</td>
<td>medium</td>
<td>6</td>
</tr>
<tr>
<td>make sense</td>
<td>correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>right</td>
<td>9</td>
<td>like</td>
<td>easy</td>
<td>3</td>
</tr>
<tr>
<td>5 tend to use</td>
<td>wrong</td>
<td>6</td>
<td>like</td>
<td>hard</td>
<td>9</td>
</tr>
<tr>
<td>redundant one</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>almost</td>
<td>8</td>
<td>like</td>
<td>hard</td>
<td>4</td>
</tr>
<tr>
<td>correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 very confident</td>
<td>wrong</td>
<td>8</td>
<td>like</td>
<td>medium</td>
<td>8</td>
</tr>
<tr>
<td>at first</td>
<td></td>
<td></td>
<td></td>
<td>9@</td>
<td>11%</td>
</tr>
<tr>
<td>2 expect reasonable</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>very hard</td>
<td>12</td>
</tr>
<tr>
<td>number</td>
<td></td>
<td>7@</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>half credit</td>
<td></td>
<td>8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>right</td>
<td>9</td>
<td>like</td>
<td>medium</td>
<td>10</td>
</tr>
<tr>
<td>8 not physics</td>
<td>almost</td>
<td>9</td>
<td>not like</td>
<td>easy</td>
<td>11</td>
</tr>
<tr>
<td>correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

@ information gathered from the second try
% information gathered from the third try

...ples both from the W-E and the F-K representations. In addition, the W-E representation was used in problems #2 and #7. This appears similar to the result of an expert's
capability of problem representation (Park, 1988). M had a relatively fluent declarative knowledge and was very proud of his problem solving ability compared with the other solvers. He continually commented that his difficulties on the MPT problems were different from the average students.

For all three problems having the same algorithm, M said he knew how to solve them, but he solved only two problems (#1 and #3) correctly. M expressed his feelings about problem #8 and appeared to lack the motivation to solve it.
CHAPTER V
DISCUSSION

5.1 ROLES OF PROBLEM SOLVING PROCESS VARIABLES

In this section, the characteristics and/or patterns of the problem solving process variables are discussed. The variables discussed include the solvers comments and ratings related to their familiarity, problem representation, solving strategy, confidence on answer, like/dislike, and difficulty of the problem. Summaries of each variable by problem and by solver are given in Table 11. Errors, characteristics, and time spent in problem solving by each problem and solver are also provided in the table. The table was generated from the tables (Tables 7, 8, 9, and 10) for each of the problem solvers.
Table 11

Problem solving process variables by MPT problems

<table>
<thead>
<tr>
<th>Problem Number</th>
<th>F am</th>
<th>rep</th>
<th>st r</th>
<th>errors</th>
<th>character</th>
<th>result</th>
<th>confi</th>
<th>dis/like</th>
<th>time</th>
<th>diff (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 K know F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>make equation</td>
<td>wrong</td>
<td>8</td>
<td>like</td>
<td>5</td>
<td>6</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>P know F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>matching unit</td>
<td>right</td>
<td>6</td>
<td>like</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E know F-K</td>
<td>K-D</td>
<td>misunderstanding</td>
<td>sentence</td>
<td>wrong</td>
<td>10</td>
<td>like</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>M know F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>expect answer</td>
<td>right</td>
<td>9</td>
<td>like</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>2 K fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>expect answer</td>
<td>wrong</td>
<td>2</td>
<td>don't like</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>expect answer</td>
<td>wrong</td>
<td>2</td>
<td>don't like</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>P know W-E</td>
<td>not consider whole</td>
<td>system</td>
<td>not understand</td>
<td>result</td>
<td>wrong</td>
<td>6</td>
<td>almost</td>
<td>correct</td>
<td>almost</td>
<td>9</td>
</tr>
<tr>
<td>E fem W-E</td>
<td>K-D</td>
<td>not recall equation</td>
<td>misunderstanding</td>
<td>right</td>
<td>6.5</td>
<td>almost</td>
<td>correct</td>
<td>almost</td>
<td>9</td>
<td>like</td>
</tr>
<tr>
<td>M fem W-E</td>
<td>K-D</td>
<td>not recall equation</td>
<td>expect number</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>12</td>
<td>70</td>
<td>very hard</td>
<td></td>
</tr>
<tr>
<td>3 K fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>wrong substitution</td>
<td>half credit</td>
<td>wrong</td>
<td>4</td>
<td>like</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>match equation</td>
<td>matching unit</td>
<td>given number</td>
<td>not realise</td>
<td>almost</td>
<td>10</td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>expect answer</td>
<td>almost</td>
<td>9</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>expect answer</td>
<td>almost</td>
<td>9</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>4 K fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>wrong</td>
<td>8.5</td>
<td>like</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>RA</td>
<td>incorrect equation</td>
<td>check answer</td>
<td>right</td>
<td>10</td>
<td>easy</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>RA</td>
<td>incorrect equation</td>
<td>check answer</td>
<td>right</td>
<td>10</td>
<td>easy</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>RA</td>
<td>incorrect equation</td>
<td>check answer</td>
<td>right</td>
<td>10</td>
<td>easy</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>make sense</td>
<td>correct</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>make sense</td>
<td>correct</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>make sense</td>
<td>correct</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>make sense</td>
<td>correct</td>
<td>wrong</td>
<td>7</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6 K fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>go up to</td>
<td>make simple</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>go up to</td>
<td>make simple</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>go up to</td>
<td>make simple</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>RA</td>
<td>not recall equation</td>
<td>go up to</td>
<td>make simple</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>7 K fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>estimation</td>
<td>wrong</td>
<td>3</td>
<td>don't mind</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>estimation</td>
<td>wrong</td>
<td>3</td>
<td>don't mind</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>estimation</td>
<td>wrong</td>
<td>3</td>
<td>don't mind</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>estimation</td>
<td>wrong</td>
<td>3</td>
<td>don't mind</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 K fem</td>
<td>F-K</td>
<td>M-E</td>
<td>not recall equation</td>
<td>correct</td>
<td>make answer</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>P fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>make answer</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>E fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>make answer</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>correct</td>
<td>make answer</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>9 E fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M fem</td>
<td>F-K</td>
<td>K-D</td>
<td>not recall equation</td>
<td>almost</td>
<td>6</td>
<td>like</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# Problem Number
* Blank in solving strategy means it could not be identified among the Knowledge-Development (K-D), Means-Ends (M-E), and Random (RA) strategies.

* Information got from additional interview session
5.1.1 **Familiarity**

The degree of familiarity came from solver's response during the interviews immediately following the last problem solving session for the MPT. Familiarity was the solver's perception as to the amount of past experience they had had with this kind of problem. The levels for familiarity were: (1) "know" meaning the solver said they knew how to solve the problem; (2) "familiar" meaning the solver remembered having seen the problem or similar problems but did not know how to solve it; and (3) "new" meaning the problem was not familiar. For one case (M) there were no "familiar" problems. He indicated he knew how to solve five problems and that three problems were new to him. There was not a direct relationship between familiarity and the solving result. Of the 32 instances (4 solvers x 8 problems), 11 were listed as familiar, 12 as known and nine as new.

5.1.2 **Problem representation**

Overall, the solvers indicated that the Force-Kinematics (F-K) representation was used to solve 27 of the 32 instances, the Work-Energy (W-E) representation for 8 of the instances. The total is more than 32 for three of the problems were solved by both representations. K used the F-K representation for all problems. P did also except for
problem #2. E identified F-K for all problems except #2 and #5 while M used the W-E representation four times on problems #2, #5, #6, and #7.

Two problems (#2 and #5) required the use of W-E principles. All the subjects understood problem #2 as requiring W-E principles. This was probably because the problem asked specifically for how much energy was transformed. In problem #5 two solvers did not understand it as a W-E problem. They could easily set up kinematic equations using the given variables such as force, mass, travel time, and distance. In problems #6 and #7, only one subject (M) had the W-E representation. That might come from his past success in solving problems like these and his fluent declarative knowledge related to W-E principles.

Specific words given in the problem sentence had a major influence on the selection of the representation. For example, M said if the problem included mass and acceleration, then work could be considered. If problem requested time, it could not be a W-E problem; if it requested velocity, it could be a W-E problem. M used very complicated rules like this (see Appendix L). The method had weaknesses when problems having superfluous or deficient information were encountered. If solvers focused on a given word too much, they could not figure out the problem (e.g., problem #5).
It may be easier to figure out movement in a problem if it could be seen in the solver's imagination than to figure out the work-energy relationships which could not be visualized. Prior experience in the problem context certainly helps a solver represent the problem. A kind of functional fixedness, Einstellung (Sweller, 1989), was another variable which may have influenced the problem representation. If a schema for a certain mechanics content is not well developed in an individual, the use of the schema may be prohibited. A strong schema, even though inappropriate, will likely be used in the problem solving process. In additional interview sessions, most subjects felt uncomfortable when the interviewer tried to get them to use the energy conservation principle. The level of knowledge of physics concepts and principles, the solver's confidence based upon previous problem solving experiences, and the understanding of the problem may be responsible for the prohibition of the appropriate representation. Between the F-K and W-E representations the W-E was usually the weaker one.

Subjects seemed to more comfortable using the F-K representation rather than the W-E representation. All problems, except one, which were solved correctly or almost correctly were done using the F-K representation. This may have resulted because the F-K problems (e.g., #1, #3, #4,
and #8) were viewed as easier than the W-E problems (e.g., #2 and #5). For the problems which could be solved either way most solvers, except M, tried to solve them using the F-K representation.

5.1.3 Problem solving strategy

For all problems which solvers did correctly or almost correctly, the K-D strategy was used. By their nature some problems required the Knowledge-Development (K-D) strategy. For example, to solve problems #1, #3, and #8, subjects should have calculated the two time periods and then subtracted them. Problem #6 asked subjects to follow the movement of the block, which is moving up, stopping at the maximum point, and going down to the bottom.

When a problem was hard to figure out and to understand, the M-E or RA strategies prevailed. The M-E strategy was used in cases where solvers easily recalled the equation which involved the given variables. In that case, the solvers did not set up a preplan to solve the problem; they just tried to recall some related formulas. During the practice of the strategies, solvers sometimes could find a way to use the K-D strategy. The more physics concepts and principles the solvers knew, the more time they devoted to setting up the solving plan before calculations, and the more frequent the use of the K-D strategy.
In terms of solving strategy, no problems were solved correctly without using the K-D strategy. This fact coincides with results of Park (1988), Simons (1988), and Smith & Good (1984). Among 28 problem solving instances which identified the solver's solving strategies, all solvers who said they knew how to solve the problems used the K-D strategy. This does not directly support Sweller's (1989) finding which was that with less familiar problems, the M-E strategy was more frequently used. The frequency of selection of K-D strategy depended upon each solver (see Table 16).

5.1.4 Confidence

When solvers solved a problem correctly, their confidence ratings were at least 5 on a 10 point scale. Although solvers often indicated maximum confidence, sometimes the answer was wrong. There were no instances of correct solutions when solvers rated their confidence less than 5. In the confidence range greater than 8, most answers were correct. For problems where low confidence was indicated, solving strategies other than the K-D were more frequent.

When a problem was hard to figure out or understand and when the related mechanics concepts/principles were not clear to understand, the subjects's confidence rating was
generally low. When the given variables were easily matched to certain formula(s), confidence ratings were high. If one or more variables in a problem was not used in the problem solving process, confidence levels were very low. When relevant formulas could not be recalled, the solver's confidence was lower. But when solvers could develop the formula, the confidence was generally increased.

Most of the solver's errors during problem solving were not detected by the solvers. For example, unit conversion errors, calculation errors, misreading and interpretation of the problem were seldom discovered during problem solving.

When solvers did not perceive an error, their confidence ratings were generally high. When the calculated answer did not match the expected range of value, confidence was lowered. Koplowitz (1979) reported that poor problem solvers tend to be more satisfied with their solutions than good problem solvers. However, in this study there was no noticeable trend in terms of confidence related to the correctness of the answer. K who had no correct solutions had relatively low confidence; M showed high and consistent confidence regardless of whether the answer were correct or incorrect.
5.1.5 Like/dislike

Solvers could express their feelings on the given problems by selecting one of three: like, not like, or not mind.

The solvers liked most of the problems, 23 of 32. The reasons given were: (1) easy to understand the problem or to solve it; (2) does not require an equation; (3) a lot of information was given; (4) logical and intuitive; (5) interesting or learned something; (6) challenging; and (7) enough time was given. In only four instances (K #2 and #6, E #5, M #8), did the solvers indicate a dislike for the problem. This was primarily because they found these problems hard to figure out or understand. M did not like problem #8, because it was not a physics problem, and, since it was his last problem, he expected it to be more challenging. M did not determine his own problem solving sequence. There was no relationship between liking the problem and success in solving the problem.

5.1.6 Difficulty

Solvers could express their perception of the difficulty of the problem by choosing one of the three: easy, medium, or hard. Problems #7, #6, and #2 were rated as hard problems; problems #1, #3, #4, and #8 were rated as easy prob-
lems. In all easy problems, subjects used the F-K representation and liked them. Overall, the harder the problem rating, the less confidence solvers expressed for their answer, and the more time spent on the problem. No problems requiring more than 15 minutes were solved correctly. Overall, confidence, like/dislike, and difficulty of a problem were interrelated. Success in solving the problems, however, was not highly related to these variables.

5.2 ROLES OF KNOWLEDGE AND SKILLS

In this section the four problem solvers' reasoning skills, computational skills, and prerequisite knowledge are presented. The MPT problems for which individual solvers did not have the required knowledge and skills are identified. Then solvers' problem solving processes on the problems are analyzed considering required knowledge and skills.

Based on the results of the RLT, CST, and PKT summaries each subject's reasoning skills, computational skills, and misconceptions are analyzed in Table 12.

Table 13 summarizes the information given in Table 12. PKT items #13 a-j asked solvers to recall 10 mathematical definitions on mechanics. Each MPT problem required one or more of the mathematical definitions found in item #13.
Table 12

Four subjects' responses on the RLT, CST, PKT items

<table>
<thead>
<tr>
<th>item</th>
<th>K</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKT 1 different forces &amp; energy different forces &amp; energy</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>2 different forces different forces</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>3 same or different forces different forces</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>4 residual force residual force</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>6 different energy changes different energy changes</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>7 residual force residual force</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>8 confuse speed &amp; position affected by diagram</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>9 same acceleration wrong acceleration</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>10 use a = x/t&lt;sup&gt;2&lt;/sup&gt; use a = x/t&lt;sup&gt;2&lt;/sup&gt;</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>11 units of work &amp; energy energy = force/time</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>12 recall 3 equations recall 6 equations</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>13 +++, +++, +++, +++, +++, +++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>14 +++, +++, +++, +++, +++, +++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>15 +++, +++, +++, +++, +++, +++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>16 +++, +++, +++, +++, +++, +++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>17 +++, +++, +++, +++, +++, +++</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>RLT 1 express wrongly</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>2/5 not solve balance item not solve frog item</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>CST 1 calculation error calculation error</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>2 calculation error calculation error</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>3 calculation error calculation error</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>4 calculation error calculation error</td>
<td>+++</td>
<td>+++</td>
</tr>
</tbody>
</table>

+++ indicates that the response was correct with no error.
Table 12 (continued)

<table>
<thead>
<tr>
<th>item</th>
<th>E</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKT 1</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>2 different forces</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>3</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>4</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>5</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>6</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>7</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>8</td>
<td>+++</td>
<td>meet at two points</td>
</tr>
<tr>
<td>9</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>10</td>
<td>+++</td>
<td>same acceleration</td>
</tr>
<tr>
<td>11 use a = Δv/t</td>
<td>+++ use a = x/t²</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>13 recall 8 equations</td>
<td>recall 9 equations</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>15</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>16</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>17</td>
<td>+++</td>
<td>wrong</td>
</tr>
</tbody>
</table>

RLT 1 misunderstanding sentence misunderstanding sentence
2/5 calculation error +++

CST 1 +++
2 calculation error +++
3 calculation error calculation error
4 +++

+++ indicates that the response was correct with no error.

Therefore, when comparing PKT #13 item, the detailed information contained in each items of #13 has to be considered. Whenever both "**" in a crossection of each item and each problem in Table 6 (page 68) and "-" in a crossection of each item and each solver in Table 13 (page 132) appear, it was decided that the solver did not have enough prerequisites to solve the MPT problem.
Table 13

**Four subjects' prerequisites**

<table>
<thead>
<tr>
<th>item</th>
<th>K</th>
<th>P</th>
<th>E</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKT 1</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
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<td>+</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
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<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
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<td>0</td>
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<tr>
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<td>-</td>
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<td>+</td>
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<td>b</td>
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<td>-</td>
</tr>
<tr>
<td>c</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>d</td>
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<td>+</td>
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<td>+</td>
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<tr>
<td>f</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>g</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<td>-</td>
</tr>
<tr>
<td>17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RLT 1</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2/5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>CST 1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+ means having no misconception
0 means having misconception in a part
- means having misconceptions

By comparing the two tables (Table 6 and Table 13), the MPT problems were identified and classified into two cat-
egories: (1) those problems for which solvers had enough prerequisite knowledge and skills to solve the problem, and (2) those problems for which solvers did not have enough prerequisite knowledge and skills to solve the problem. Table 14 shows for which problem the solver had enough knowledge and skills, and the solving result. A "-" in the table indicates that the solver did not have enough knowledge and skills to solve the problem and did not solve them correctly.

Table 14

<table>
<thead>
<tr>
<th>problem</th>
<th>K</th>
<th>P</th>
<th>E</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>C</td>
<td>W</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>A</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>C</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>W</td>
<td>W</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>W</td>
<td>W</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>C</td>
<td>W</td>
<td>A</td>
</tr>
</tbody>
</table>

Note: C = had prerequisites, solved correctly  
A = had prerequisites, solved almost correctly  
W = had prerequisites, did not solve correctly  
- = lacked prerequisites, did not solve

K did not have one problem for which she was judged to have adequate prerequisite knowledge or skill. She was not able to solve any of the eight problems correctly. P and M had the same six problems (#1, #2, #3, #4, #7, and #8) and
E had seven problems for which they had adequate knowledge and skills. In P's case, the specific content of his misconception in PKT item #14 was not directly related to solving MPT problem #4. In M's problem #6, the misconception measured by PKT item #17 was related to solving it.

Here, problem solving of some MPT problems for which the solvers had enough prerequisites are discussed. The solving of the MPT problems for which the solvers did not have the prerequisites will be discussed later.

First of all, no MPT problems for which solvers lacked prerequisites were solved correctly by the four subjects. And not all of the MPT problems for which solvers had enough prerequisites were solved correctly.

Prerequisite knowledge and skills are very important to solve MPT problem correctly. Table 15 shows that all of the 13 instances in which solvers did not have the prerequisites, they failed to solve them. Most of the minor errors were computational. The other errors were related to failure to read the problem and question carefully before and after solving. Most of the minor errors may have been detected by answer checking before finishing the problem.
Table 15

Numbers of problem in each category

<table>
<thead>
<tr>
<th>result</th>
<th>prerequisites</th>
<th>no prerequisites</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>almost</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>unsolved</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

Although solvers had the prerequisite knowledge and skills, several problems remained unsolved. As seen in Table 15, eight of 19 instances in which the solvers had enough prerequisites were unsolved. In case P, problem #2 and #7 were not solved. P did not consider the total system in #2 and did not understand a necessary assumption given in the last sentence. In problem #7, P represented it as an F-K problem. He was confused by the equation and could not use it correctly. He was not able to gather all of the necessary information from the three points. E did not correctly solve four of the problems although he had enough knowledge to do so. In problem #1, E misunderstood the problem sentence. In #2, he did not figure out how to get the initial velocity of the bullet and did not use the momentum conservation principle. In problem #6 E confused initial velocity with final velocity in the linear motion formula. In problem #7, E did not understand an equation correctly and confused himself after spending a relatively long time (22 minutes). In problem #8, he measured the
wrong distance on the given photograph. E seemed to fail to solve problem #1 and #8 because of his quickness. M incorrectly considered the situation in problem #2 as an elastic collision.

Overall it is interesting to note that three solvers who had the necessary prerequisites did not solve problem #2, and two did not solve #7, even though they could recall enough mathematical equations to solve them and did not have misconceptions related to them.

Problem #2 was expected to be hard to solve. All subjects tried to solve it using the W-E principle. Nobody derived the initial velocity of the bullet using the momentum conservation principle. The multiple stages required for this problem were very hard for the solvers to get through.

Problem #7 was the only problem that nobody said they knew how to solve. All subjects thought that it was a hard problem. All the subjects, except M, understood this problem as the F-K one. Diverse solving strategies were applied. Only M used the K-D strategy; his result was almost correct. The most frequent error was the misunderstanding of the related concepts and the mathematical definitions. For example, E assumed that the two time periods were equal, and applied the constant velocity equation.
Sometimes he confused initial velocity with final velocity in the linear motion formula. Using the EC principle looked like a simpler and easier method than using the F-K formula. The time spent by the three solvers who used the F-K representation was 15, 28, and 22 minutes respectively, whereas M using the W-E representation spent only 4 minutes. In an additional interview session, the interviewer asked solvers why they did not try to solve this problem using the EC principle. They did not seem familiar with the EC principle for solving this problem. E got a correct answer using the EC principle, but during checking his answer he became confused about his procedure. Finally he gave up and did not finish. P was able to get a correct answer with a couple of hints from the interviewer.

In summary, subjects could not solve some problems, although they remembered the required mathematical equations and did not have misconceptions related to the problems. It may be because of (1) careless attitude; (2) lack of broad, integrated schemas on specific content; and/or (3) unorganized solving procedures, especially in long, multistage problems. The last reason seemed to reflect a lack of strategic knowledge and/or reasoning skill in multistep problems. Examples of the strategic knowledge are how to organize their work and/or the ability to read carefully as reported by Greenbowe (1983), Lochhead (1988), and Whimby & Lochhead (1986).
When subjects did not have enough prerequisite knowledge and skills to solve the MPT problems, they tried to compensate for its lack by using whatever methods they could remember. One such method was unit matching to develop a formula. This method was very popular, for example K used the method in #8, #3, and #1, and E used it in #5. It was unsuccessful in all cases. Another method observed was estimation/approximation. In problem #7, K used this method and E used it in #6. These methods were not effective. Without having a strong base of mechanics concepts or principles, the methods always gave the subjects incorrect results.

For the problems which the solvers did not have the prerequisites, solving strategies other than the K-D were frequently used. Table 16 shows solving strategy used by each solver in terms of the problem solving results and prerequisites. Overall, when solvers had adequate prerequisite knowledge and skills, they used K-D strategy more than other strategies.

Problems #5 and #6 are typical examples in this category for all subjects. Excluding P, all three solvers said problem #5 was new to them. E and M tried to solve it based on the W-E representation, but could not. Solvers' confidence level was medium and time spent was relatively
Table 16

Solving strategy in terms of results and prerequisites

<table>
<thead>
<tr>
<th>Case K</th>
<th>prerequisites</th>
<th>K-D</th>
<th>others</th>
<th>no prerequisites</th>
<th>K-D</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>result</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>solved</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>almost</td>
<td></td>
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<td>3</td>
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<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Case P</th>
<th>prerequisites</th>
<th>K-D</th>
<th>others</th>
<th>no prerequisites</th>
<th>K-D</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>result</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case E</th>
<th>prerequisites</th>
<th>K-D</th>
<th>others</th>
<th>no prerequisites</th>
<th>K-D</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>result</td>
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<td></td>
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<table>
<thead>
<tr>
<th>Case M</th>
<th>prerequisites</th>
<th>K-D</th>
<th>others</th>
<th>no prerequisites</th>
<th>K-D</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>result</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>solved</td>
<td></td>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>almost</td>
<td></td>
<td>3</td>
<td>0</td>
<td></td>
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</tr>
<tr>
<td>unsolved</td>
<td></td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

short (4 through 9 minutes). Interpreting this problem as Force-Kinematics was the most frequent, critical error.
For those cases where solvers understood the problem as a W-E one, not having the spring constant given was the another barrier. The solvers were generally confused by superfluous information given in a problem. Although three solvers used the K-D strategy to solve this problem, two of them represented it as the F-K problem, and the remaining one solver understood it wrongly although he used the W-E representation. Identifying a correct representation seemed more important than selecting strategy in this case.

Problem #6 needed equations on both force-kinematics and work-energy. Only M did that, but he had a misconception about the kinetic frictional coefficient. The RA strategy was widely used for this problem. Getting the acceleration of the block on a slope by considering frictional coefficient, slope angle, and gravitational acceleration was the hardest part in the solution of this problem. All subjects spent more than ten minutes on this problem.

In problems which solvers did not have the prerequisites, errors occurred most frequently at the stage of understanding the problem to be solved and gathering the necessary information for solving it. Errors generally occurred early in the problem solving process.

Table 17 shows the types of errors which occurred in each situation according to whether they had adequate pre-
Table 17

Errors in each category

<table>
<thead>
<tr>
<th>result</th>
<th>prerequisites</th>
<th>no prerequisites</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>almost computational skills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>reading problem &amp; question</td>
<td></td>
</tr>
<tr>
<td>unsolved</td>
<td>problem representation</td>
<td>derive formula</td>
</tr>
<tr>
<td></td>
<td>understanding concepts/principles/equations</td>
<td>unit matching estimation/approx.</td>
</tr>
<tr>
<td></td>
<td>multiple steps</td>
<td>previous errors</td>
</tr>
<tr>
<td></td>
<td>careless attitude</td>
<td>solving strategy</td>
</tr>
</tbody>
</table>

requisites versus the success at solving the problems correctly. When solvers had adequate prerequisites, diverse patterns of errors appeared. Solvers without prerequisites made errors in addition to those of the solvers with prerequisites.

5.3 PROBLEM SOLVING MODEL BUILDING

Based on the results of this study, a model for the process of solving mechanics problems is proposed in Figure 2. It shares a common basis with the basic model of Champagne et al. (1982) and Mayer (1985). In contrast to others, this model emphasis the problem understanding stage because in this study many errors occurred during this stage.
```
<table>
<thead>
<tr>
<th>process</th>
<th>variable</th>
<th>confidence change</th>
</tr>
</thead>
<tbody>
<tr>
<td>read problem sentence</td>
<td>reading ability</td>
<td>no change or lower</td>
</tr>
<tr>
<td>understand problem</td>
<td>no change to very low</td>
<td></td>
</tr>
<tr>
<td>draw diagram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>decide problem type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(motion, force, work &amp; energy, momentum, or some)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>consider relevant principles, boundary conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>check given/required variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gather necessary information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(measure, unit conversion)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plan solving procedure</td>
<td></td>
<td>increase</td>
</tr>
<tr>
<td>(long term, short term)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>strategic knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>problem understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>recall/derive formula(s)</td>
<td></td>
<td>lower</td>
</tr>
<tr>
<td>understand the formula(s)</td>
<td></td>
<td>no change</td>
</tr>
<tr>
<td>(meaning, assumption, limitation, sign)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>declarative knowledge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>computational skill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reasoning skill</td>
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<td></td>
</tr>
<tr>
<td>calculate</td>
<td></td>
<td>lower</td>
</tr>
<tr>
<td>check or make sense</td>
<td>previous experience</td>
<td>increase or lower</td>
</tr>
<tr>
<td>solved</td>
<td>strategic knowledge</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Mechanics problem solving process model
In Figure 2, the solver's problem solving process is described with the variable(s) affecting the process and confidence change which depends upon the success or failure of the process stage.

When solvers meet a problem, they read it using their reading comprehension ability. Based on the reading, the solvers tried to understand what the problem meant, what was going on in the problem and what the problem asked. In the process, they may (1) draw a diagram to help understanding the problem; (2) decide problem type, such as force, work and energy, momentum, or some combinations of them; (3) consider relevant principles or boundary conditions; (4) check given and required variables; and (5) gather necessary information. The variables, such as misconceptions, mechanics concepts and principles, given and required physics variables, previous experience, repertoire of familiar problem patterns, and reasoning skills influence the understanding of the problem. When solvers did not recognize their mistake, their confidence was not affected; when they felt that it was hard to understand the problem, their confidence was lower.

Solvers set up a solving plan based on their understanding. If they had enough understanding and strategic knowledge, a long term plan was made. When the long term plan
was used, solvers tended not to go back to the understanding stage, and tended to use K-D strategy. Unless, a short term plan was used and solvers frequently went back to the previous stages. When solvers did not meet a dead end and the solving procedure went along with the original plan, their confidence increased. In very easy, simple problems, solvers spent a very short time for planning. Some solvers who did not have enough prerequisites tended to skip this stage and went to the next stage.

Solvers tried to recall relevant formulas to solve the problem. If they could not recall the formulas, their confidence was lowered. Memory of certain mathematical definitions was needed in this stage. When solvers could not recall the formulas, they tried to develop equations they could remember and make the needed formula. In both cases, understanding the formulas was very important. Solvers often missed the meaning, assumptions, limitations, or signs of the formulas, so they frequently used the formulas in an incorrect way at an incorrect place. However their confidence was not changed by the incorrectness.

Then solvers computed the mathematical equations based on the planned procedure. Many computational errors were not discovered during the solving process. After getting a solution, solvers often checked it by applying it to the
original problem situation or by comparing to their expected range of values. If a contradiction occurred at the checking stage and solvers did not find the reason, their confidence was lower. In the case when there was no contradiction or solvers found the error and corrected it, their confidence was raised.

5.4 CONCLUSIONS

1. Prerequisite knowledge and skills are very important in solving mechanics problems correctly. If solvers did not have the prerequisites, they could not solve the problem. Although solvers had the prerequisite knowledge and skills, careless attitude, computational skills, wrong representation, lack of understanding of equations, lack of broad schemas, or disorganization were often harmful to the problem solver's success. When subjects did not have the prerequisites, they tried unit matching or estimation methods to avoid the obstacles. The results of the trials were not successful.

There have been no previous studies dealing with mechanics problem solving errors by considering prerequisite knowledge and skills. All three subjects who missed one problem (#2) had sufficient declarative knowledge but lacked sufficient reasoning skills to handle the problems, especially requiring multistep reasonings.
The assumption stated in chapter 1 that subjects were selected with B- or better grades to ensure sufficient declarative knowledge was found to be invalid. A grade of B- or better did not mean these subjects had sufficient declarative knowledge for solving all of the MPT problems. Further, at least in this sample, the subjects did not have functional use of a substantial amount of the declarative knowledge.

2. Among the five selected variables, task structures, declarative knowledge, and procedural knowledge seem to have the strongest relation to the selection of mental representation and problem solving strategy. The task structures interacted with the declarative and procedural knowledge.

The following variables influenced the selection of the problem representation between the F-K and W-E: (1) specific words or series of words given in the problem sentence; (2) prior experience with the same kind or similar kind of problem context seemed to influence solver's memory and/or confidence; (3) mind set of problem solving, such as the Einstellung; (4) amount of declarative knowledge the subjects have; and (5) ability to translate the written problem into a physical situation that can be perceived or visualized accurately and meaningfully. These findings
agree basically with Singley (1989) and Sweller (1989). This study was able to add the last variable into their lists and to describe more precisely.

When subjects do not have enough declarative and procedural knowledge, they do not set up a solving plan and tend to use the M-E or RA strategy. These results agree with many studies (e.g., Schultz & Lochhead, 1988; Simmons, 1988; Smith & Good, 1984).

3. Errors identified during problem solving were classified as follows: (1) misunderstanding the problem; (2) misunderstanding the equation; (3) misunderstanding the mechanics concepts and principles; (4) not recalling a needed equation; (5) computational errors, including wrong substitutions; and (6) unit conversion errors. These errors are consistent with findings of other studies (Greenbowe, 1983; van Ausdal, 1988; Whimby & Lochhead, 1986).

Subjects felt more comfortable using force-kinematics principles rather than work-energy ones. Even though subjects could explain the energy and momentum conservation principles in general terms, they could not apply them to a specific problem situation or in a different problem context. Formula-centered knowledge (Clement, 1981) or fragmented conceptions (Hammer, 1989) was observed in several
instances. The most common misconceptions retained by the problem solvers were: (1) different force pairs between two different bodies; (2) residual force on moving bodies; and (3) wrong definitions of acceleration. These misconceptions were also reported in other studies (Brown & Clement, 1987; Ivowi, 1986; McDermott, 1981; Viennot, 1979).

4. There were individual differences of perceptions on the role of problem mode, problem familiarity, problem solving characteristics, and confidence level.

The role of problem mode was different among subjects. K liked the pictorial problems. She thought they seemed easier because she perceived that more information was included. However P did not like the photograph because a lot of extra variables were involved. He did like problems having diagrams because they were more descriptive and made it easy to figure out the relationship between variables. E felt that diagrams were very helpful but pictorial problems were not much different than word problems. Photographs in problems did not help M to solve the problems, but they helped him to understand the general meaning of the problems.

5. Mechanics problems used in this study were very similar to problems in a regular physics textbook. The belief system did not seem to have much influence on the problem
solving of such problems compared to nontraditional problems, such as used in Carter (1987). However, some of the solver's belief system appeared during the problem solving process. For example, solvers' beliefs such as expecting partial credits, problems generally having the exact information needed and no more, and expecting that the answers will be relatively simple were observed. In addition solvers generally had some expected range within which the expected the answer was to fall (e.g., E #1, #3, #6, and #7, M #2) and tried to make their solution reasonable (e.g., K #5 and #6, P #8, E #6). Confidence and solving results are better matched in good problem solvers than in poor problem solvers.

There were no observable changes for problem sequence choices by the solvers before and after problem solving. Easy-to-difficult was the most popular arrangement for the problem solving sequence, but overall results, confidence ratings, like/dislike, or difficulty of the problems did not match with the arrangement set during the prestudy session. Solvers stated that some problems were very different in nature than originally perceived. This was taken to mean that a short look (2 to 4 minutes) at the eight problems did not permit the subjects to analyze the deeper structures of the problem and/or that the subjects did not have the ability for the deep processing.
5.5 RECOMMENDATIONS

Based on the results of this study, the following recommendations are suggested for changes in physics teaching:

- more emphasis on understanding mathematical definitions rather than memorizing them (Voss, 1989);
- more emphasis on understanding the problem from what is given in the problem than on calculating the correct answer;
- grading and feedback based upon correct process rather than just upon the final result or the existence of calculation traces;
- more emphasis on teaching and testing for integrated, broad content rather than for single, specific content;
- use of dimension matching only to check a mathematical representation not as a means to derive it; and
- teach strategic knowledge in physics problem solving, such as preplanning, checking after getting an answer, and organizing the solving process.

- emphasize functional use of knowledge by providing problem solving experiences more frequently and spaced over time.

The following issues are recommended for further research:
- Make a physics problem solving model based on solvers' solving process. Examine the effect of solver's errors at each stage of the model compared to the solver's confidence ratings.

- Investigate the role of superfluous or deficient information in physics problem solving related with problem solver's amount of declarative and procedural knowledge.

- Investigate the difference between problem solving process variables in terms of the solving result and the interaction effects among the problem solving process variables.

- Compare students' problem solving structures with the textbook's or instructor's recommended problem solving strategy.

- Investigate the mechanism of Einstellung. What are the conditions of the effect? Are they similar to previous problems or/and student's characteristics, such as the tendency to follow the same procedures they have already used or avoid the weak schema used?

- Develop an instrument to measure reasoning skills for energy conservation and examine the interaction effects of reasoning and knowledge on energy and momentum conservation problems.
• Develop an instrument to measure reasoning skills for multistep problem solving and examine the effect of the skill in multistep problems.

• What are the effects of wording in the problem sentence? Compare the positioning of key variables and question when they are in the beginning or the end of the problem sentence.

• Are there more powerful and effective methods to determine how solvers set up and preplan to solve a problem without directly asking about it?

• What are the differences in students' perceptions of different problem modes, such as computer simulation, laboratory experiment, motion pictures, videotape, or stop action video?

• Analyze the learning and problem solving effects of courses designed to stress functional use of knowledge over a year to separate courses (quarter or semester) that do not stress accumulated knowledge and applications of that knowledge in problem solving in a spaced basis throughout the courses.
REFERENCES


163


Simmons, P. E. (1988). Problem solving behaviors of successful and unsuccessful subjects leading to a genetics problem solving model. (ERIC Document Service No. ED 303376)


Appendix A

ANNOUNCEMENT FOR GETTING VOLUNTEERS

Need volunteers to participate
in physics problem solving study

This study will require 10 hours physics problem solving (Physics 131 level) and interviews. It will take 4-5 sessions (2-2.5 hours in each) at Smith Laboratory. Hours are flexible depending upon your schedule. Forty dollars as a reward will be given to the volunteers only when they have finished all sessions.

The subjects will be selected on their Reasoning Level Test (RLT) scores and Physics 131 course grades. The subjects should have received a grade of B- or higher in the Physics 131 course.

For more information, please call: Yune Park
614/292-6718 (M,W,F 10:00 am until 5 pm)

and

Application Forms are available in
Room 3156 Smith Laboratory, 174 W. 18th Avenue
Appendix B

APPLICATION FORM

I am willing to participate as a volunteer in physics problem solving study.

______________________________ (signature)

Name_________________________ Sex: (M/F) Phone #___________

Address: (street)_______________ (city)______ (zip)_______

Major_________________________ Status: (Fr/So/Jr/Sr)

Study at this SU Qt.: (Y/N) Grade in Physics 131_____

Circle the physics course(s) taken or currently enrolled in and write Qt/Yr studied the course(s).

<table>
<thead>
<tr>
<th>course number</th>
<th>Qt/Yr</th>
</tr>
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<tr>
<td>100.01</td>
<td>/</td>
</tr>
<tr>
<td>100.02</td>
<td>/</td>
</tr>
<tr>
<td>101</td>
<td>/</td>
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<tr>
<td>102</td>
<td>/</td>
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<td>111</td>
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<tr>
<td>132</td>
<td>/</td>
</tr>
<tr>
<td>133</td>
<td>/</td>
</tr>
</tbody>
</table>

Return to Room 3156 Smith Lab.

You will be notified your result by mail or telephone.

Thank you.
Appendix C

QUESTIONS FOR SCREENING SESSION

1. Did you complete high school physics and/or AP physics? What was the name of your high school?
2. Did you like your high school physics class? (not like, like, very like) Why?
3. What physics course(s) are you taking or have you completed?
4. How would you rate yourself on the amount of physics that you know? (poor, fair, good, very good)
Appendix D

QUESTIONS FOR PRESTUDY SESSIONS

1. Which part (topic/section) do you think is the most important and the least important? Why?

2. Which part are you most confident and least confident about? Why?

3. Which is more important for you, explanations or formulas? Why?
Appendix E
QUESTIONS FOR FOLLOW-UP SESSION

Typical interview questions were as follows:

1. On a scale from 1 - 10 how sure are you of your solution?
2. Have you seen problems like this before?
   ___ Problem was totally new to me.
   ___ I have seen problems like this before, but I have forgotten how to solve them.
   ___ I remember other problems like this and how to solve them.
3. If you have seen problems like this before, what were they like?
4. How do you feel about problems like this one?
   ___ I like.
   ___ I do not mind.
   ___ I do not like.
   Why? Please explain.
5. Is there any obscure or missing thing (part) in this problem?
6. Why did you pause at this stage?
7. What were you thinking about at that time?
8. Is this problem easy, medium, or hard compared with
regular test of the course?

9. What was the most difficult part of this problem?

10. What makes this problem difficult?
Appendix F

QUESTIONS FOR ADDITIONAL INTERVIEW SESSION

1. What strategies did you use to solve this problem?
2. What characteristics of this problem affected your solving process?
3. Do you think there are other ways to solve this problem? If yes, can you describe?
   (If no, show possible alternatives then ask next question.)
   Why didn't you try that way?
   (e.g., difficulty, not recall, not like)
What is the specific reason(s) of above answer?
   (e.g., teaching style, text, test, context, formula)
Are there any recommendations about teaching of this concept?
Appendix G

THINK-ALOUD INSTRUCTIONS

The main purpose using think-aloud method is to know your thinking process itself whether it is right or wrong. So, think, reason in a loud voice. Tell everything that passes through your head during your work searching for the solution to the problem. Do not plan what to say or speak after the thought, but rather let your thoughts speak, as though you were really thinking out loud.
Appendix H

MULTIPLE CHOICES OF MPT ITEMS

The following choices were used in item #2, 3 and 4.
1) Both exert (or feel) a force, but the first exert (or feels) a greater force.
2) Both exert (or feel) a force, but the second exerts (or feels) a greater force.
3) Both exert (or feel) a force, and these forces are of equal size.
4) Only the first exerts (or feels) a force.
5) Only the second exerts (or feels) a force.
6) Neither exerts (or feels) a force.

The following choices were used in item #5.
1) The floor pulls down on the suitcase, causing it to stop.
2) There is a frictional resistance to the motion of the suitcase, but it is not in any particular direction.
3) The floor does not exert a force on the suitcase which affects its motion, but the weight of the suitcase pushes down against the floor.
4) The floor exerts a force on the suitcase in
the direction opposite to the suitcase's motion causing it to stop.

5) Other (explain).

The following choices were used in item #6.
1) There is a frictional force exerted in a downward direction on the book from the one above it.
2) There are frictional forces acting horizontally on the book.
4) Gravity pulls down on the book.
5) Roger exerts the only force on the book, but the book is trapped because of the number of books on top of it.
6) Other (explain).

The following choices were used in item #8.
1) same energy change in all positions.
2) least energy change in position 1.
3) maximum energy change in position 1.
4) no energy change in any of the positions.
5) average of energy changes in positions 2 and 4 occurs in position 3 only.
Appendix I
DATA INSTRUMENTS AND DESCRIPTIONS FOR K

I.1 LEARNING HISTORY

K rated herself above average on the amount of physics that she knew:

(I'm) above average. I'm not good at mathematics. But I like to have physics in spite of (the fact that) I don't need any physics. I like lab (better) than lecture or recitation because of hands-on activities. Although I don't like chemistry but I like chem lab.

Later K said:

I don't like chemistry, because it's more abstract. There maybe different levels of physics, but you can understand what's going on here, draw it and figure out. In chemistry (it's) hard for me to comprehend.

I.2 MISCONCEPTIONS

On item #1 of the PKT, K said:

Forces are different, because acceleration by gravity is the same in all balls but acceleration by juggler are different.

K considered the initial force given by juggler. In #6, K drew an arrow for upward force which was an initial force
when moving up and an arrow for down force which was a gravitational force when going down.

K had misconceptions related to forces acting upon each other. On item #2:

lb (pound) means force. So ball exerts more force than pin, therefore ball comes through the pins.

She was influenced by movement of the pin and the ball.

On item #3:

Force of a on b > Force of c on b, because it pushes it.
Force of a on b = Force of b on a,
Force of c on b < Force of b on c, because weight of (A + B)

K stated the last sentence wrongly. She seemed to be affected by figure given for the item.

K knew total energy = potential energy + kinetic energy, however, considered potential energy change only for item #7 when asking for the change of total energy:

Energy change from at top and at bottom is negative. Because it's going from stage of higher potential to stage of no potential. The total energy here (top) is higher than here (bottom) because here is not stored any more, it's at rest.

Total energy, the change in total energy ..
I guess it's going to be twice that because it started out total .. It's still going to decrease.
If there is the same distance between positions, change of total energy is twice as much, because (it) started out at higher velocity.
On item #9 asking whether two balls have the same speed when one ball started to roll from rest whereas the other rolling ball came to a stop, K said:

A is decelerating (and)
B is accelerating.
So there is no instant having the same speed

K seemed to confuse velocity with acceleration.

On item #10, K did not think logically but thought about all factors together. K seemed not to know that the acceleration of the ball consists of gravity, angle, and friction.

(It) appeared this one (B) has higher acceleration because this one (A) will leave sooner.

K seemed to have a good start:

But they both started from at rest.
I didn't see any high acceleration..
Both gravity picked in both cases, ..
different angle, but gravity is the same. Caused to get the speed higher, acceleration (9.8) is same.
It might be caused to be greater here because it got more component of downward ..
B is greater because of it's higher angle.
Component of acceleration ... going to be the same.
Acceleration is the same during the motion,
unless you take out the component of angle.
If angle is the same, acceleration is the same.
I don't know how they did that.

Initially K thought that gravity was the only variable influencing acceleration; then she considered the slope angle. Then K saw the diagram included with the item and concluded, from observation, that the two slope angles were the same.
In item #11, K got two values for the acceleration of the Ball A case: 4.5 on the slope and 9 on the level by using the same method used at MPT. At that point K noticed that acceleration on the level should be zero and thought the above equation was wrong. K had no idea how to calculate the exact acceleration; so she just said "because of the angle, the acceleration at the slope should be less than 9.8." At item #12, K did not see that work (Nm) and energy (J) had the same unit. She could remember the mathematical definitions only for force, kinetic energy, and work.

K might have confused the concept of potential energy with kinetic energy. At item #13, K wrote the same equation twice both for kinetic energy and for potential energy. But K's understanding of potential energy was very nebulous. In item #16, K used an example in which only one body is moved during the collision. For item #17, K wrote kinetic energy as \( \frac{1}{2}mv^2 \sin\theta \), potential energy as \( mg \sin\theta \), and frictional force as potential energy minus kinetic energy. When asked why she multiplied the regular energy terms by the \( \sin\theta \) term, K replied:

K: It is moving on the slope. 
(The term) should be smaller than on the plane, so multiply \( \sin\theta \).
(The term) should consider component of height.
I: Why sine, instead of cosine or tangent?
K: (she murmured trying to find reasons) just to make smaller ..
I.3 PRESTUDY

On the question of what is more important, equation or explanation, K replied:

I think both. Because I have trouble just looking at a diagram and then looking at the formula and trying to see what it is saying. But I can read it a lot easier and look at the formula trying see what they are saying. I do a little bit of both. I like both.

I.4 PROBLEM REPRESENTATION

In an additional interview session right after solving #7, the researcher asked a question to determine what variables influenced the selection of the K's representation.

I: During class was an energy conservation (EC) related problem emphasized?
K: Not really, not so many different types.
Two balls collide and conserved, we did that in class.
At lab, the same situation using two gliders (was used).

In problem #2.

I: Is there any energy involved in this problem?
K: Yea, (when) it's pulled back, (it) takes energy to do. (You) have to know spring constant like that.
I: From $U = \frac{1}{2} kx^2$ and $F = -kx$,
can you merge these two formulas to solve this problem?
K: Looks like, let me try to do.

$U = -Fx/2$
I didn't know (that) this F is equal to the force (50 N).

K: I didn't know force and a. I need velocity.
I may use angle to get distance.
I: The formula $F = ma$ should be used in this problem?
K: That's what I thought
I: Why?
K: Bullet has force going through block with that acceleration .. I don't know, .. that force is directly converted to the energy, isn't it?
As previously stated, K initially represented #2 as F-K then changed to use kinetic energy equation, but thought of it as F-K problem after finishing.

I.5 SOLVING STRATEGY

To solve problem #8, K computed the distance between the two points (which was wrong). Then she developed her own equation and used it to get the time spent. In other words K started with the desired quantity and looked for equations. This could be named the M-E strategy.

In problem #3 and 1, K figured out two distances, which needs a pre-plan for calculating two times traveling the distances and then subtract them, and then got the times using the linear motion equation. This might be the K-D strategy, which begins with known quantities and applies equations to derive the desired quantity. Problems #8, #3, and #1 looked like they needed the K-D strategy by nature to solve them successfully as just seen in K's approach to #3 and #1.

In problem #6, K used equations for linear motion and multiplied variables, such as \( \cos 40 \) and frictional coefficient (.15), to make the velocity smaller. There was no consistent plan and K looked like trying to fit given variables into certain equations. This study could be called RA strategy.
There was no consistent approach in problem #4 either. K wrote down the values of the given variables and calculated time traveled 30 m by the passenger, then multiplied it by the acceleration of the train and thought she got the velocity of the train. However, it was incorrect.

Initially K tried to use an equation that she remembered from problem #7, but was unable to. K gave up using the equation and used an estimation method. So K's strategy did not match any of the K-D, M-E, or RA strategies.

In problem #5, K wrote down \( F = ma \) equation and found that \( a = .5 \). Substituting this value for \( a \) in \( v = at \) resulted in a value for \( v \). So K's approach was basically forward chaining.

In problem #2, K tried to use the \( F = ma \) equation but she could not. Then K used kinetic energy equation. This may have been because the term "energy" was in the problem and the values of \( m \) and \( v \) were given from which the kinetic energy could be calculated.

How much energy .... energy?
(read question)

.. um .. so

\( F = ma \)

potential energy .. kinetic energy

\[ U = \frac{1}{2}mv^2 \]

for using this equation on the bullet .. mass, velocity squared energy

\[ U = \frac{1}{2}(1 \text{ kg})(200, \text{ doesn't sound } \ldots \text{ square,} \]

\[ = 20000 \text{ J} \]
I.6 ERRORS

The interviewer asked why the measuring mistake happened again in problem #8.

I: You used 1.236 m as the distance between them. Do you think that traveling the same distance (1.236 m) at top or bottom is the same?
K: No, I didn't think about that. That'll be different because she keeps accelerating. At bottom she travels faster.
I: Is there any way to get the time?
K: Take his distance from top to feet, calculate the time traveling independently. Take her (time) independently and subtract. This method will be better.
I: I don't know (if) the answer will be same or not. This method will be giving (the) correct answer.

I: The question is "How long did Jim wait after Clara jumped?" You just measured the distance from top of Clara to bottom of Jim.
K: Oh? That's a mistake . . . measure same place for both of them. I didn't even think about that.

Problem #3 needed the same equation as #8, because the two problems have the same algorithm. K did not recall the equation for #8 or #3. K used the same equation \( a = \frac{x}{t^2} \) here to get the time traveled. This time K had a correct plan, which was to get the time traveled from the top of the basketball players jump to the floor (76 cm) and the time traveled from the top to the position 15 cm above the floor (61 cm) and subtract them. K used her invented equation with the given information (.175 second to fall the top 15 cm) and got 4.89 m/s\(^2\) as the value of acceleration. She puzzled at this point over the two acceleration values,
which are 9.8 m/s² which she expected and 4.89m/s² her result.

How come?
I'm suppose to be using the given velocity, I mean acceleration of gravity.

You know he is falling with gravity.
When you work it out how much he is done he has gone 1.5 m in that many seconds.
So I don't know.. you work it out a = 4.89 m/s^2 that's what I understand.
(Am) I supposed to be using this acceleration for the rest of problem ..? This is (the) problem what I have.

At this time, K might have changed her equation which was in error, or she might use her acceleration value, 4.89. K did not make either of these two choices and kept calculating the time difference using both accelerations and getting two answers. When the time came to make a decision, K said:

.278 - .249 = .029 s  .394 - .353 = .041 s between these two answers
Um .. he spent ... I don't know.
.. have to go with .029, because that's given, the information is given to this problem.

K chose the given number, which was 9.8, because it was given. This resulted in the wrong answer. Later K recalled the most difficult part was getting the acceleration value.

For problem #1, exactly the same problem occurred as in #3. K used her equation.
To solve problem #6, the acceleration of the block was derived using frictional coefficient, slope angle and gravitational acceleration. K could not do that. As seen at the PKT items #1, 13, and 17, K did not have a good understanding of kinetic energy, potential energy, and frictional force. So K just tried to use some mathematical equations which she knew related to linear motion; then she multiplied some related variables to make the velocity smaller. K assumed that the upward velocity is the same when going down at the same point. During an additional interview, when asked for a reason for this assumption K did not have a rationale for it. It appears that she assumed that they are the same in order to make the problem simpler.

I: Do you think upward v is the same as downward v at the same point?  
K: um, it's lower than 9.8, something around there  
I don't know that's smaller, I don't know  
friction, gravity, velocity ..  
friction is same, distance is the same.  
At upward, gravitational (force) is opposite  
at downward, gravitational (force) is pushing.  
So at downward, (it'll move) faster than 4.5 m/s.  
I: How about considering friction then?  
K: slower ... I don't know,  
faster because I don't think .. (it) depends on ..  
I don't know what it depends upon  
probably the same like free fall, I don't know.

K's explanation was:

After that many seconds (3.75 s), the passenger can catch the train, because the velocity of the passenger (8 m/s) is greater than the velocity of train (3.75 m/s).

K understood this problem as a true or false question.
It is not asking (for me to) solve (the) problem. (I) did not need to know equations. You can use logic to figure it out, not necessary to use equations, maybe it is, but ..

K's thought, as shown in the transcript data, indicated that she might decide to compare two velocities as a rationale for her decision. Even at the additional interview, K could not proceed in a productive manner with the equations. She tried to calculate each person's acceleration. At an early point K might have had the idea that the answer was 'yes' as to whether the two persons can met. Consequently she did not worry much about the solving process using the equations, or perhaps she was unable to use the equation correctly. Her confidence level (8.5) seemed to support the first statement.

K tried to solve problem #7 using many equations which she knew but failed. According to the PKT, K did not remember the equation needed. Then K tried to estimate the relationship between velocity and height. It seems that the given v and 1/2v were used as a clue for the estimation.

We know v, 1/2v cutting into half .. cut this in half. (draw diagram) I can't remember that equation, um ...

During the additional interview, K explained more about her thinking:

K: I couldn't figure out the equation to do it. I knew it was accelerating by half the velocity
in each time. 3 m to one v to half v, each time
down by half v. (It is) serially going to
decrease by distance 3 go half v. It is going to
go here to there, going forever. You know some-
time it ended. I guess (it) make sense. going
from v to half v, put it up to zero 3 again.

I: Is there any rationale for your reasoning?

K: Because I can't figure out anything else.
This is the easiest way. Figure might be 3 going
to half v, seems logical ... I just divided
everything.

When asked why K was not very sure about her answer
after solving #7 at the additional interview with note, she
replied:

I could make a mistake. I may not use the right
formula. I used the same formula again. If
working with s = vt, then a different answer
(will come). Having formulas here help me
because I can easily say yes that's one I want to
use here or I can tell no that one I don't want
to use.

K misrepresented problem #5 as F-K, instead of W-E.
That might be the most difficult stumbling block in this
problem. In addition while solving the problem, K got .5
as the acceleration value of the projectile, but she found
she did not convert all numbers into MKS units. After con-
verting all, K got 500 as the acceleration value. K
thought it was too big number. So K choose "reasonable"
value of acceleration, which was .5, and stayed with it.
It was a wrong decision.
At problem #2, K did not understand the problem as W-E. It was the major obstacle to solving this problem. K used kinetic energy equation later, but her confidence was very low. After solving this problem, K kept looking for missing variables such as acceleration, time for the traveling bullet, and force. All were based on the F-K representation. At that time, K still did not know the initial velocity of bullet.

I: Is there any way to get the initial velocity?
K: (read last sentence) You might use this angle here, I don't know.

I.7 CONFIDENCE

In problem #8:
I don't know what acceleration is ... seems misleading, miscalculating ...
Standard a is 9.8, but my calculation gives 4.9.
It was easy to understand what you are suppose to do, but .. hard to get an answer, hard to know what a is.

This confusion may have been responsible for K's low confidence rating. K said she liked this problem because she had enough time to do it. She rated this problem as a hard one. K said she remembered how to solve this kind of problem except for the equation.

This is more straightforward because a is given.
I can assume a = 9.8 m/s².
I can assume no initial velocity, because it doesn't say anything.
No conversion, it will be easier.

make sense, got faster at bottom 50.
3.19 - 2.25 = .94 second, hum, seems little faster but I have to go with that.

K was relatively confident about her result. And K liked the problem because it was easy and straightforward.

For problem #6, K admitted that her answer was wrong right after she got her answer.

(It was) very hard to understand, determine what to do, what to set up what equations, (and) what to do (with the) initial velocity. Even (though the) picture is given, it's hard to understand. It's going up and going back down. (I) didn't know about stopping point. (There is) a lot of information. Even (when I) draw my picture, it's still not clear.

K did not like this problem because it was hard for her to figure out and to know how to do it. K rated this problem as very hard one.

You can use logic in figuring out. (It is) not necessary to use equations, may be it is, but...

When asked about the meaning of "logic":

"Logic" means draw picture, .. (and) think about with formula. You know basically (that the) train is really not accelerating that fast unless accelerating faster than the man. You know the man can catch up even though this velocity if the distance (of the platform) is far away. That's pretty much logical.

The confidence rating of 8.5 on problem #4 was the highest confidence rating among the 8 problems. K liked this problem because she could use "logic" to figure it out and did not use equations.
K was not very sure about the estimation method used for #7. K said she did not solve it although she got an answer. K stated that it was very hard to find the correct equation. The problem was also hard to figure out. K was not so concerned about not being able to solve it. If the equation was, given she would like this problem. The second time K met this problem at the additional interview session, she still found it hard to apply the EC principle even though the interviewer suggested it as a possible method.

K rated her confidence at 7 on her answer for problem #5. She was confident about using \( F = ma \) equation in this problem, but was not sure about using \( v = at \) equation to get the final velocity to calculate the acceleration value. K liked this problem because a lot of information was given, the wording was understandable, and it was "logical."

K rated her confidence level at 2 for her answer to problem #2, because she just could not figure out. K did not like this problem and rated as a hard problem.

1.8 CHARACTERISTICS

For example in #6

\[
\cos 40^\circ = .76, \text{ which it slows down. so times by that I got an answer again. times } .15 \text{ again that slows down. the friction .. try to make it large number.}
\]
So times makes smaller number.

In problem #7, K rated this problem as a hard one when the equation was not given and as an easy one with the equation. But in an additional interview, K tried to solve the problem again with equation notes. Here K met another obstacle which was the application of the energy conservation principle.

I.9 RAW DATA
I am interested in your ideas about science and physics. Please tell me what you really think. Write your answer in the space below each question.

1. What is science? The study of natural phenomenon so that we as humans can understand the world around us and apply it to new technologies to make life better.

2. What is physics? The science of physical properties and the explanation of certain regularities in our environment.

3. Is science created or discovered? Science is created in that humans must design techniques and the way to find phenomena. It could also be discovered, but scientists must find it through experimentation.

4. How much of your ability to do physics shows up when you take physics tests? About 85% is the correct answer to this question. Another possibility could be 100%.

5. What can you do if you get stuck while doing a physics problem? Substitute in fewer letters, or variables, that are easier to work with, and try to work backwards to solve the problem.

6. How important is memorizing in learning physics? If anything else is important, please explain how.

Memorizing will not teach the concepts of physics. It is just as memorizing anything will not give a true understanding, just a formula to go by. It can be beneficial to write out problems and understand them, but not to memorize the formulas.
Part IV

Please state whether you agree or disagree with the following statement. Then briefly explain your reasons for agreeing or disagreeing. Two to four sentences should be enough to make your reasons clear. If you cannot agree or disagree, then explain why a choice is not possible for you.

1. Scientists should be concerned with the potential effects (both helpful and harmful) that might result from their discoveries.

   [ ] agree  [ ] disagree  [ ] can't tell

   Reasons: Scientists should be concerned because they are ultimately responsible for the outcome of their experiments and they must live with the consequences of disasterous effects. A careful analysis of the project should be performed to determine if helpful effects will outweigh the harmful.

2. Although advances in science and technology may improve living conditions around the world, science and technology offer little help in resolving such social problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war.

   [ ] agree  [ ] disagree  [ ] can't tell

   Reasons: Often science and technology create problems that need to be solved. S&T would only be trying to solve the nuclear war problem. However, if the nuclear war never happened, it is true that more social problems could be solved with the money saved. Science and technology could be spent in other areas.
3. When scientific investigations are done correctly, scientists discover knowledge that will not change in future years.

4. Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories; we should not believe that these models are duplicates of reality.

5. The best scientists are those who stick to the steps of the scientific method, but instead use any approach that might help them.
6. Communities or government agencies should tell scientists what problems to investigate; otherwise scientists will investigate only what is of interest to them and not necessarily investigate the problems of interest to the country.

agree  disagree  can't tell

Reasons: I do think that there should be more community input as to what types of research should be done so that everyone in the environment will benefit. Often government agencies have the power to give & to the agencies what they deem "good," when in actuality it is not.

7. A scientist may play tennis, go to parties or attend conferences with other scientists or with non-scientists. Because these social contacts can influence the scientist's work, these social contacts can influence the content of the scientific knowledge he or she discovers.

agree  disagree  can't tell

Reasons: Scientific knowledge should not be quantified in this manner, however I do feel that it is important that scientists & non-scientists discuss problems & issues of importance scientifically & socially so that there be a consensus of what scientific knowledge is useful to pursue.
Part II

Please select the one best response in your opinion for each item and mark your choice. You may mark two or more responses if they seem equally good. If you do not like any of the responses, then please add your own response.

1. The main motivation of most scientists is

   (1) earning a decent salary.
   (2) earning recognition from other scientists. (For some)
   (3) satisfying their curiosity about natural phenomena.
   (4) ________________________________

2. In my mind, the primary purpose of science is

   (1) the furtherance of the well-being of humanity.
   (2) the compilation and categorization of all laws and facts about natural phenomena.
   (3) the mastery and control of nature through a set of relations that successfully predict events.
   (4) the establishment of theoretical structures which integrate and explain.
   (5) ________________________________
3. Which of the following is the best description in your judgement of a scientific law?

___(1) It is an exact report of a set of observations.

___(2) It is a generalized statement of relationships among natural phenomena.

___(3) It is a theoretical explanation of a natural phenomenon.

___(4) It is dictated by nature and cannot be violated.

___(5) ________________________________

4. Of the following, which is the best statement about the objectivity of the scientist in your judgement?

___(1) The scientist is basically objective because he is indifferent about the conclusions and outcome of his work.

___(2) The scientist is objective because making progress and achieving answers is a matter of grinding things out via the scientific method.

___(3) The scientist's objectivity consists of inter-subjective testability, i.e. agreement between members of the scientific community on matters of observation and verification.

___(4) The scientist's objectivity is the result of the fact that science is impersonal throughout.

___(5) ________________________________
5. When a new theory replaces an older theory, it is frequently incompatible with its predecessor in the sense that

(1) successive theories often change the meaning of familiar terms and/or add new postulates.

(2) the old theory is erroneous and the new theory is a correction of former mistakes.

(3) a new battery of experimental apparatus must be designed.

(4) The premise is false; new theories are not usually incompatible with their predecessors.

(5) _________________________________________________________

6. Concerning the verification of a scientific theory, I think that

(1) experimentation and observation proves the correctness of a theory.

(2) a theory can be enforced or weakened by new data, but not proven or falsified.

(3) theories are sometimes conclusively verified without recourse to experimentation or observation.

(4) a theory is usually discarded as soon as a piece of experimental evidence is found which falsifies it.

(5) _________________________________________________________
7. The concept 'demons' is not part of the repertoire of science because it

(1) lacks explanatory power.  
(2) involves appeal to unfamiliar qualities.  
(3) is non-observable.  
(4) fails to be testable.  
(5) _________________________________________________________

8. The fields of natural science and social science in my view

(1) are similar in that the chief goal of both is the discovery of universal laws.  
(2) are different in that the judgements of natural science are objective because the investigator does not interfere with the object, but observation and interpretation in social science are influenced by the values and actions of the investigator.  
(3) are similar in that both seek to establish connections between particular events and make use of generalizations in understanding events.  
(4) are different in that the phenomena of natural science are recurrent, reproducible, and regular, but the phenomena of social science are nonrecurrent, unique, and erratic.  
(5) _________________________________________________________
9. Getting a good or bad grade in physics is depend upon

(1) my effort
(2) teacher
(3) luck
(4) test
(5) __________________________________________________________

10. The physics that I learn in school is

(1) mostly facts and procedures that have to memorized.
(2) thought provoking. It can be applied outside of school.
(3) just a way of thinking about mechanics, thermodynamics, and electricity.
(4) ______________________________________________________________

11. The reason I try to learn physics is

(1) to help me think more clearly.
(2) it is required for my program.
(3) it is interesting.
(4) ______________________________________________________________
1. Write an equation to represent the following statements.

A) "In a classroom there are five times as many boys as girls." Use B for the number of boys and G for the number of girls.

\[ B = 5G \]

B) "A country sells four times as much wheat as corn."

Let W represent the amount of wheat and C represent the amount of corn.

\[ \frac{W}{C} = 4 \]

C) "There are six times as many students as professors at this university." Use S for the number of students and P for the number of professors.

\[ \frac{S}{P} = 6 \]

D) "At Mindy's restaurant, for every four people who ordered cheesecake, there are five people who ordered strudel."

Let C represent the number of cheesecakes and S represent the number of strudels ordered.

\[ \frac{C}{S} = \frac{4}{5} \]
2. There are two plastic cylinder containers of equal height but with different diameters. A given quantity of water rises 4 units in the wide container and rises a corresponding 6 units when poured into the narrow container. Using the same plastic containers, if 11 units of water are poured from the narrow cylinder to the wide cylinder, the level in the wide cylinder will be _______ units. Why?

\[ \text{Vol} = \frac{\pi D^2 h}{4} \]

\[ \text{(n)} \frac{V}{v} = \frac{\pi r^2 h}{\pi R^2 h} \]

If the 100 gram weight is hung at 4 cm on the left side of the balance at which position will the 50 gram weight have to be placed on the right to balance the arm?

Why?

202
4. A biologist did an experiment to find out how many frogs lived in a pond. He did not have enough time to catch and count all the frogs. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to spread themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg. Using all of this information, how could the biologist figure out about how many frogs are in the pond?

\[
\frac{55}{x} = \frac{12}{72}
\]

\[
x = \frac{55 \times 72}{12}
\]

5. Walking back to my room after class yesterday afternoon, I noticed my six-foot frame cast a shadow eight feet long. A rather small tree next to the sidewalk cast a shadow eighteen feet long. My best guess of the height of the tree would be _________.

\[
\frac{6}{8} = \frac{x}{18}
\]
Computational Skill Test

1. Fill in the blank.
   a) 106 cm = \(1.06\) m
   b) 4 g = \(0.004\) Kg

2. Calculate the following expressions.
   a) \(\frac{1}{3\times23} \times (16 \times 10^2)^2 - (7 \times 10^2)^2\)
      \[ \frac{1}{3\times23} \times (16 \times 10^2)^2 - (7 \times 10^2)^2 = 24.910 \]
   b) \(\frac{\sqrt{2\times7\times10^2}}{\sqrt{5\times10}}\)
      \[ \frac{3.74158}{5.477} = 0.68 \]
   c) \(\frac{\sqrt{4\times0.57-\sqrt{3\times0.29}}}{\sqrt{7.4\times7}}\)
      \[ \frac{1.509 - 3.21}{4.711} = -0.34 \]
   d) \(\sin 37^\circ = 0.6018\)
   e) \(\cos 37^\circ = 0.795\)

3. Solve the following equations.
   a) Solve for \(x\).
      \[ 2x^2 - x - 6 = 0 \]
      \[ (2x + 1)(x - 3) = 0 \]
      \[ (2x - 3)(x + 2) = 0 \]
      \[ (x + 3)(x + 2) = 0 \]
      \[ x = 2 \quad \frac{2x + 3}{2x - 3} = 0 \quad x = \frac{-3}{2} \]
b) Solve for $x$ and $y$.

\[
\begin{align*}
2x + 5y &= 2 \\
3 + 30x &= -20y
\end{align*}
\]

\[
\begin{align*}
x + \frac{1}{3}y &= 2 \\
30x + 20y &= -3
\end{align*}
\]

\[
\begin{array}{c}
2x + \frac{1}{3}y = 2 \\
30x + 20y = -3
\end{array}
\]

\[
\begin{align*}
x + 6.5y &= 2 \\
2x - 3.4y &= 1.5
\end{align*}
\]

\[
\begin{align*}
x^2 - 3.24y &= 1.5x^2 \\
1.5x^2 - 3.24y &= 0
\end{align*}
\]

\[
x^2 = 0.4y \\
x = \pm 0.63
\]

c) \[2ab = a^2 - d^2 + 100, \text{ where } a = -200, \quad c = -10\sqrt{5}\]

d) What is the value of the $b$?

\[
2(-200)(b) = (-200)^2 - (30)^2 + 100
\]

\[
y = \frac{5}{2} \Rightarrow b = -2.23
\]

e) \[\frac{at^2}{2} + ab = \frac{1}{3}(0.5)^2 a + ab(t + 2), \text{ where } b = 4\]

What is the value of the $t$?

\[
\frac{t^2 + y}{2} = \frac{25 + y^2}{3}
\]

4. What are the values of $y$ and $z$ in terms of the $x$ and $\theta$?

\[
\sin \theta = \frac{y}{x} \\
\cos \theta = \frac{z}{x}
\]
e) \[ \frac{(3t^2 + 4)}{2} = \frac{25}{8} \]

\[ 3t^2 + 246 - 74 = 0 \]

\[ 3t^2 - 4t - 74 = 0 \]

\[ (3t + 2)(t - 37) \]

\[ (3t - 37)(t + 2) \]

\[ -b \pm \sqrt{2ac} \]

\[ \frac{2}{2} \]
K: PKT

1. A juggler plays with seven identical balls. At time \( t \), the seven balls are in the air at the same height, on trajectories shown in dashed line in the figure. Also shown are the velocity vectors of the balls at this instant. Are the forces acting on the balls at this instant the same or different? Are some the same and others different? Justify your answer. (Neglect air resistance.) Are the potential energies of the seven balls the same or different?

\[
|F_x| > |F_y|
\]

(gravitation: Acceleration is force acting on all balls which is the same.

If the juggler gives an initial acceleration different on the balls, then the will differ which each ball.

\( \text{P&K is different because they are all at different stages of travel.} \)

\[
ul = \frac{1}{2} mv^2 \quad \text{and} \quad \text{gh}
\]
2. A bowling ball weighing 16 lbs hits a bowling pin weighing 4 lbs. Compare the force the ball exerts on the pin with the force the pin exerts on the ball.

3. Three boxes are stacked on top of each other with the lightest on the bottom and the heaviest on the top. Think about whether the top and bottom blocks A and C exert a force on the middle block B.
4. A suitcase slides from a ramp onto the steel floor of the baggage area at an airport. Explains why the suitcase will stop?

Friction of wheels & floor.

5. Twenty large books are stacked in a pile in Roger's garage, and Roger wants to read the black one in the middle. He tries to pull it horizontally out of the pile without taking the books above it off, but can't move it. Explains the primary reason why this is happen?

Force Roger exerts on the books is not large enough to overcome the forces due to gravity (weight) of the books on top. It could also be the friction.
6. A coin is tossed from point A straight up into the air and caught at point E. On the dot to the left of the drawing, draw one or more arrows showing the direction of each individual force acting on the coin when it is at point B.

(Draw longer arrows for larger forces.)

Explain your drawing.

7. A body is dropped freely from position A to reach the position 1 on level XY. The body is projected from A with different horizontal velocities such that it successively reaches the position 2, 3, 4 as the projecting velocities increase.

What is the change in total energy for each body as it reaches each position?

\[ \frac{\Delta E_i}{m} = \Delta E + \frac{1}{2}m v^2 \]

\[ \Delta E_i < 0 \]

In all deceleration due to loss of potential energy.
8. Ball A travels with uniform motion from left to right while ball B travels in the same direction, starting with an initial velocity greater than that of ball A. As ball B travels up a gentle incline, it slows down and eventually comes to rest. Ball B first passes ball A, but later ball A passes ball B. Do these two balls ever have the same speed? Explain your choice.

Yes when B

9. Ball A starts with some high initial velocity, slows down, and comes to rest. Another ball, ball B, starts from rest at a point ahead of ball A. It accelerates uniformly down a gentle incline. Ball A never overtakes ball B as is shown. Do these two balls ever have the same speed? Explain your choice.

No instant.
10. Both balls start from rest and reach the same final velocity at the end of the incline just as they simultaneously enter a tunnel at the bottom. They are not released at the same point or the same time and do not travel equal distances. Ball A is released first from a point several centimeters behind ball B. After rolling a few centimeters, ball A strikes the lever and ball B is released. Do these two balls have the same or different accelerations? Explain your choice.
11. The initial velocity of both balls is zero. The two balls are rolling down inclined tracks and level tracks. Given numbers on following diagram are the length of each track and the time which the ball travels the track. Calculate the accelerations of two balls.

Ball A

\[ a = \frac{m}{S^2} = \frac{40.5}{9} \] 

Ball B

\[ \frac{27}{3} = v \]
12. What are the dimensions of the following expressed in fundamental units?

a) N (Newton) = \( \frac{kg \cdot m}{s^2} \)
b) J (Joule) = \( \frac{kg \cdot m^2}{s^2} \)

Do the "force," "work," and "energy" have the same dimension? 

No, all three differ.

13. Fill in the blanks and define symbols.

a) \( v = v_0 + \left( \frac{ax}{t^2} \right) \)

b) \( 2gs = v^2 + \left( \frac{ax}{t^2} \right) \)

c) \( s = v_0 t + \left( \frac{ax}{t^2} \right) \)

d) \( F = \frac{\Delta x}{t} \)

e) Kinetic Energy = \( \left( \frac{1}{2}kmv^2 \right) \)

f) Potential Energy = \( \left( \frac{1}{2}kmv^2 \right) \)

g) Work = \( \left( F \cdot s \right) \)

h) Frictional force on plane with \( \mu \) and \( m = \left( \frac{Ff}{m} \right) \)

i) Energy loss by frictional force \( (Ff) = Ff \cdot s \)

j) Stored energy in spring = \( \frac{1}{2} (k \cdot x^2) \cdot d \)
14. How are the following quantities related?

- Speed, velocity, and acceleration
- Speed is numerically same as velocity but indicates a direction; acceleration is the first derivative of velocity.

15. Explain the energy conservation principle and show the mathematical expression using Kinetic Energy (KE), Potential Energy (PE), and Work by friction (Wf).

\[
\text{KE} + \text{PE} + \text{Wf} = E_{\text{total}}
\]

\[
\frac{1}{2}mv^2 + mgh + W_f = E_{\text{total}}
\]

Energy is not created or destroyed.

16. Explain the momentum conservation principle and show the mathematical expression using mass (m) and velocity (v).

\[
mv = \text{constant}
\]

17. A block is sliding down an inclined plane with \(\mu\) as the coefficient of friction. At the position shown in the figure, write an expression for each of the following.

- Kinetic energy: \(\frac{1}{2}mv^2\)
- Potential energy: \(mgh\sin\theta\)
- Frictional force: \(\mu mg \sin \theta - \frac{1}{2}mv^2\)
problem H

As the figure shows, Clara jumps from a bridge, followed closely by Jim. How long did Jim wait after Clara jumped? Assume that Jim is 170 cm tall and that the jumping-off level is at the top of the figure. Make scale measurements directly on the figure.

\[ \begin{align*}
S &= vt \\
\frac{S^2}{2} &= \frac{1}{2}a \frac{S^2}{2} = \frac{1}{2} \frac{9.8 \text{ m/s}^2}{1.7} \\
9.8 \text{ m} &= \frac{1.13 \text{ m}}{t^2} \\
9.8 &= 11.3 \\
11.3 &= 9.8 \\
L &= 0.3395 \\
T &= 0.34 \text{ seconds}
\end{align*} \]
problem C

A basketball player, standing near the basket to grab a rebound, jumps 76 cm vertically. During falling from top, 0.175 second is measured in the top 15 cm of this jump. How much time does the player spend in the bottom 15 cm during the falling? Does this help explain why such players seem to hang in the air at the tops of their jumps?

\[ a = 9.8 \text{ m/s}^2 \]

\[ \text{travels 1.5 m in 0.175 s} \]

\[ a = \frac{m}{s^2} = \frac{4.09 \text{ m/s}^2}{1.5} \]

\[ t = \frac{u}{a} = \frac{0.1}{9.8} = 0.04 \text{ s} \]

\[ t = \frac{1}{3.53} \text{ s} \]
The image contains handwritten mathematical calculations and equations. The text is not fully legible due to handwriting style and some symbols are not clearly visible. The calculations appear to involve fractions, exponents, and possibly logarithms, with calculations for values such as 't' and 'h'. The specific details of the calculations are not clear due to the quality of the image.
problem A
A rock is dropped from a 100-m high cliff. How long does it take to fall from the mid-point (50-m high point) to the bottom?

\[ 9.8 \text{m/s} \]

\[ 100 \quad \downarrow \quad \theta \quad \downarrow \quad 0 \]

\[ 9.8 \frac{m}{s^2} = \frac{50 \text{m}}{t^2} \]

\[ t^2 = \frac{50}{9.8} \]

\[ t = \sqrt{5.10} \]

\[ t = 2.25 \text{s mid} \]

\[ 100 = 9.8 \cdot t^2 \]

\[ \frac{100}{9.8} = t^2 \]

\[ 10.2 = t^2 \]

\[ 3.19 = t \]

\[ 3.19 - 2.25 = 0.94 \text{ seconds} \]
problem F

A block is moving up a 40° incline. At a point 1.8 m from the bottom of the incline (measured along the incline), it has a speed of 4.5 m/s. The coefficient of kinetic friction between block and incline is 0.15. How fast will it be going after it slides back to the bottom of the incline?

\[ F = ma \]

\[ \frac{1}{2} m (v_f)^2 = u \]

\[ \theta = \cos \theta = \frac{1.8 \text{ m}}{10} \]

\[ a = 2g \cos \theta \]

\[ S = vt \]

\[ V = \frac{8}{2} \]

\[ V = 1.8 \cos 40° \]

\[ S = vt \]

\[ 9.8 \text{ m/s}^2 \times 1.8 \]

\[ a (2.42) = v \]

\[ 2.42 \text{ m/s} = v \]

\[ (15)(2.42) = v \]

\[ \frac{34.3}{5} = v \]

\[ \text{Calculate distance to stop.} \]

\[ v = \frac{14.5}{5} \]

\[ (15) (\cos 40°) (\sin 40°) \]

\[ g = -9.8 \text{ m/s}^2 \]
problem D
A late passenger, sprinting at 8 m/s, is 30 m away from the
rear end of a train when it starts out of the station from
rest with an acceleration of 1 m/s². Can the passenger
catch the train if the platform is long enough?

\[
v = v_0 + \frac{1}{2}at
\]

\[
V = \frac{v_0 + v}{2}
\]

\[
S = v_0 t + \frac{1}{2}at^2
\]

\[
v = at
\]

\[
V = (8 m/s)(3.75 s) = 30 m
\]

Yes the passenger can catch it.
problem G

A stone is thrown vertically upward. On its way up it passes point A with speed \( v \), and point B, 3.0 m higher than A, with speed \( \frac{1}{2}v \). Calculate the maximum height reached by the stone above point B.

\[
\begin{align*}
S &= vt \\
\frac{1}{2}v &= v_2 \\
v &= v_1 \\
a &= \frac{v}{t} \\
a &= \frac{v_{\text{top}} + \frac{1}{2}v}{t} \\
a &= \frac{v_{\text{top}} + \frac{1}{2}v}{t} = -\frac{1}{2}g
\end{align*}
\]
problem E

A 100-g projectile is placed in a slingshot, and a band is pulled back 0.5 m and held with a force of 50 N before being released. The slingshot takes 0.05 sec to accelerate the projectile to its final speed. What is the final speed of the projectile?

\[ F = m \cdot a \]

\[ s = \frac{1}{2} a t^2 \]

\[ v = \frac{s}{t} \]

\[ F = 50 \text{ N} \]

\[ m = 100 \text{ g} = 0.1 \text{ kg} \]

\[ s = 0.5 \text{ m} \]

\[ t = 0.05 \text{ s} \]

\[ v = \frac{1}{2} \cdot \frac{50}{0.1} \cdot 0.05 \]

\[ v = 0.25 \text{ m/s} \]

\[ (50 \text{ N}) = a \]

\[ \frac{1}{0.1 \text{ kg}} \]

\[ s = \frac{1}{2} a (0.05 \text{ s}) \]

\[ (50 \text{ N}) \cdot 0.05 \text{ s} = 2.5 \text{ m} \]
problem B

A 5-g bullet horizontally penetrates a 1 kg block suspended at rest from a 1 m long thread of negligible mass. The bullet leaves the block from its far side with velocity 200 m/s. How much energy was transformed into heat if the block rose through a height of 0.3 m? (You may assume that the block did not rise while the bullet was inside it.)

\[ E = \frac{1}{2}mv^2 \]

\[ U = \frac{1}{2}(kg)(200)^2 \]

\[ U = 20000 \text{ J} \]
Appendix J

DATA INSTRUMENTS AND DESCRIPTIONS FOR P

J.1 LEARNING HISTORY

P remembered his high school physics as:

I liked it very much because it was new for me
(and) made me choose mechanical engineering as my major.
(It's) different from biology or chemistry, which needs
a lot of memorization.
Physics solves problems based on given information.

When asked about his grade, he said:

I: Do you have any reason for not having good grades
in the series?
P: A lot of factors are involved (in there).
Yea, it's lower than I expected,
could be slack off in final.

I: What's your problem in problem solving?
P: I'm a pretty decent problem solver, usually.
I did decent in math class like that. Usually what
happens in physics tests is I do pretty good (on) 4 out
of 5 sheets, (and) one sheet, pretty much bombed.
I: Is it because you did not study?
P: Everyone made stupid mistakes (which) cost a lot.
(I solved) 80 % on test, very happy with it at that time.
I think problem interpretation bugs, stupid mistake.

On his physics knowledge:

(I think I am) fair.
I like and (am) good at math.
But (I) feel sometimes hard in visualizing or intuitively
figuring out some physics problems,
because physics is more than math.
J.2 MISCONCEPTIONS

At item #1 of the PKT, P believed that the different directions and different magnitudes of the given velocities made different force vectors. He was also confused on the concept of potential energy. In regard to the potential energies of seven balls in item #1:

Potential energies are different.
Potential energy of ball #2 is mgh, others are 0, because all other vectors are in motion.
So they have pretty much kinetic energy.
In ball #2 case, it is at rest, so some potential energy but no kinetic energy (is there).

P knew the expression for potential energy is mgh, but did not understand what it meant and how to apply it in this situation.

According to his answer on item #6, P had the misconception that some kind of pushing, residual force is still acting on the upward moving body. After the interviewer explained that if the initial force is greater than the gravitational force, then an upward acceleration is present, and the coin would fly upward faster and faster, P changed his mind:

I thought initial force shortly after (start). Velocity is slower but residual force continued to go up, later (there will be) no force.
I know the original force is still stronger, (when) pass the coin to the point B.
I don't know how to show the factor of ...
just one force at the point.
No force is acting on going up except gravitational force.
P was not sure about it.

I: Small amount of initial force is still affecting on the coin, right?
P: I don't know.

During falling from the top, P said that only gravitational force was exerted.

For item #2, P thought that the ball exerted more force on the pin than the pin did on the ball. At first P confused between "feel" and "exert" and said "I'm not sure how momentum would be conserved in there." Although item #3 was the same kind of item as #2, P analyzed item #3 correctly, maybe because there was no movement in #3; it was easy to think about the same force being exerted on each object. P seemed to be influenced by the movement of the ball and the pin.

In item #7, P knew that total energy is kinetic energy plus potential energy, however:

In (ball) #1 case, total energy change is 0 (and) in other cases, it is less than 0, because some energy was dissipating in the air during falling. The biggest energy was lost in (ball) #4, because of the greatest air resistance.

P wanted to say that energy is conserved in all cases. But in response to specific questions, P felt that it was very difficult to consider energy change, like ball 2, 3, and 4. He said the initially added kinetic energy has disappeared
because it was all horizontal. P thought that ball 4 had the greatest kinetic energy among the balls because it had the fastest initial velocity. Then at the bottom, ball 4 had the same amount of energy as the others, so the most energy was lost. P did not think about the velocity difference (two dimensional) in the XY-plane for the four cases; he only perceived the same final velocities.

On item #8, P initially commented that they had the same speed at the instant of the second meeting location. But later as the interviewer asked what happened at the first meeting place, P changed his answer so they can meet at two points. P was affected by what he saw without thinking about the physical meaning of speed and time. In item #9, P also depended upon what he saw by saying they do not meet. No matter what the velocity of A was, they had the same speed at one point in time.

On item #10, P believed that the two balls had different accelerations, with the acceleration of A greater than that of B. On item #11, which required calculation of the acceleration on the slopes and on the horizontal planes, P got average velocities on the slope and on the planes, and calculated the difference of the average velocities divided by time, then said that the acceleration at slope A was greater than that at slope B. After seeing contradiction
of his answers, P knew his answers were wrong, but he could not resolve this discrepancy.

P said that because work is force times distance and energy is force per time, work, energy, and force are different but related. P could recall the equations for getting the final velocity from the initial velocity, acceleration, and time; $F = ma$; kinetic energy; potential energy; and work. He remembered an equation for getting the distance from velocity, time, and acceleration incorrectly. The velocity should have been the initial velocity whereas he recalled it as final velocity. He knew velocity was the time derivative of distance but could not use it for checking the equation. P did not recall the equation for frictional force, the energy loss by friction, or the stored energy in spring. Although P stated that speed is velocity at a certain instant, knew that velocity is the time derivative of distance, and knew that acceleration is the time derivative of velocity, but he could not apply them to obtain the equation including velocity from the equation including distance. P thought velocity and potential energy terms should be multiplied by $\sin \theta$ term to consider the slope effect.
On the question of importance of formulas and explanations, P stated:

I think both. When you are doing it, (a) formula is more important but most (of the) time you can't. I mean a formula gets you the answer, but you don't know what the formula is, how to use (it), and how to apply (it) to given situation. It's not going to do any good. You need them both.

After three minutes of reviewing the problems, P decided his solving sequence to 6-2-1-5-4-3-7-8. The reason was:

Basic principle is easiest to most difficult.
Picture helps me to solve.
I like a diagram with physical quantities (because it's) more descriptive.
#1 didn't sound so complicated and I remembered the formula and intuitively looked easy.
I don't like action photo, because it has a lot more variables.

P himself acknowledged that his understanding of the problem was different before and after the solving problem. For example, for problem #3:

It wasn't hard for me to solve myself.
I thought I couldn't do it at first, but after looking at it (I) figured out I could.

In a later interview session:

I: You said you like a diagram problem.
Why then is #7 put almost the end of your sequence?
P: When I looked at it really quick,
I thought I don't remember so much about free fall.
If I resolve these problems (again), I will decide my sequence based on the same principle, from easiest to difficultiest.
J.4 PROBLEM REPRESENTATION

At the additional interview session, problem #6 of MPT was given to P again and asked:

I: Can you solve this problem using EC?
P: I guess I can find it.
Kinetic energy is there ... total energy is there that I'm not sure about.
Still don't know how to deal with frictional coefficient.
I: EC related problem was emphasized in class?
P: Yes, I think so.
I: Why didn't you use EC? Is it difficult?
P: I don't know. I was always try to find easiest way to do. I don't think I will be able to work out the way I did it. EC principle seems more powerful and easy to remember.
... I didn't think I could make to work out that way.

J.5 SOLVING STRATEGY

At problem #6 of MPT, P calculated the acceleration value, then got the time needed to travel to the maximum point. By plugging it into the linear motion formula without considering friction, P could get the incorrect distance traveled. The traveling time was calculated from total distance and acceleration, and then the final velocity was determined. Therefore it could be said that the K-D strategy was used. But there was no strong preplan present. It appeared that the RA strategy was used.

I didn't remember any formula related with kinetic friction ... I was trying anything I could possibly try to hit some value to help me out.
P just used one equation for problem #2. It's hard to say which strategy was used.

For problem #1, he calculated two time periods (1) from the top to 50 m and (2) from the top to bottom. He then could have subtracted these values. But, P gave up at that point and started over again to calculate the mid-point velocity. By using the same equation, P got the time spent traveling. The basic strategy used was K-D, but it was executed very ineffectively. Later P said:

Stupid mistake, I didn’t know.
I’m sure I was thinking at beginning but lost track of what I was doing, lost what I was thinking about.

To find the final speed in problem #5, P got the acceleration of the projectile and calculated the final speed by using a linear motion formula. In problem #4, during most of time P wondered around and finally set up two equations on calculating distance at certain time and solved for the time by making them equal. P calculated the times for traveling 76 cm and 61 cm (actually he used 76 m and 61 m instead of cm unit) and subtracted them to find the time spent in the bottom 15 cm for problem #3.

Problem #7 was an example of using the M-E strategy. P started with an equation having distance and velocity. Then he tried to find the velocity. The second time, P started with an equation having maximum height. In problem
#8, two distances from the top of the bridge to the feet of each person were measured, converted, and used in the equation including acceleration solving for time. The time which Jim waited was calculated by subtracting the two times which was the correct process.

**J.6 ERRORS**

Near the end of P's session for solving the MPT problems he remarked:

I'm still haven't taken friction. I don't know how to try. At least I don't think it is.

I don't know how to account for friction. I don't account for friction in this problem. I can't remember (the) formula.

I need to know how to bring (friction) into the problem. Friction (is) involved. (I'm) just not sure how to bring into friction.

(I have a) problem dealing with coefficient of friction not with formula.

At problem #2, P considered the energy change for the block as the energy transfer into heat. P knew that energy was conserved before and after the collision.

I'm not sure that the energy caused the block to fly out and the energy caused heat .. it's the same thing. I think I have to take energy before minus energy of the bullet afterwards .. energy the block gains from the bullet striking it.
But P could not get the initial velocity of the bullet. It kept puzzling him during the problem solving. At the follow-up interview:

P: I thought about use momentum stuff somehow, but I didn't know initial velocity of bullet. So I thought 'I can't use it.'
I: Why didn't you try to calculate the initial velocity of bullet using the momentum conservation principle?
P: um .. yes I can.
It is still puzzling (read last sentence) ...
If you assume the block doesn't rise (read last sentence) it's sounds so weird.

During additional interview session, when P was questioned about his confusion he responded:

P: The assumption (that) the block did not rising when the bullet is inside the block causes problems. I couldn't see that happening, heat drives what? The friction of bullet going through the block transfers energy.
I: What makes this block rise?
P: Momentum from transferring bullet.
I: Not heat, was that your problem?
P: Yea, I guess I didn't know. (Laugh)

For some reason, P seemed to think that the heat caused the block to rise.

In problem #1, P calculated two time periods once traveling from top to bottom and the other from top to mid-point. If he had subtracted the two numbers, he would have solved the problem. But he stopped here, and determined the velocity at the mid-point using the time to traveling from top to mid-point. He then used the velocity at the mid-point as the initial velocity and computed the time to
travel the bottom 50 m correct but much more work than necessary.

In problem #4 P at first got a time of 240 seconds for the person who ran the 30 m by using an incorrect equation, $t = \frac{v}{d}$. Later P found that the train will go 28800 m in 240 seconds and questioned his calculations. In a short time, P found the incorrect equation and wrote two equations one each for the train and the person. In that process, he made another error. P set his frame of reference at the person's starting point. In that case, the distance term should be +30, instead of -30. He did not recognize this as an error. Later he got a quadratic equation and solved it for the value of $t$. At that point, P made another error. According to his quadratic equation, the numbers inside the square root should be $64 + 60$. But he calculated it $64 - 60$, which corrected his previous sign mistake. Answer was correct and P was absolutely confident; however, in his solution two procedural mistakes were made.

In problem #3, P used the same equation he used for problem #1. Although P had the experience of solving this kind of problem in #1, P spent a lot of time trying to figure out and set up his plan. By using the same equation, P calculated the times traveled during the fall. However, P
missed the unit conversion from cm to m, so he got about 4 seconds as the falling time. During his solving and after, P never worried about the reasonableness of the time spent traveling during the fall. He just checked whether his time (.410 second) was greater than the given time (.175 second). During the early part of solving this problem, P knew the speed at the bottom would be greater than that at the top. His answer was greater than the given number. Therefore P finished the problem with absolute confidence. But the number represented was time, so the answer should be less than .175 second. It appeared as though P just missed this fact, his high confidence rating came from the relatively simple algorithm which was very familiar and with his previous experience with #1.

P took the change in velocity between the two points as equal to the change in distance divided by change in time, so \(-1/2v = 3/t\) in problem #7. Then P substituted the time into the linear motion formula to get the maximum height. Although it is wrong, the time was conceptually the time spent traveling between the two points. Anyway P got maximum height involving variable \(v\). At that time, P had already spent about 8 minutes. Then the interviewer asked him to write down an answer without using variable \(v\). From then on P tried to find the value of \(v\), but could not recall the exact equation and again plugged the wrong t
value into that equation. P got 4.43 for the value of \( v \), then he substituted it into the former maximum height expression and obtained his answer, 6 m. P noticed that this was too big compared with the 3 m given in the problem. At the follow-up interview, P said:

I'm not sure without any (additional information).
I need both time interval between A and B then
I could solve for \( v \).
I still have to know time from there to maximum height.
If value of \( v \) is given, I think I (can) solve it.

P could have solved the problem given both the time interval and the \( v \) value using the two equations which he knew. He said "variables are sometimes confusing to me rather (than) numbers." The situation given from the middle of the motion did not bother P. At additional interview session, P had a chance to solve the problem again with formula notes. He just considered the kinetic energy of the points and tried to use \( W = Fs \) equation to get a value of \( s \).

Kinetic energy, which is \( \frac{1}{2}mv^2 = 0 \) at maximum height
Work = Fs ...
Ok, I think I found a way.
I'm not sure this is correct, but I will use it.
Work is the change of kinetic energy and
the kinetic energy in beginning is \( \frac{1}{2}mv^2 \).
0 at the maximum height, so work done is \( \frac{1}{2}mv^2 \).
\( W = Fs = mas \)
\( \frac{1}{2}mv^2 = m(-9.8)s \)
\( s = \frac{1}{2}(1/9.8)v^2 \)
.. trying to think .. originally I (was) trying to
see how much energy was lost during that distance.
that distance.
It wouldn't work because it's not linear.
What he seemed to mean by "linear" was that the energy decreased in proportion to the change in distance. The variable v was still included in his answer.

After practicing one simple problem using EC principle, P was again asked to solve this problem using EC principle. At this time, P considered point A and maximum point, and made them equal. The term v was still there. P said "I'm not sure (this problem is) related to energy." After the interviewer gave a hint considering point B, P got more information from the point B and solved the problem. The interviewer asked why he did not use the EC principle to solve this problem at first:

Well, always I thought about it but I didn't think I could. I am tied in. I mean, I didn't think it canceled. I knew it could turn out to be a complicated process, but it didn't turn out to be (that) complicated. What I am doing is against it, but every time at first I started I thought about it. I knew energy here, (and) I knew the kinetic energy be zero.

During solving problem #8, P did not convert cm to m at the beginning. When he got .39 seconds as his answer, P checked his solution and then found the mistake.
After solving problem #6, P rated his confidence as 1. The most deleterious factor on his confidence was his failure to consider friction:

First time I thought weight of box will be given, then it'll be easier. But it wasn't. I didn't remember any formula related with kinetic friction working against friction of box .. slow it down, but I didn't ..

But the weight of the block actually does not matter here. If it appeared in any equation(s), its effect cancels out. P seemed to fear using variables instead of numbers (e.g., #6, #7). In both problems, P's confidence was extremely low. He did not mind the variables in problem #6 because all he needed was the appropriate equations. However, as already seen in a previous section, he did not mean a specific equation, but he meant that he did not know how to deal with the concepts of coefficient of friction. This problem was a hard one for him.

P planned to solve problem #2 using the EC principle. But he could not find the initial velocity of the bullet. And he did not understand the last sentence of the problem. P worried about his interpretation of the last sentence but was pretty confident about his calculation. P liked this problem because the basic principle of comparing before and after was clear. He rated this problem as medium in difficulty.
In problem #1, P questioned the use of the linear motion formula. But by using it, P got two times traveling from the top to bottom and to mid-point. Then he thought there was a "nicer formula" for calculating the time for traveling the bottom 50 m. After he got the velocity at the mid-point, P plugged them into the same equation. Later he said he could not recall the "nicer formula." This lowered his confidence on his answer. After he got his first answer of 7.7 second, he said:

It looks messy, .. possibly. Well, if I say my a is negative, my v (will) also be negative. Actually this (-31.3) is positive (change the sign). I changed that a little bit.

P changed it and calculated \((31.3 - 44.27)/(-9.8)\) and got 1.32 second as the answer.

That's the fall from mid-point to bottom.
Um .. okay, I think I'm done.

P changed his signs to get a reasonable value. Later he confessed that keeping the sign straight with the direction for velocity and acceleration was difficult. That process might be responsible for his confidence level of to 6 although he got the correct answer. P liked this problem because it was easy and he could use his intuitive sense.

During the first couple of minutes in solving problem #5, P tried to use all the given variables. But after using the \(F = ma\) equation and the definition of accelera-
tion, P's confidence was better than the last problem (#1). He thought he followed the right procedures. P liked this problem because it was easy for him to understand and visualize. He rated it as an easy problem.

For problem #4, there was some difficulty at first. P discovered that he could get an answer by making the two equations equal. He made a sign error and a calculational error of which he was unaware. Then he checked his answer (6 second) and saw it worked. So P was absolutely confident about his answer. P liked this problem because it was easy to relate all variables, and easy to check himself.

For problem #3, P made a mistake in the unit conversion. However the mistake was not detected during the problem solving and even at the final checking. P appeared to be overconfident about his solving process. This researcher also did not recognize the mistake initially.

In problem #7, P was not sure about the difference between speed and velocity (see misconception part) and was confused about the signs. P knew some of the physics conditions at maximum height, but said "I couldn't know initial values. I can't figure out." This problem was a hard one because it looked like a two part problem to him.
In problem #8, after getting a scale factor from the picture and the problem sentence, P worried about the two persons' weights.

Because, just because . . .
They are not so bad as long as you know equations like free falling bodies.
It just seems weird, because I mean they're assuming the initial velocity = 0.

That kind of small thing may have decreased his confidence. It appeared that the ideal situation (initial velocity = 0) decreased his confidence on this problem.

J.8 CHARACTERISTICS

P did not know how to start to solve problem #6, so he just "tried to flow all related things" he knew to find some useful equations. During this problem solving, this interviewer thought that P looked like an explorer on the western frontier. He just kept going forward in spite of all kinds of struggles.

P did not understand the last sentence of problem #2. This misunderstanding may have been related to his reading ability. But there is no data to support this right now. While doing the same procedure almost twice, P explained he lost track of what he was doing. P's original plan was to get the mid-point velocity, substitute it into the linear motion formula and calculate the travel time during the
second 50 m. He did not recognize that there was another way to get the solution. P complained a lot about the need for equations, although he used the correct equation in problem #1. P got two answers from solving a quadratic equation in problem #4. But he just picked up one answer and checked whether it worked or not. Because he saw that it was working, P paid no attention to the other one. At the additional interview session, the interviewer asked what happened to the other solution. P said he forgot about it. He had difficulty explaining the movement of the train and person near the two time instances which were given by his solution. He chose 6, 8, and 10 seconds and calculated the positions of the person and the train at each time to explain.

P made a recommendation on wording of this problem sentence to make it easy to read and understand: "During falling from the top, ..." to "The first 15 cm of the jump ..."

In problem #8 after measuring the height of Clara, P said "she is tall." And later he worried that the weights of the two persons was not given. The worry came from his thought that the acceleration of the two different weights would be different. He said "Jim is going to accelerate quicker than Clara." This statement came from P's expectation that Jim (a man) might be heavier than Clara (a woman). The third example was:
It just seems weird, because I mean they're assuming the initial velocity = 0.

P could not imagined jumping with zero initial velocity.
I am interested in your ideas about science and physics. Please tell me what you really think. Write your answer in the space below each question.

1. What is science? Science is observation and testing and theorizing in order to gain a better understanding of a subject.

2. What is physics? Physics is the science of explaining why something does what it does.

3. Is science created or discovered? Science is discovered, it is already here, we just have to find a link to explain it and understand it.

4. How much of your ability to do physics shows up when you take physics tests? Maybe 50%. Basically you have to recognize what the problem is asking, and then find a formula or formulas to solve for it.

5. What can you do if you get stuck while doing a physics problem? After doing this study, I've learned just to go back to the basics, try to solve it with what you know. Simply to imagine the situation at hand.

6. How important is memorizing in learning physics? If anything else is important, please explain how. Memorizing is unimportant to me, since we have a short test, it shouldn't be very important. It should be a test to find out what you intuitively know about physics.
Part II

Please state whether you agree or disagree with the following statement. Then briefly explain your reasons for agreeing or for disagreeing. Two to four sentences should be enough to make your reasons clear. If you cannot agree or disagree, then explain why a choice is not possible for you.

1. Scientists should be concerned with the potential effects (both helpful and harmful) that might result from their discoveries.

    □ agree    □ disagree    □ can't tell
    Reasons: some discoveries can be very deadly, such as nuclear bombs. Nuclear power is fine, but bombs is something I think we could do with. (also biologically unhealthy)

2. Although advances in science and technology may improve living conditions around the world, science and technology offer little help in resolving such social problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war.

    □ agree    □ disagree    □ can't tell
    Reasons: science and technology are the only ways to help overpopulation, world hunger, etc.
3. When scientific investigations are done correctly, scientists discover knowledge that will not change in future years.

[Agree: ___ Disagree: X Can't tell: ___]

Reasons: There is almost always a better way method of doing things, it's just someone hasn't discovered it.

4. Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories; we should not believe that these models are duplicates of reality.

[Agree: X Disagree: ___ Can't tell: ___]

Reasons: Models are created specifically to help visualize and explain but are not necessarily duplicates of reality.

5. The best scientists are those who do not lock themselves into following the steps of the scientific method, but instead use any approach that might help them.

[Agree: X Disagree: ___ Can't tell: ___]

Reasons: Everyone has their own methods of doing things.
6. Communities or government agencies should tell scientists what problems to investigate; otherwise scientists will investigate only what is of interest to them and not necessarily investigate the problems of interest to the country.

___ agree    X disagree    ___ can't tell
Reasons: Scientists are people too, they have the same interests as most any other person would.

7. A scientist may play tennis, go to parties, or attend conferences with other scientists or with non-scientists. Because these social contacts can influence the scientist's work, these social contacts can influence the content of the scientific knowledge he or she discovers.

X agree    ___ disagree    ___ can't tell
Reasons: You never know from what source knowledge will come.
Part III

Please select the one best response in your opinion for each item and mark your choice. You may mark two or more responses if they seem equally good. If you do not like any of the responses, then please add your own response.

1. The main motivation of most scientists is
   ____ (1) earning a decent salary.
   ____ (2) earning recognition from other scientists.
   x (3) satisfying their curiosity about natural phenomena.
   ____ (4) __________________________________________________________

2. In my mind, the primary purpose of science is
   x (1) the furtherance of the well-being of humanity.
   ____ (2) the compilation and categorization of all laws and facts about natural phenomena.
   ____ (3) the mastery and control of nature through a set of relations that successfully predict events.
   ____ (4) the establishment of theoretical structures which integrate and explain.
   ____ (5) __________________________________________________________
3. Which of the following is the best description in your judgement of a scientific law?

(1) It is an exact report of a set of observations.
(2) It is a generalized statement of relationships among natural phenomena.
(3) It is a theoretical explanation of a natural phenomenon.
(4) It is dictated by nature and cannot be violated.
(5) __________________________________________________________

4. Of the following, which is the best statement about the objectivity of the scientist in your judgement?

(1) The scientist is basically objective because he is indifferent about the conclusions and outcome of his work.
(2) The scientist is objective because making progress and achieving answers is a matter of grinding things out via the scientific method.
(3) The scientist's objectivity consists of inter-subjective testability, i.e. agreement between members of the scientific community on matters of observation and verification.
(4) The scientist's objectivity is the result of the fact that science is impersonal throughout.
(5) __________________________________________________________
5. When a new theory replaces an older theory, it is frequently incompatible with its predecessor in the sense that

(1) successive theories often change the meaning of familiar terms and/or add new postulates.
(2) the old theory is erroneous and the new theory is a correction of former mistakes.
(3) a new battery of experimental apparatus must be designed.

(4) The premise is false; new theories are not usually incompatible with their predecessors.

(5) usually it is just a mission the old wasn't totally wrong, it's just that new information has been found.

6. Concerning the verification of a scientific theory,

I think that

(1) experimentation and observation proves the correctness of a theory.

(2) a theory can be enforced or weakened by new data, but not proven or falsified.

(3) theories are sometimes conclusively verified without recourse to experimentation or observation.

(4) a theory is usually discarded as soon as a piece of experimental evidence is found which falsifies it.

(5)
7. The concept 'demons' is not part of the repertoire of science because it

(1) lacks explanatory power.
(2) involves appeal to unfamiliar qualities.
(3) is non-observable.
(4) fails to be testable.
(5) [Blank]

8. The fields of natural science and social science in my view

(1) are similar in that the chief goal of both is the discovery of universal laws.
(2) are different in that the judgements of natural science are objective because the investigator does not interfere with the object, but observation and interpretation in social science are influenced by the values and actions of the investigator.
(3) are similar in that both seek to establish connections between particular events and make use of generalizations in understanding events.
(4) are different in that the phenomena of natural science are recurrent, reproducible, and regular, but the phenomena of social science are norecurrent, unique, and erratic.
(5) [Blank]
9. Getting a good or bad grade in physics is depend upon

(1) my effort
(2) teacher
(3) luck
(4) test

10. The physics that I learn in school is

(1) mostly facts and procedures that have to memorized.
(2) thought provoking.
(3) just a way of thinking about mechanics, thermodynamics, and electricity.

11. The reason I try to learn physics is

(1) to help me think more clearly.
(2) it is required for my program.
(3) it is interesting.
(4) physics is everywhere.
1. Write an equation to represent the following statements.

   a) "In a classroom there are five times as many boys as girls." Use $B$ for the number of boys and $G$ for the number of girls.
      
      $B = 5G$

   b) "A country sells four times as much wheat as corn."
      Let $W$ represent the amount of wheat and $C$ represent the amount of corn.
      
      $W = 4C$

   c) "There are six times as many students as professors at this university." Use $S$ for the number of students and $P$ for the number of professors.
      
      $S = 6P$

   d) "At Mindy's restaurant, for every four people who ordered cheesecake, there are five people who ordered strudel." Let $C$ represent the number of cheesecakes and $S$ represent the number of strudels ordered.
      
      $C = \frac{4}{5}S$
2. There are two plastic cylinder containers of equal height but with different diameters. A given quantity of water rises 4 units in the wide container and rises a corresponding 6 units when poured into the narrow container. Using the same plastic containers, if 11 units of water are poured from the narrow cylinder to the wide cylinder, the level in the wide cylinder will be \( \frac{7}{3} \) units. Why?

\[
\frac{3}{2} \cdot \frac{2}{3} \cdot 11 = \frac{3}{2} \text{ (large units)}
\]

3. If the 100 gram weight is hung at 4 cm on the left side of the balance at which position will the 50 gram weight have to be placed on the right to balance the arm?

Why?

Since 50 g = \( \frac{1}{2} \) 100 g

I knew that the distance should be twice as much
4 cm \( \cdot \) 2 = 8 cm
to give equal distribution.
A biologist did an experiment to find out how many frogs lived in a pond. He did not have enough time to catch and count all the frogs. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to spread themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg. Using all of this information, how could the biologist figure out about how many frogs are in the pond?

The biologist knew he had at least 115 frogs. But he can't be sure about the number total. He could catch all the frogs in a given area he could catch all the frogs in a given area and use that number to get of the pond, then use that number to get of the pond. But there are many factors. He'd need to do this many times at different parts of the pond.

5. Walking back to my room after class yesterday afternoon, I noticed my six-foot frame cast a shadow eight feet long. A rather small tree next to the sidewalk cast a shadow eighteen feet long. My best guess of the height of the tree would be 13.5 ft.

\[
\frac{H}{h} = \frac{S_1}{S_2} \Rightarrow \frac{H}{8} = \frac{18}{2} = 13.5 \text{ ft.}
\]
Computational Skill Test

1. Fill in the blank.
   a) \(106 \text{ cm} = (1.06 \text{ m})\) 
   b) \(4 \text{ g} = (0.004 \text{ kg})\)

2. Calculate the following expressions.
   a) \(\frac{1}{3 \times 23} \left( (16 \times 10^2)^2 - (7 \times 10^2)^2 \right) = \frac{100x+9}{30,000}\)
   b) \(\frac{\sqrt{2x7 \times 10^2}}{\sqrt{3x10}} = 6.831\)
   c) \(\frac{\sqrt{4x0.57} - \sqrt{3x0.29}}{\sqrt{7.4x5}} = 0.1225\)
   d) \(\sin 37^\circ \approx 0.6018\)
   e) \(\cos 37^\circ \approx 0.7966\)

3. Solve the following equations.
   a) Solve for \(x\).
      \(2x^2 - x - 6 = 0\)
      \((2x+3)(x-2) = 0\)
      \(x = -\frac{3}{2}, x = 2\)
b) Solve for $x$ and $y$.

\[
\begin{align*}
2x + 5y &= 2 - 2x \\
3 + 50x &= -20y \\
3 + 30x &= -40 + 40x
\end{align*}
\]

\[
\begin{align*}
5y &= 2 - 2x \\
10x &= -55 \\
5y &= 3
\end{align*}
\]

\[
\begin{align*}
5y &= 2 - 2x \\
10x &= -55 \\
5y &= 3
\end{align*}
\]

\[
\begin{align*}
\frac{15 + 150x}{5} &= -40 + 40x \\
\frac{10x}{5} &= -55 \\
\frac{5y}{5} &= 3
\end{align*}
\]

\[
\begin{align*}
\lambda &= \frac{1}{3} \\
\gamma &= \frac{3}{5}
\end{align*}
\]

c) $2ab = c^2 - d^2 + 100$, where $a = -200$, $c = 5 \times 10^2$.

\[
\begin{align*}
d &= 30. 	ext{ What is the value of the } b? \\
2 \cdot (-200)b &= (5 \times 10^2)^2 + 100 - (-200)
\end{align*}
\]

\[
\begin{align*}
b &= -523
\end{align*}
\]

d) \[
\begin{align*}
\frac{z^2}{3} - 2.7x^2 &= \frac{5}{2}x^2 \\
2x^2 - 6(2.7x^2) &= 3.5x^2 \\
-5x^2 &= 6(2.7x^2) \\
x^2 &= 6 \cdot \frac{5}{2} \\
x^2 &= (6.2) \left( \begin{array}{l} 
\lambda = \pm 4.02 \\
\gamma = \pm 8.04
\end{array} \right)
\end{align*}
\]

e) \[
\begin{align*}
\frac{ab^2}{2} + ab &= \frac{1}{3}(.5)^2 a + ab(t + 2) \text{, where } b = 4.
\end{align*}
\]

\[
\begin{align*}
\frac{a\left(\frac{1}{2}\right)^2 + ab}{2} &= 0.083a + ab t + 2b \\
a\left(\frac{1}{2}\right)^2 - 4a t &= 0.083a + 4a \\
a\left(\frac{1}{2}\right)^2 + 4at &= 4.083a = 0
\end{align*}
\]

4. What are the values of $y$ and $z$ in terms of the $x$ and $\theta$?

\[
\begin{align*}
\tan \theta &= \frac{y}{x} \\
\cos \theta &= \frac{x}{\sqrt{x^2 + y^2}} \\
\sin \theta &= \frac{y}{\sqrt{x^2 + y^2}} \\
\end{align*}
\]

\[
\begin{align*}
z &= x \cos \theta \\
y &= x \sin \theta
\end{align*}
\]
\[ t = \frac{4a \pm \sqrt{16a^2 - 4(-9.083)a}}{2} \]

\[ t = \frac{4a \pm \sqrt{16a^2 - 8.166a^2}}{a} \]

\[ t = \frac{4a \pm 2.8a}{a} \]

\[ t = 4 \pm 2.8 \]

\[ t = 6.8 \quad \text{or} \quad t = 1.2 \]
A juggler plays with seven identical balls. At time $t$, the seven balls are in the air at the same height, on trajectories shown in dashed line in the figure. Also shown are the velocity vectors of the balls at this instant. Are the forces acting on the balls at this instant the same or different? Are some the same and others different? Justify your answer. (Neglect air resistance.) Are the potential energies of the seven balls the same or different?

Different forces

Yes, $V_1$ and $V_6$ could be the same. Others are different.

Potential energies are different $P + V_2 = mg h$ $P + V_2 = 0$
2. A bowling ball weighing 16 lbs. hits a bowling pin weighing 4 lbs. Compare the force the ball exerts on the pin with the force the pin exerts on the ball.

The ball accelerates the pin, and the pin accelerates the ball. The force is equal but opposite.

\[ F = m \cdot a \]

3. Three boxes are stacked on top of each other with the lightest on the bottom and the heaviest on the top. Think about whether the top and bottom blocks A and C exert a force on the middle block B.

Block A exerts a downward force equal to its weight, and block C exerts a normal force equal to the weight of A and B.
4. A suitcase slides from a ramp onto the steel floor of the baggage area at an airport. Explains why the suitcase will stop?

- gravity effects the bag while it is on the ramp and causes acceleration while on the flat floor gravity can cause no acceleration.
- friction between the steel floor and bag and an resistance.

5. Twenty large books are stacked in a pile in Roger's garage, and Roger wants to read the black one in the middle. He tries to pull it horizontally out of the pile without taking the books above it off, but can't move it. Explains the primary reason why this is happen?

- because he is trying to pull the weight of 11 or 12 books all of ether (the books) weight is going down while Roger is pulling to the side.

- there is a force in the downward direction caused by all of the books above the one in question and there is also a horizontal force of friction.
6. A coin is tossed from point A straight up into the air and caught at point E. On the dot to the left of the drawing, draw one or more arrows showing the direction of each individual force acting on the coin when it is at point B.

(Draw longer arrows for larger forces.)

Explain your drawing.

7. A body is dropped freely from position A to reach the position 1 on level XY. The body is projected from A with different horizontal velocities such that it successively reaches the position 2, 3, 4 as the projecting velocities increase.

What is the change in total energy for each body as it reaches each position?
8. Ball A travels with uniform motion from left to right while ball B travels in the same direction, starting with an initial velocity greater than that of ball A. As ball B travels up a gentle incline, it slows down and eventually comes to rest. Ball B first passes ball A, but later ball A passes ball B. Do these two balls ever have the same speed? Explain your choice.

At this point they have the same speed for that instant, but for only that instant.

At two pts, first when B passes A, then when A passes B, the balls have the same speed.
9. Ball A starts with some high initial velocity, slows down, and comes to rest. Another ball, ball B, starts from rest at a point ahead of ball A. It accelerates uniformly down a gentle incline. Ball A never overtakes ball B as is shown. Do these two balls ever have the same speed? Explain your choice.

At some point, the balls might approach each other, but they do not overtake each other.
10. Both balls start from rest and reach the same final velocity at the end of the incline just as they simultaneously enter a tunnel at the bottom. They are not released at the same point or the same time and do not travel equal distances. Ball A is released first from a point several centimeters behind ball B. After rolling a few centimeters, ball A strikes the lever and ball B is released. Do these two balls have the same or different accelerations? Explain your choice.

![Diagram of two balls on inclines with a lever in between them](image)

depending on how A struck the lever and how the lever struck B, A may have transferred momentum to B through the lever.

The balls have different accelerations.
11. The initial velocity of both balls is zero. The two balls are rolling down inclined tracks and level tracks. Given numbers on following diagram are the length of each track and the time which the ball travels the track. Calculate the accelerations of two balls.

\[ v_0 = 0 \]

\[ a = \frac{v}{t} \]

\[ a_A = 1.5 \text{ m/s}^2 \]

\[ a_B = 3.75 \text{ m/s}^2 \]
12. What are the dimensions of the following expressed in fundamental units? 

a) \( N \) (Newton): \( \frac{kg \cdot m}{s^2} \)  
\( F \)

b) \( J \) (Joule): \( \frac{kg \cdot m^2 \cdot s^{-2}}{s} \)  
\( E \)

c) Do the "force," "work," and "energy" have the same dimension? No, but all related.

work = force \times distance  
energy = force \times per time

13. Fill in the blanks and define symbols.

a) \( \dot{v} = v_0 + \left( \frac{1}{2} at \right) \)  
acceleration \( a \)

b) \( 2gs = v^2 + ( \quad ) \)

\( c) s = v_0 t + \left( \frac{1}{2} at^2 \right) \)  
accelerated \( v = v_0 + at \)

d) \( F = ma \)  
( \( A \) )

e) Kinetic Energy = ( \( \frac{1}{2} mv^2 \) )

f) Potential Energy = ( \( mgh \) )

g) Work = ( \( F \cdot d \) )

h) Frictional force (on plane with \( \mu \) and \( m \)) = ( \( \mu mgh \) )

i) Energy loss by frictional force (\( Ff \)) = \( Ff \times (KE + PE) \)

j) Stored energy in spring = \( \frac{1}{2} (kF^2) \times d. \)

\( \epsilon = \text{spring constant} \)
14. How are the following quantities related? Speed, velocity, and acceleration

\[ \text{speed} = \frac{\text{distance}}{\text{time}} \]
\[ \text{velocity} = \frac{\text{distance}}{\text{time}} \]
\[ \text{acceleration} = \frac{\text{change in velocity}}{\text{time}} \]

15. Explain the energy conservation principle and show the mathematical expression using Kinetic Energy (KE), Potential Energy (PE), and Work by friction (Wf).

\[ W_f = mgh + \frac{1}{2}mv^2 \]

\[ W_{\text{En}} + \text{KE} + \text{PE} + W_f = W_{\text{En}} + \text{KE} + \text{PE} + W_f \]

16. Explain the momentum conservation principle and show the mathematical expression using mass (m) and velocity (v).

\[ m_1v_1 + m_2v_2 = m_1v' + m_2v' \]

17. A block is sliding down an inclined plane with \( \mu \) as the coefficient of friction. At the position shown in the figure write an expressions for each of the following.

a) kinetic energy
\[ \frac{1}{2}mv^2 = \frac{1}{2}m(v_0 \cos \theta)^2 \]
b) potential energy
\[ mgh \sin \theta \]
c) frictional force
\[ \mu \frac{1}{2}m(v_0 \cos \theta)^2 \]
A block is moving up a 40° incline. At a point 1.8 m from the bottom of the incline (measured along the incline), it has a speed of 4.5 m/s. The coefficient of kinetic friction between block and incline is 0.15. How fast will it be going after it slides back to the bottom of the incline?

\[ v_0 = 4.5 \text{ m/s} \]
\[ v_f = 0 \text{ m/s} \]
\[ a = \frac{v}{t} \]
\[ \alpha = \frac{-7.5 \text{ m/s}^2}{2} \]
\[ t = \sqrt{\frac{2v}{a}} = 0.6 \text{ sec} \]
\[ \Delta x = 4.5 \text{ m/s} \cdot (0.6 \text{ sec}) + \frac{1}{2}(-7.5 \text{ m/s}^2 \cdot 0.6 \text{ sec}^2) \]
\[ \Delta x = 2.25 \text{ m} \]

\[ \frac{dv}{dt} = \frac{d}{dt} \left( \frac{v}{t} \right) \]
\[ -7.5 \text{ m/s}^2 = \frac{(4.5 \text{ m/s} - 0)}{0.6 \text{ sec}} \]

\[ v_f = -5.78 \text{ m/sec} \]
problem B

A 5-g bullet horizontally penetrates a 1 kg block suspended at rest from a 1 m long thread of negligible mass. The bullet leaves the block from its far side with velocity 200 m/s. How much energy was transformed into heat if the block rose through a height of 0.3 m? (You may assume that the block did not rise while the bullet was inside it.)

\[ U = \frac{1}{2}mv^2 \]

\[ U = mgh \]

\[ U = mg(h_2 - h_1) \]

\[ U = I_k (\frac{1}{I_2} - \frac{1}{I_1}) \times (0.3 \text{ m}) \]

\[ U = 2.94 \text{ Joules} \]
Problem A

A rock is dropped from a 100-m high cliff. How long does it take to fall from the mid-point (50-m high point) to the bottom?

\[ \begin{align*}
V_0 &= 0 \text{ m/s} \\
\gamma &= x_0 + V_0 t + \frac{1}{2} a t^2 \\
a &= -9.8 \text{ m/s}^2 \\
\end{align*} \]

\[ -50 = \frac{1}{2} at^2 \]

\[ t = 3.19 \text{ sec} \]

\[ \begin{align*}
\Delta v &= 9.8 \text{ m/s} - 31.9 \text{ sec} \\
\Delta v &= 100 = \frac{1}{2} (9.8 \text{ m/s}^2) t^2 \\
V_0 &= 31.3 \text{ m/s} \\
-50 &= V_0 t + \frac{1}{2} (9.8 \text{ m/s}^2) t^2 \\
t &= 4.52 \text{ sec} \\
\end{align*} \]

\[ t = 31.3 \pm 1.32 \text{ sec from 50 m to 0 m} \]
problem E

A 100-g projectile is placed in a slingshot, and a band is pulled back 0.5 m and held with a force of 50 N before being released. The slingshot takes 0.05 sec to accelerate the projectile to its final speed. What is the final speed of the projectile?

\[ x = x_0 + v_0 t + \frac{1}{2} a t^2 \]

\[ F = ma \]

\[ 50 \text{N} = 0.1 \text{kg} \cdot a \]

\[ a = 500 \text{ m/s}^2 \]

\[ a = 500 \text{ m/s}^2 = \frac{v_f - v_0}{0.05} \]

\[ v_f = 25 \text{ m/s} \]
problem D

A late passenger, sprinting at 8 m/s, is 30 m away from the rear end of a train when it starts out of the station from rest with an acceleration of 1 m/s². Can the passenger catch the train if the platform is long enough? Yes

\[ v_p = 8 \text{ m/s} \]

\[ v = \frac{d}{t} \]

\[ t = \frac{2d}{v} = \frac{2 \times 30}{8} = 7.5 \text{ sec} \]

\[ s_k = \frac{1}{2} \cdot 1 \text{ m/s}^2 (5)^2 = \frac{3 \text{ m}}{1 \text{ m}} = 7.03 \]

\[ v_t = \frac{1}{2} at^2 - 20 \]

\[ 8 \text{ m/s} \cdot t = \frac{1}{2} \cdot 1 \text{ m/s}^2 t^2 - 30 \]

\[ 0.5t^2 - 8t - 30 = 0 \]

\[ t = \frac{8 \pm \sqrt{64 + 120}}{10} \]

\[ t = 6 \]
problem C

A basketball player, standing near the basket to grab a rebound, jumps 76 cm vertically. During falling from top, 0.175 second is measured in the top 15 cm of this jump. How much time does the player spend in the bottom 15 cm during the falling? Does this help explain why such players seem to hang in the air at the tops of their jumps?

\[ x = x_0 + \frac{1}{2} a t^2 \]

\[ v = v_0 + at \]

\[ x = 76 + \frac{1}{2} (-9.8 m/sec^2) t^2 \]

\[ t^2 = \frac{76}{0.5 (9.8 m/sec^2)} \]

\[ t^2 = 15.510 \]

\[ t = 3.948 \text{ sec} \]

\[ 3.985 \text{ sec} - 3.528 \text{ sec} = 0.410 \text{ sec} \]

Yes
A stone is thrown vertically upward. On its way up it passes point A with speed \( v \), and point B, 3.0 m higher than A, with speed \( \frac{1}{2} v \). Calculate the maximum height reached by the stone above point B.

\[
\begin{align*}
V &= 0 \\
\alpha &= -9.8 \text{ m/sec}^2 \\
\frac{1}{2} v - \frac{1}{2} v &= \frac{3 m}{t} \\
v - 0 &= \frac{3 m}{\frac{1}{2} v} (x = vt - \frac{1}{2} \alpha t^2)
\end{align*}
\]

\[
\begin{align*}
X &= \frac{1}{2} at^2 \\
X &= \frac{1}{2} (9.8 \text{ m/sec}^2) \left( \frac{3}{v} \right)^2 \\
X &= 18(9.8 \text{ m/sec}^2) \left( \frac{3}{v} \right)^2
\end{align*}
\]

\[
\begin{align*}
H_{\text{max}} &= 18(9.8 \text{ m/sec}^2) \left( \frac{3}{v} \right)^2 - 3m \\
H_{\text{max}} &= 176.4 \frac{m}{v^2} - 3m \\
x &= x_0 + v_0 t + \frac{1}{2} \alpha t^2 \\
X &= 4.43 \text{ m/sec}
\end{align*}
\]
problem H

As the figure shows, Clara jumps from a bridge, followed closely by Jim. How long did Jim wait after Clara jumped? Assume that Jim is 170 cm tall and that the jumping-off level is at the top of the figure. Make scale measurements directly on the figure.

\[ \text{Jim: } T = 0.39 \text{ sec} \]

\[ \text{Clara: } T = 1.105 \text{ sec} \]

\[ 3.15 m = -\frac{1}{2} (9.8 \text{ m/sec}^2) T^2 \]
\[ T = 0.802 \text{ sec} \]

\[ 5.99 m = -\frac{1}{2} (9.8 \text{ m/sec}^2) T^2 \]
\[ T = 1.105 \text{ sec} \]
Appendix K
DATA INSTRUMENTS AND DESCRIPTIONS FOR E

K.1 LEARNING HISTORY

I: Is there any secret method to getting A's?
E: I like it. I didn't think I did wrong, but as long as you read the assignment because so many people of the classes don't even do that. Always try to do. Sometimes I don't have answers. At least at next time of the class, they explain and I understand. Most of people don't even do the minimum stuff, read the stuff or do the homework.

To the question on the amount of his physics knowledge:

Fairly well. I think the way they run the course is they expect to make you think that when you get out of this, everybody has all this stuff memorized. But in reality, all they are trying to do is to introduce the stuff. So when 20 years from now, if you want to use something you look it up in the book, it looks like new. As long as you are introduced to it, you know how to use. These courses are not only introduced to you, (but also) expect to memorize. I understand material well.

K.2 TEST RESULTS ON RELATED VARIABLES

I remembered the original ratio, and remembered the latter ratio. But I'm confident the result will be correct. I assigned wrong value. (Making a) mistake twice always saved me. I thought (I was) good at test, but I (would) get a C like that. That kind of quick read is my main problem in this stuff.
K.3 MISCONCEPTIONS

For item #2, E said:

Force of ball to pin is greater than force of pin to ball. If you push (on the) wall, the force is equal because they don't move. But in this case, they are not the same.

He seemed to be affected by visible movement. In static situation like item #3, E could explain the forces correctly.

For item #9, E drew a graph with speed and time axes to explain the existence of an instant having the same speed. He could explain item #10 correctly, but for item #11, E had trouble. He calculated average velocities for the slope and for the plane, then divided the difference of the average velocities by half the total time. This may be an example in which problem becomes difficult in a different context. He neither used any mathematical equations nor did he apply physics principles to this problem.

E did not know the equation for linear motion involving gravitational acceleration, distance, and velocity, nor the equation for stored energy of a spring in terms of force and distance.
K.4 PRESTUDY AND PROBLEM SEQUENCE

After studying the prestudy material for 12 minutes, E reflected:

Energy part is more important than motion because motion parts are a sort of straight forward stuff. Most are confident except the last equation on velocities on elastic collision between two bodies.

E believed that:

At first looking a formula is not give any understanding, so explanation is needed, but (on) second (look) or now, just looking without explanation is enough.

On the solving sequence:

E: Problem #7 looks like easier than #3.
#8 is similar to #3.
The order of 6,5,2 is from easier to more difficult.
To me momentum is difficult because hard to understand the momentum.
#5 looks like spring problem, related potential energy.
I: Why motion part comes first?
E: Because it's easier, and (I) remember lots of formulas. I didn't have many formulas memorized, but I think I can derive them.

K.5 PROBLEM REPRESENTATION

The term "kinetic" used in the problem sentence did not give him a hint to use the W-E representation because "it meant just moving" in problem #6.

I can't solve this (problem) using energy, because it has friction. If this is smooth surface, I can use energy.
E could set up an equation using the EC principle. In addition, he could recall the frictional force on slope according to the PKT. But to get the distance to a maximum point, he said he should use the friction coefficient and \( F = ma \) equation, not the energy conservation equation.

At the additional interview session on problem #7, E said:

As I told you, concepts related to energy are a lot harder, but equations are easy.
Also I grouped them, it seemed like given distance and velocity. I just didn't think it would be energy related problem. Already I solved one problem a certain way and this seemed similar with the ones before.

This was another example of the Einstellung. For him, The W-E representation was harder than the F-K one.

Real picture doesn't give any extra information, but it helps a little (and) makes me feel I know what's going on. It does not include any extra numbers or equations. Word problem doesn't give me any extra information.

K.6 SOLVING STRATEGY

In problem #1, E attempted to use one equation to solve this problem because of his misunderstanding of the problem. So his strategy could not be identified among the three strategies. E started with an equation having the maximum height, velocity, acceleration, and time in problem
#7. He tried to use the equation for two distances, between points A and B, and between point B and the top. Apparently because of too many variables in the problem, E quit this approach. Then E tried again to determine the time with an equation. Again E quit. A moment later, E used the equation showing the relationship between point A and B, and calculated velocity using the time value. Then he quit this second approach, back tracked to this original, and substituted the time value into the linear motion formula. Finally he got a value for x. This process may be identified as the RA strategy.

For problem #3, E calculated two time periods traveling from the top to bottom and from the top to the position of 61 cm, and subtracted. In problem #4, E made equations for the train and for the person, and set them equal. In problem #8, E calculated the distance obtained from the direct measurement. Then he substituted them into the linear motion formula. These solving processes could be named as the K-D strategy.

In problem #6, E got the upward acceleration, travel time to the top, and the distance to the top. From there, he calculated the final velocity using downward acceleration and then the travel time to the bottom. He did it although it was unreasonable. The second time, he used the
total distance, downward acceleration, and total travel time to get the final velocity. Although he used the wrong equation, the strategy could be identified as the K-D.

In problem #5, E just used the energy conservation principle: potential energy of the slingshot transferred to kinetic energy of the projectile. This approach did not match any of the three strategies. In problem #2, E applied the EC principle, but he could not find the initial velocity of the bullet. The basic strategy was the K-D, but it was not completed.

K.7 ERRORS

During an additional interview session, E discovered his misunderstanding of the problem sentence in #1.

I: Why did this happen?
E: That's how I read the problem.
That's my main problem. (At) a lot of stuff, I don't read the problem.
I read problems too fast. (When) I start to read a problem, half way before (I finish) reading the problem, I think I know what the question is already. So I start trying to figure out in my head before I even finish (reading) the whole problem. Once they give me a number 50 m, I got all (the) information I need. (I said to myself) let's (get) working on the problem.

In problem #7, he just used the time traveling between points A and B as the time traveling between point B and the maximum point. During the follow-up interview, he recog-
nized this mistake. In addition, E did not make use of an additional equation here. He could not solve the problem with only the one equation. According to the PKT, he could remember the equation, \( v = v_0 + at \). If that equation had been used here, the \( t \) variable could have been eliminated and it would have been much easier to solve. But E did not do that during his 22 minutes solving time.

In problem #3, E understood correctly what the problem meant. He did not convert cm to m and made a computational error, 76 \( \times \) 2 = 132, not 152. If he had computed it correctly, he might have gotten 3.94 as his time for traveling 76 cm (actually it was 76 m). Then he might find that something was wrong because it was bigger than the given number.

During the first attempt in solving problem #4, E did not put 30 m into the equation. When the interviewer asked about his confidence on the answer of 16 seconds, E wanted to find out what the other answer is. He found it to be zero. Then E recognized something was wrong and found that 30 m was not considered.

E could get the working acceleration using the slope angle and frictional coefficient by drawing a diagram in problem #6. Then he substituted the calculated time traveling to the top and the working acceleration into the lin-
ear motion formula to get a final velocity at the bottom of the slope.

I: Do you think the number of $a$ is the same when traveling up and down?
E: Yes, number doesn't change, just sign changes.
At upward, (it's) negative direction.
At down, (it's) decelerating in the positive direction.
Ok, I'm sorry, there's something. Yes because here is acting against gravity going up and going down with it.

E calculated another acceleration at downward movement and plugged the acceleration, total travel distance, and travel time into the wrong equation.

Interesting thing is that the travel time was calculated using the same linear motion formula, but this time he used it correctly compared to problem #6. Consequently E got a zero velocity. If he had used the correct equation, it would have given him the correct answer.

His difficulty was with the potential energy in problem #5. All he remembered was $1/2kx^2$, but there was no spring constant given. This puzzled him. He tried to replace the constant with some other things. Since the 50 N of force was given, he tried to use it. He tried to figure out how the spring constant was related to the force by using unit dimensions, but it was too complicated. So E just substituted force in place of the spring constant, which was wrong. He could not derive potential energy involving force and distance.
In problem #2 using the EC, E got the energy difference, which was heat energy generated. But the energy difference was a function of the bullet’s velocity. He could not go forward from there. During the follow-up interview, E stated that the velocity equation for an elastic collision might be used here. He was not sure about the equation.

K.8 CONFIDENCE

E was absolutely confident about his solution for problem #1. His mistake occurred during the reading of the problem. Since he did not recognize the error, it did not influence his confidence level. After solving the problem, E said that it was an easy problem.

In problem #7, E ceased his first try because too many variables confounded the process. He was confident, however, about the time calculated for traveling to the top.

I'm sure if the t (1.1066) is the time between the two points, my answer will be correct. I'm not sure about the process to solve (for) t but my answer comes out to be a good answer because I expected 1 or 2 seconds instead of 20 or 30 seconds.

He had assumed that the time traveling from the point A to B and the time traveling from point B to the top were the same.

The fact I have different t should be different .. no way keep the same, um .. Ok, continue a little bit, \( \frac{1}{2}vt = 3 \).
(I'm) not totally in agreement with this. (It) lessens
my confidence, but (when I) solve the problem . . .
that . . . canceled, see . . .

E rated this problem as hard because it was a little bit hard to understand. He said "if numbers would be given, the problem would be easier."

During the first part of solving problem #3, E predicted the range of the answer. When he got about 4 second to travel less than 1 m, actually it was for about 80 m, he questioned that the time was larger than he expected.

Answer doesn't look like (right).
I can't see any mistake.

But his confidence was quite high and he rated it an easy one.

During the first attempt to solve problem #4, E did not consider the 30 m distance between the person and the train. But when he got two answers, E was very confident. After finding his mistake and getting a correct answer, E's confidence rating was unchanged compared to the first rating.

E measured the distance incorrectly for problem #8. He did not know of the mistake, so he was totally confident. E liked this problem because he could look at it.
In the first attempt to solve problem #6, E got .723 m/s as the final velocity.

I should not be more confident (because) reading the problem took me a while. I figured out what forces are actually going to be accelerating. After (I) drew a diagram, I don't know. Just from intuition, it should be faster because it starts from 4.5. If (there is) no friction, at the same point (going down) at least it is 4.5, probably twice as much as at the bottom, but friction slows down. (Is it) still less than 1? I would expect something, may be 2,3,4,5. I am not too sure about it. I'm pretty confident about my procedures, (but when he saw the answer) I was not sure exactly where I was going to start, but I know someway the object, that'll cause an additional acceleration. Not gravity, but the normal force and friction will cause another acceleration. See the friction coefficient is small, not large.

When E saw that his initial answer was incorrect, he pointed out the diagram he drew for calculating the acceleration as the suspicious part. When he got zero as the final velocity the second time, E's confidence rating was raised from 5 to 8.

I'm a little more confident at this time because I considered two accelerations. Large process should decrease my confidence but just came (out and) canceled to zero. I'm pretty confident that people designed this problem made it zero.

E liked this problem because it was challenging and an interesting answer resulted.

E could not find the spring constant in problem #5.

After finishing the problem:

(I'm) not sure at all. Definitely pretty low because spring constant was not
given but they gave force. (I) tried to relate somehow.

He understood this problem as the W-E representation, but the spring constant was not given. In addition force and time variables were given by the problem. It confused him. E did not like this problem because it was hard to understand.

E could not find the initial velocity of the bullet in problem #2. It was a puzzle for him because he could not figure out the kinetic energy of the initial state.

In tests I'm not sure at all. Something very important is missing in this side. If problem asks for equation of heat depending on initial v, I'm 10, but otherwise 2, because of not having answer but equation.

E liked this problem although it was hard.

This is very interesting problem. You brought a lot of interesting problems. I guess whole concept with energy is not confident for me. (It's) hard sometimes to understand or figure out which energy is loss (of) heat. (it's) harder but (I) like it.

E rated problem #1, 3, and 8 as easier than #4; problem #7 was rated more difficult than #4.

K.9 CHARACTERISTICS

When asked why he thought there was two answers in problem #6, he said:

Any kind of information like this, like some have receive $100 everyday, someone receive $1 the first day, double the next day .. there are two different
instants they have the same amount of money. This kind of problem always have two answers. It came just from previous experiences, not based on these results.

After working on problem #6 for the second time, E got zero as the final velocity. He gave two reasons for his increase in the confidence of his answer. One reason was "people designed this problem to make it zero." E expected simple numbers for solution in most physics problems. He most likely learned this through his previous experience in school physics.

K.10 RAW DATA
Part I

I am interested in your ideas about science and physics. Please tell me what you really think. Write your answer in the space below each question.

1. What is science?
   - Study of any natural relationship

2. What is physics?
   - Study of the relationships of matter and its surroundings

3. Is science created or discovered?
   - No, the word is used wrong

4. How much of your ability to do physics shows up when you take physics tests?
   - Not much

5. What can you do if you get stuck while doing a physics problem?
   - Stand over by looking at the problem from a different angle

6. How important is memorizing in learning physics?
   - If anything else is important, please explain how.
Part II

Please state whether you agree or disagree with the following statement. Then briefly explain your reasons for agreeing or for disagreeing. Two to four sentences should be enough to make your reasons clear. If you cannot agree or disagree, then explain why a choice is not possible for you.

1. Scientists should be concerned with the potential effects (both helpful and harmful) that might result from their discoveries.

   X  agree  ___  disagree  ___  can't tell

   Reasons:
       Of course they should be concerned, and to my knowledge they are aware of some effects, but others would be impossible to predict.

2. Although advances in science and technology may improve living conditions around the world, science and technology offer little help in resolving such social problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war.

   X  agree  ___  disagree  ___  can't tell

   Reasons:
       Little help yes. But science could easily be used to help these areas.
       Most folks like all of these problems were a result, harmful effect, of science.
3. When scientific investigations are done correctly, scientists discover knowledge that will not change in future years.

agree  disagree  

Reasons: Many physical relationships are true for Earth and may change because of some astronomical reasons. Biological discoveries could change with time.

4. Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories. We should not believe that these models are duplicates of reality.

agree  

Reasons: We are coming closer to actually knowing what these things look like. These models are based on facts.

5. The best scientists are those who do not lock themselves into following the steps of the scientific method, but instead use any approach that might help them.

agree  

Reasons: The scientific method is not a wall that bounds experiments and a scientist. It should increase precision in experiments. Of course there are exceptions, creating relationships with no formal testing; Newton and Einstein, and some of it has now been proven.
6. Communities or government agencies should tell scientists what problems to investigate; otherwise scientists will investigate only what is of interest to them and not necessarily investigate the problems of interest to the country.

____ agree  ____ disagree  X can't tell

Reasons:
- Scientists who investigate what they want must be rich. They usually study what other people pay them for.
- Gov. Agencies do affect what scientists study.
- The EPA puts lots of money into science.

7. A scientist may play tennis, go to parties, or attend conferences with other scientists or with non-scientists. Because these social contacts can influence the scientist's work, these social contacts can influence the content of the scientific knowledge he or she discovers.

X agree  ____ disagree  ____ can't tell

Reasons:
- Too much or bad use of free time can affect anyone's job performance.
Part III

Please select the best response in your opinion for each item and mark your choice. You may mark two or more responses if they seem equally good. If you do not like any of the responses, then please add your own response.

1. The main motivation of most scientists is
   (1) earning a decent salary.
   (2) earning recognition from other scientists.
   (3) satisfying their curiosity about natural phenomena.
   (4) __________________________________________

2. In my mind, the primary purpose of science is
   (1) the furtherance of the well-being of humanity.
   (2) the compilation and categorization of all laws and facts about natural phenomena.
   (3) the mastery and control of nature through a set of relations that successfully predict events.
   (4) the establishment of theoretical structures which integrate and explain.
   (5) __________________________________________
3. Which of the following is the best description in your judgement of a scientific law?

- (1) It is an exact report of a set of observations.
- (2) It is a generalized statement of relationships among natural phenomena.
- (3) It is a theoretical explanation of a natural phenomenon.
- (4) It is dictated by nature and cannot be violated.
- (5) _________________________________________________________

4. Of the following, which is the best statement about the objectivity of the scientist in your judgement?

- (1) The scientist is basically objective because he is indifferent about the conclusions and outcome of his work.
- (2) The scientist is objective because making progress and achieving answers is a matter of grinding things out via the scientific method.
- (3) The scientist's objectivity consists of inter-subjective testability, i.e. agreement between members of the scientific community on matters of observation and verification.
- (4) The scientist's objectivity is the result of the fact that science is impersonal throughout.
- (5) _________________________________________________________
5. When a new theory replaces an older theory, it is frequently incompatible with its predecessor in the sense that

   (1) successive theories often change the meaning of familiar terms and/or add new postulates.
   (2) the old theory is erroneous and the new theory is a correction of former mistakes.
   (3) a new battery of experimental apparatus must be designed.
   (4) The premise is false; new theories are not usually incompatible with their predecessors.
   (5) _________________________________________________________

6. Concerning the verification of a scientific theory, I think that

   (1) experimentation and observation proves the correctness of a theory.
   (2) a theory can be enforced or weakened by new data, but not proven or falsified.
   (3) theories are sometimes conclusively verified without recourse to experimentation or observation.
   (4) a theory is usually discarded as soon as a piece of experimental evidence is found which falsifies it.
   (5) _________________________________________________________
7. The concept 'demons' is not part of the repertoire of science because it
   (1) lacks explanatory power.
   (2) involves appeal to unfamiliar qualities.
   (3) is non-observable.
   (4) fails to be testable.
   (5) I think it is a part of science

8. The fields of natural science and social science in my view
   (1) are similar in that the chief goal of both is the discovery of universal laws.
   (2) are different in that the judgements of natural science are objective because the investigator does not interfere with the object, but observation and interpretation in social science are influenced by the values and actions of the investigator.
   (3) are similar in that both seek to establish connections between particular events and make use of generalizations in understanding events.
   (4) are different in that the phenomena of natural science are recurrent, reproducible, and regular, but the phenomena of social science are nonrecurrent, unique, and erratic.
   (5)
9. Getting a good or bad grade in physics depends upon

(1) my effort — 1
(2) the teacher — 2
(3) luck — 4
(4) the test — 3
(5) EVERYTHING YOU CAN THINK OF

10. The physics that I learn in school is

(1) mostly facts and procedures that have to be memorized.
(2) thought provoking.
(3) just a way of thinking about mechanics, thermodynamics, and electricity.
(4) ________________________________

11. The reason I try to learn physics is

(1) to help me think more clearly.
(2) it is required for my program.
(3) it is interesting.
(4) ________________________________
1. Write an equation to represent the following statements.

a) "In a classroom there are five times as many boys as girls." Use \( B \) for the number of boys and \( G \) for the number of girls.

\[
\begin{align*}
B &= 5G \\
\Rightarrow B &= 5G
\end{align*}
\]

b) "A country sells four times as much wheat as corn." Let \( W \) represent the amount of wheat and \( C \) represent the amount of corn.

\[
C = \frac{1}{4}W
\]

c) "There are six times as many students as professors at this university." Use \( S \) for the number of students and \( P \) for the number of professors.

\[
6S = P
\]

d) "At Mindy's restaurant, for every four people who ordered cheesecake, there are five people who ordered strudel." Let \( C \) represent the number of cheesecakes and \( S \) represent the number of strudels ordered.

\[
\begin{align*}
\frac{1}{4}C &= \frac{1}{5}S \\
S &= \frac{5}{4}C
\end{align*}
\]
There are two plastic cylinder containers of equal height but with different diameters. A given quantity of water rises 4 units in the wide container and rises a corresponding 6 units when poured into the narrow container. Using the same plastic containers, if 11 units of water are poured from the narrow cylinder to the wide cylinder, the level in the wide cylinder will be \( \frac{165}{3} \) units. Why?

\[ \text{If the 100 gram weight is hung at 4 cm on the left side of the balance at which position will the 50 gram weight have to be placed on the right to balance the arm?} \]

\[ \text{Why?} \]
4. A biologist did an experiment to find out how many frogs lived in a pond. He did not have enough time to catch and count all the frogs. The first day he caught 55 frogs and out a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to spread themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg. Using all of this information, how could the biologist figure out about how many frogs are in the pond?

\[
\frac{12}{72} \text{ was the percentage of banded frogs in the pond}
\]

\[
\frac{12}{72} = \frac{55}{x} \quad \text{TOTAL FROGS}
\]

\[
55 \times x = 72 \times 55
\]

\[
x = \frac{72 \times 55}{55} = 72
\]

5. Walking back to my room after class yesterday afternoon, I noticed my six-foot frame cast a shadow eight feet long. A rather small tree next to the sidewalk cast a shadow eighteen feet long. My best guess of the height of the tree would be 13.5 ft.

\[
\frac{3}{8} = \frac{x}{18}
\]

\[
x = \frac{3 \times 18}{8} = \frac{54}{8} = \frac{27}{4} = 13.5
\]
Computational Skill Test

1. Fill in the blank.
   a) 106 Cm = (   ) m   b) 4 g = (   ) Kg

2. Calculate the following expressions.
   a) \( \frac{1}{3 \times 23} \left( (16 \times 10^2)^2 - (7 \times 10^2)^2 \right) \)

   b) \( \frac{\sqrt{2 \times 7 \times 10^2}}{\sqrt{3 \times 10}} \)

   c) \( \frac{\sqrt{4 \times 0.57} - \sqrt{3 \times 0.23}}{\sqrt{7.4 \times 3}} \)

   d) \( \frac{1.51 - 0.93}{4.71 \times 8} \)

   e) Sin 37°

3. Solve the following equations.
   a) Solve for x.

   \( 2x^2 - x - 6 = 0 \)

   \( \left( 2x - 2(2x + 3) \right) = 0 \)

   \( x = 2 \) or \( x = -\frac{3}{2} \)
b) Solve for x and y.

\[ \begin{align*}
2x + 5y &= 2 \\
3 + 30x &= -20y
\end{align*} \]

\[ \begin{align*}
x &= \frac{1 - \frac{3}{5}y}{3} \\
y &= \frac{2 - \frac{3}{5}x}{5} \\
\end{align*} \]

\[ \begin{align*}
x &= \frac{19}{10} = \frac{9}{5} \\
y &= \frac{5}{20} = \frac{1}{4} \\
\end{align*} \]

\[ \begin{align*}
y &= \frac{3}{5} \\
x &= \frac{3}{5}
\end{align*} \]

c) \[ 2ab - c^2 - d^2 + 100 \]

where \( a = -200 \), \( c = 5 \times 10^2 \), \( d = 30 \). What is the value of the b?

\[ y = -\frac{3}{5} \times \frac{9}{5} = -\frac{27}{25} \]

\[ y = \frac{57}{50} - \frac{27}{25} = \frac{5}{50} \]

\[ y = -\frac{18}{50} \text{ or } -\frac{9}{25} \]

d) \[ \frac{x^2}{3} - 2.7x^2 = \frac{5}{2}x^2 \]

e) \[ \frac{2t^2}{3} + ab = \frac{1}{3}(\cdot 5)^2 x + ab(t + 2) \]

where \( b = 4 \).

What is the value of the \( \frac{t^2}{3} + 4 \)?

\[ t^2 + 4 = \frac{1}{3}(-25) + 4 (t + 2) \]

\[ \left( \frac{1}{3} \right)^2 + 4 + 4.083 \]

\[ \theta = 2.9 \]

\[ \cos \theta = \frac{2}{x} \]

\[ \sin \theta = \frac{y}{x} \]

\[ z = x \cos \theta \]

\[ y = x \sin \theta \]
1. A juggler plays with seven identical balls. At time $t$, the seven balls are in the air at the same height, on trajectories shown in dashed line in the figure. Also shown are the velocity vectors of the balls at this instant. Are the forces acting on the balls at this instant the same or different? Are some the same and others different? Justify your answer. (Neglect air resistance.) Are the potential energies of the seven balls the same or different?

\[ \begin{align*}
V_1 & \uparrow \\
V_2 & \uparrow \\
V_3 & \uparrow \\
V_4 & \uparrow \\
V_5 & \uparrow \\
V_6 & \uparrow \\
V_7 & \downarrow \\
\end{align*} \]

Since, the only force acting on each ball is the force of gravity.

Potential energies are all the same high up, it is same.
2. A bowling ball weighing 16 lbs. hits a bowling pin weighing 4 lbs. Compare the force the ball exerts on the pin with the force the pin exerts on the ball.

\[ F_{\text{Ball to Pin}} > F_{\text{Pin to Ball}} \]

3. Three boxes are stacked on top of each other with the lightest on the bottom and the heaviest on the top. Think about whether the top and bottom blocks A and C exert a force on the middle block B.
4. A suitcase slides from a ramp onto the steel floor of the baggage area at an airport. Explains why the suitcase will stop?

Because of different surface.

And the normal force’s component of the weight force is equal.

5. Twenty large books are stacked in a pile in Roger’s garage, and Roger wants to read the black one in the middle. He tries to pull it horizontally out of the pile without taking the books above it off, but can’t move it.

Explains the primary reason why this is happen?

The weight of all the other books on top of it increases.

The friction force.

(3.9)
6. A coin is tossed from point A straight up into the air and caught at point E. On the dot to the left of the drawing, draw one or more arrows showing the direction of each individual force acting on the coin when it is at point B. (Draw longer arrows for larger forces.) Explain your drawing.

7. A body is dropped freely from position A to reach the position 1 on level XY. The body is projected from A with different horizontal velocities such that it successively reaches the position 2, 3, 4 as the projecting velocities increase.

What is the change in total energy for each body as it reaches each position?

\[ \Delta E \] is affected by the horizontal velocity only since all other factors, height, and vertical speed are the same.
8. Ball A travels with uniform motion from left to right while ball B travels in the same direction, starting with an initial velocity greater than that of ball A. As ball B travels up a gentle incline, it slows down and eventually comes to rest. Ball B first passes ball A, but later ball A passes ball B. Do these two balls ever have the same speed? Explain your choice.

Yes.

Since B started out with a greater speed and came to rest before A, somewhere its speed was equal to A.
9. Ball A starts with some high initial velocity, slows down, and comes to rest. Another ball, ball B, starts from rest at a point ahead of ball A. It accelerates uniformly down a gentle incline. Ball A never overtakes ball B as is shown. Do these two balls ever have the same speed? Explain your choice.

**Yes**

While B starts A has a speed
while B stops B has a speed

B's speed increases
A's speed decreases
10. Both balls start from rest and reach the same final velocity at the end of the incline just as they simultaneously enter a tunnel at the bottom. They are not released at the same point or the same time and do not travel equal distances. Ball A is released first from a point several centimeters behind ball B. After rolling a few centimeters, ball A strikes the lever and ball B is released. Do these two balls have the same or different accelerations? Explain your choice.

Their acceleration is due to gravity, angle, _______. If these are all equal then their accelerations should be equal.

Once you include friction the acceleration is dampened and from friction since A has traveled a greater distance its acceleration should be less.
11. The initial velocity of both balls is zero. The two balls are rolling down inclined tracks and level tracks. Given numbers on following diagram are the length of each track and the time which the ball travels the track. Calculate the accelerations of two balls.
\[ V_t = \frac{d}{t} \]

\[ V = \frac{405}{3} \]

\[ V_i = 13.5 \]

\[ V_r = 27 \]

\[ \alpha = \frac{\Delta V}{V} = \frac{13.5}{2.5} \rightarrow \frac{1}{2} \text{of total} \]

\[ 37.4 \frac{\text{cm}}{s^2} \]

\[ V_1 = \frac{d_1}{t_1} \]

\[ V_2 = \frac{d_2}{t_2} \]

\[ V_1 = 60 \]

\[ V_2 = 18 \]

\[ V_1 = 15 \]

\[ V_2 = 30 \]

\[ \alpha = \frac{\Delta V}{V} = \frac{15}{2.9} = 5.17 \frac{\text{cm}}{s^2} \]
12. What are the dimensions of the following expressed in fundamental units?

a) N (Newton): 
\[ \frac{1 \text{kg} \cdot \text{m}}{\text{s}^2} \]

b) J (Joule): 
\[ \frac{1 \text{kg} \cdot \text{m}^2}{\text{s}^2} \]

Do the "force," "work," and "energy" have the same dimension?

13. Fill in the blanks and define symbols.

a) \[ v = v_0 + (\alpha t) \]

b) \[ 2gs = v^2 + (\_\_\_\_) \]

c) \[ s = v_0 t + (\frac{1}{2} \alpha t^2) \]

d) \[ F = m x (\alpha) \]

e) Kinetic Energy = \( \frac{1}{2} m v^2 + \frac{1}{2} k d^2 \)

f) Potential Energy = \( mgh \)

g) Work = \( F \cdot d \)

h) Frictional force on plane with \( \mu \) and \( m = (\mu N) \)

i) Energy loss by frictional force (Ff) = \( Ff \cdot d \)

j) Stored energy in spring = \( \frac{1}{2} k d^2 \)
14. How are the following quantities related?

- Speed, velocity, and acceleration (rate of change of another).

15. Explain the energy conservation principle and show the mathematical expression using Kinetic Energy (KE), Potential Energy (PE), and Work by friction (W_f).

\[ \text{DIFFERENTIAL ENERGY} = \text{WORK BY FRICTION} \]

\[ KE_i + PE_i = W_f + (KE_f + PE_f) \]

16. Explain the momentum conservation principle and show the mathematical expression using mass (m) and velocity (v).

\[ m_1 v_1 = m_2 v_2 \]

17. A block is sliding down an inclined plane with \( \mu \) as the coefficient of friction. At the position shown in the figure write an expressions for each of the following.

- a) kinetic energy = \( \frac{1}{2} m v^2 \)
- b) potential energy = \( m g h \)
- c) frictional force = \( \mu m g \cos \theta \)
A rock is dropped from a 100-m high cliff. How long does it take to fall from the mid-point (50-m high point) to the bottom?

\[ x = \frac{1}{2}at^2 \]

\[ t^2 = 2ax \]

\[ t^2 = (2 \times 9.81)(50) \]

\[ t = \sqrt{981} = 31 \]

\[ t^2 = \frac{2x}{a} \]

\[ t^2 = \frac{(2 \times 50)}{9.81} \]

\[ t = \sqrt{1020} \]

3.7 seconds
A stone is thrown vertically upward. On its way up it passes point A with speed v, and point B, 3.0 m higher than A, with speed 1/2 v. Calculate the maximum height reached by the stone above point B.

\[ x = v + \frac{1}{2}at^2 \]

\[ x_1 = v_1 + \frac{1}{2}a t_1^2 \]
\[ x_2 = v_2 + \frac{1}{2}a t_2^2 \]

\[ \frac{1}{2}v - u \left( \frac{1}{2}at_2 - \frac{1}{2}at_1 \right) = 3 \]
\[ \frac{1}{2}vt = 3 \]

\[ x = v + 4.9t^2 \]
\[ x(0) = x(1) - 4.9t^2 \]
\[ x(2) = \frac{1}{2}v + 4.9t^2 \]

\[ \frac{1}{2}v + 4.9t^2 + 3 \]
\[ v = 9.8t^2 + 6 \]
\[ 4.9t^2 + 6 \]
\[ t = 1.1066 \]
\[ 3 = \frac{1}{2} v + -4.9 + 2 \]
\[ 3 + 4.9 + 2 = \frac{1}{2} v + 1 \]

\[ v_1 = 6 + 9.8 t^2 \]
\[ v = \frac{6}{1.1066} + 9.81 (t - 1.1066) \]
\[ v = 5.422 + 10 - 8.56 \]
\[ v = 16.23 \text{ m/s} \]
problem C

A basketball player, standing near the basket to grab a rebound, jumps 76 cm vertically. During falling from top, 0.175 second is measured in the top 15 cm of this jump. How much time does the player spend in the bottom 15 cm during the falling? Does this help explain why such players seem to hang in the air at the tops of their jumps?

\[ x = \frac{1}{2} \alpha t^2 \]

\[ 76 = \frac{1}{2} \alpha t^2 \]

\[ + 2 = \frac{132}{9.81} \]

\[ t = 3.67 \]

\[ t^2 = \frac{122}{9.81} \]

\[ t = 3.53 \]

\[ t = 67 - 53 \]

\[ 14 \]
problem D

A late passenger, sprinting at 8 m/s, is 30 m away from the rear end of a train when it starts out of the station from rest with an acceleration of 1 m/s$^2$. Can the passenger catch the train if the platform is long enough?

1. \( u = 8 \text{ m/s} \)

\[
\begin{align*}
  x &= \frac{1}{2}at^2 \\
  x &= 8 + \\
  t &= 16 \text{ seconds}
\end{align*}
\]

2. \( u_0 = 0 \), \( a = 1 \text{ m/s}^2 \)

\[
\begin{align*}
  x &= \frac{1}{2}a + t^2 \\
  x &= 8 + \\
  t &= 16 \text{ seconds}
\end{align*}
\]

\[
\begin{align*}
  \frac{1}{2}t^2 - 8 &= 0 \\
  t^2 - 16 &= 0 \\
  t(\pm 4) &= 0 \\
  t &= 0, 4
\end{align*}
\]
train  
\[ x = \frac{1}{2} t^2 \]  

person  
\[ x = 8 + -30 \]

\[ \frac{1}{2} t^2 = 8 + -30 \]
\[ t^2 = 16 + -60 \]
\[ (x^2 + 16 + t^2 + 60) = 0 \]
\[ (t - 6)^2 + 10 \]
\[ t = 4 \pm 10 \]
As the figure shows, Clara jumps from a bridge, followed closely by Jim. How long did Jim wait after Clara jumped? Assume that Jim is 170 cm tall and that the jumping-off level is at the top of the figure. Make scale measurements directly on the figure.

\[ x = \frac{1}{2} a + 2 \]

\[ +^2 = \frac{2 \times 170}{9.81} \]

\[ x = \frac{2 \times (1 - 0.75)}{2 \times 0.75} \]

\[ + = 0.503 \text{ seconds} \]

\[ x = 1 - 2^4 \]
problem F

A block is moving up a 40° incline. At a point 1.8 m from the bottom of the incline (measured along the incline), it has a speed of 4.5 m/s. The coefficient of kinetic friction between block and incline is 0.15. How fast will it be going after it slides back to the bottom of the incline?

\[ x = x_0 + v_0 t + \frac{1}{2} a t^2 \]

\[ v = v_0 + at \]

\[ v = 4.5 - at \]

\[ 0 = 4.5 + at \]

\[ at = 4.5 \]

\[ a = \frac{4.5}{t} \]

\[ g = 9.8 \]

\[ 9(\sin 40° + \mu k \cos 40°) = \frac{4.5}{t} \]

\[ t = \frac{4.5}{9.8(\sin 40° + (0.15) \cos 40°)} = 0.6054 \text{ seconds} \]
\[ x = x_0 + vt + \frac{1}{2}at^2 \]

\[ 0 = 1.8 + v(0.6054) + \frac{1}{2}(-7.433)(-0.6054)^2 \]

\[ v = \frac{1.362 - 1.8}{-0.6054} \]

\[ v = -2.723 \text{ m/s} \]

\[ x = x_0 + vt + \frac{1}{2}at^2 \]

\[ x = \frac{1}{2}at^2 \cdot (-5)(7.433)(0.6054)^2 \]

\[ x = 1.362 \]

\[ v = \frac{3.862}{5} \cdot (-5)(5.18) \]

\[ x = vt + \frac{1}{2}at^2 \]

\[ v = \frac{x}{t} - \frac{1}{2}at \]

\[ v = \frac{3.162}{5} \cdot (-5)(5.18) \]

\[ \alpha_2 = 5.18 \]
\[ X = \frac{v^2}{2a} + vt + \frac{1}{2}at^2 \]

3.162 \quad = \quad \text{?}

\[ t = \frac{X}{\frac{1}{2}at^2} \]
\[ t^2 = \frac{X}{\frac{1}{2}a} \]
\[ t = \sqrt{\frac{2X}{a}} \]
\[ t = \sqrt{2 \cdot \frac{3.162}{5.18}} \]
\[ t = 1.105 \text{ seconds} \]

\[ V = \frac{3.162}{1.05} - (\cdot\cdot)(5.18)(1.105) \]

\[ V = 2.862 - 2.862 = 0 \]
problem E

A 100-g projectile is placed in a slingshot, and a band is pulled back 0.5 m and held with a force of 50 N before being released. The slingshot takes 0.05 sec to accelerate the projectile to its final speed. What is the final speed of the projectile?

\[ P_E = \frac{1}{2} k x^2 = \frac{1}{2} m v^2 \]

\[ \frac{k x^2}{m} = v^2 \]

\[ v = \sqrt{\frac{k x^2}{m}} = \sqrt{\frac{500}{0.1}} = 11.2 \text{ m/s} \]
A 5-g bullet horizontally penetrates a 1 kg block suspended at rest from a 1 m long thread of negligible mass. The bullet leaves the block from its far side with velocity 200 m/s. How much energy was transformed into heat if the block rose through a height of 0.3 m? (You may assume that the block did not rise while the bullet was inside it.)

\[
E_i - E_f = E_L \\
E = \frac{1}{2}mv_1^2 - \left(\frac{1}{2}mv_2^2 + \frac{1}{2}Mgh\right) \\
E = \frac{1}{2}m(v_1^2 - v_2^2) + \frac{1}{2}Mgh \\
E = (0.005)(v_1^2 - v_2^2) + (9.8)(0.3) \\
E = (0.0025)(v_1^2 - 40000) + 14.7 \\
E = 0.0025v_1^2 - 100 + 14.7 \\
E = 0.0025v_1^2 - 85.3
\]
Appendix L

DATA INSTRUMENTS AND DESCRIPTIONS FOR M

L.1 LEARNING HISTORY

M said he liked physics because it was fun.

Mathematics is straightforward, but physics requires understanding. I'm (an) engineer, so how to apply (it) is important to me.

L.2 MISCONCEPTIONS

In item #1 and #6 of the PKT, M demonstrated a correct understanding of forces and potential energy. And he did not have trouble with objects acting upon each other for items #2 and #3. For the suitcase situation in item #4, M explained it would be stopped because of energy loss due to the work done by the frictional force. In regard to the total energy change in item #7, M said that the total energy changes of all cases were the same. He considered the potential energy and kinetic energy and partitioned the falling velocity into x and y components. In item #8, M said there are two points at which the two balls having the same speed.
In item #10, when asked whether the two balls had the same acceleration, M said they have the same acceleration because \( F = ma \) is the same. He assumed both have the same mass and slope. He wrote an equation for a definition of acceleration, but did not apply it correctly. M's response on item #11 was another example of the power of problem context. Even though he demonstrated a very fluent knowledge of physics concepts, in this specific item M was similar to other subjects who did not have as much knowledge. He just calculated the acceleration as the distance divided by the spent time squared \( (a = x/t^2) \) on the ramp and floor. From the total distance of slope and floor divided by square of total time, he got an average (incorrect) acceleration. He did not even think about the fact that the acceleration is zero on floor. His acceleration values in both cases on the floor were greater than those on the slope. At additional interview session, when his mistake was pointed out by the interviewer, M tried a different way to calculate the acceleration. This time, he calculated the average velocity on the slope and floor and got the acceleration by dividing the difference of the average velocities by total time—another incorrect procedure.

M remembered all the equations for the given item #13 of the PKT, except one for getting the stored energy in a spring in terms of force and distance. He knew the energy
in terms of spring constant and distance, but could not express the change correctly. Explanation of the EC and momentum conservation principles were easy for him. The kinetic and potential energy on the slope were also easy. But M wrote \( mgs\sin\theta \) as frictional force and \( mg\cos\theta \) as normal force. He seemed confused about static frictional coefficient and kinetic frictional coefficient because he claimed \( \mu = \tan\theta \).

L.3 PRESTUDY AND PROBLEM SEQUENCE

After reading the prestudy of material for 10 minutes, M said:

Most important parts are concept of velocity and acceleration—not formulas because I can derive most of them using integration, energy concept, and impulse—sometimes energy is not conserved because of impulse. Less important part is collision part because for given formula, just apply, no tricky questions and just remember two formulas that's it.

He was most confident about the parts of linear motion, energy, and friction.

On the question of which is more important, the explanations or the formulas:

Definitely explanations because (although it's) easy to memorize formula but usually forget the details in tricky problem, these details help out with what and when you are to do. The night before a test, (I) just read explanation (thinking about) how they said and how these came from like that. I'm only reading. Exercise makes you to understand formulas, (but)
does not give you difficult aspects of problems.

L.4  PROBLEM REPRESENTATION

In problem #5 of MPT, M calculated the initial velocity of the projectile from work done by the force. Then he used kinematics for getting a velocity increase during the projectile release. M's idea appeared to be triggered by the given time value which he did not use for calculating the initial velocity of the projectile. A similar representation was used in problem #6 also. M set up a basic equation based on EC principle and calculated force components to get the frictional force. Therefore it could be said that both the W-E and F-K representations were used in problems #5 and 6.

At first M considered the momentum in problem #2 by using a velocity equation for elastic collisions. Then he applied EC principle. In problem #7 the W-E representation was used. For the other remaining problems, the F-K representation was used.

M understood that problem #3 was the same as #4 because they both required finding t using the same equation, and were one directional movement with g or a.

(They) look like (they are) different but use similar equations and same reasoning.
He thought problems #1, #4, #8 were the same kind of problem as #3. Among them, #1 was the most similar to #3 because both problems had the same given variables and the same required variables.

L.5 SOLVING STRATEGY

In problem #4, M set equations for the person and the train by using the linear motion formula and made them equal to calculate the time. He calculated the two times using the same equation and subtracted them in problem #1. In problem #5, M got the work done by the force and calculated a velocity by making it equal to the kinetic energy of the projectile. Then he added some increased velocity during release. In problem #7, M considered EC principle between point A and B, and got a v value. Then he made an additional equation by considering point A and the maximum point and got the height by substituting the v value into an additional equation. In problem #6, M set up a work-energy relationship between the starting point and the bottom point on the slope. By substituting in all the needed variables and numbers into the equation based on the relationship, he got the final velocity at the bottom. In problem #2, M calculated the initial velocity by finding the velocity from an equation for EC before and after the collision. Later he used three steps to get the trans-
formed energy. But the solving strategy was the same. In both problems #3 and #8, M calculated the times using the linear motion formula and subtracted them.

L.6 ERRORS

M's mistake in solving problem #4 was solving the quadratic equation, $t^2 - 16t + 60 = 0$. He got a positive t value (10.63), which was wrong. He checked whether the time was working or not. Of course it did not. During checking his procedure, M found that the number inside the square root sign was negative. He concluded that the person could not catch the train because there was no positive, even real number, solution. During the additional interview session, M made the same mistake two more times trying to solve the quadratic equation, before getting a correct answer. During the CST, M solved that kind of quadratic equation very easily. He said sometimes it happens.

M had no difficulty solving problem #1. M thought he needed an equation, $v^2 - v_0^2 = 2as$. He substituted the distance and acceleration (9.8) which was not derive from force and mass, into the equation and got 3.13 as "average velocity." While checking his process, M had some new thoughts:

Who is working? This force is working.
What is that working? What else is working?
What will be wrong here (2as)?
May be initial velocity is not equal to zero . .
Yes, I think that's the point.
That initial velocity shouldn't be equal to zero
because the band is exerting force.
So initially set to be zero, but
for \( t \) is very small, it has some initial velocity.

He understood the time taken for accelerating as time
between releasing and leaving. M considered the first as
the initial velocity and the second as the change increment
during that time. The addition of the two velocities yield
his answer. He got all the necessary equations, but there
was one more obstacle, it was the redundant information.
He tried to use all the information then was puzzled and
wondered. He finally substituted the wrong value \( a = 9.8 \).

M solved problem #7 correctly, but at the final stage,
he did not check the question one more time. The problem
asked the height above point B, but M answered the height
above point A. When asked the reason for this mistake, M
said:

I know they ask for the height, maximum height.
I didn't read twice.
Sometimes, I have trouble in English.
I don't (read) careful (on) every words.

When reading the first time, M did not understand the mean-
ing of the sentence.

Also in problem #6, he thought the block just went down
to the bottom.

(I) didn't check sentence. We have velocity and
distance, (Problem is asking) how fast it will going at here (bottom). (That's the) easiest way for block to go from here to there.

He used the frictional force as \(-mgsin\theta\). By doing that he did not need to use the frictional coefficient because he believed \(\tan \theta = \mu\) (see misconception section). Later he denied \(\tan \theta = \mu\), but he used it. During calculating the potential energy of the block at the starting point, he calculated it as \(mgd\tan \theta\), instead of \(mgdsin\theta\). At the follow-up interview, he realized his misunderstanding of the problem when clarified by the interviewer. M changed the sign of the frictional force from - to +, then got a velocity using the same equation..

I: This velocity (8.52 m/s) is at where?
M: .. yes, it is ... you're right.
   .. uhm ... strange, very strange.
I have distance and velocity.
This distance doesn't mean anything.
You need velocity when it's going up ...
Aha, this sounds right, this answer is right (laugh),
because I made the same mistake twice it catches my mistake. When it comes back, it has the same velocity (as original). That's right.

Again M returned to the first answer because he believed the upward speed was the same as the downward speed at the same point. On the reason of this belief:

I: You assumed the upward velocity is the same as the downward velocity at this point, right?
M: Yes, because energy is conserved.
They're the same.
It's going like \(v^2/d = \text{const}\), like parabola at this distance.
When it's here, it has the same velocity at both side because of parabola effect.
He remembered the equation studied during the prestudy session in problem #2. M could set up the equation based on EC principle during and after the collision. During the numerical solution, he substituted in the mass of the block for that of the bullet. He got 503.1 J as the heat energy by subtracting the energy during the collision from the final energy. He considered the energy during the collision as the initial energy. When his inconsistency in the solving process was pointed out, M started to consider three stages: bullet comes to the block before collision, bullet goes through the block, and the two travel separately after the collision. These three stages seemed to be cued by the last sentence of the problem. M attempted to calculate the initial velocity of the bullet by considering the before collision and during collision stages using the elastic collision equation. By substituting the initial velocity into the energy conservation equation, he could get the heat energy generated. But the value was too large, 9521.6 J. At that time, he substituted 1 kg for the value of all masses. At the follow-up interview, the interviewer asked him about the relatively small change of velocity of the bullet compared with the mass ratio of the bullet and the block. M agreed that it was not reasonable and checked his process again. He found the mistake concerning the mass and got a reasonable number, 45 J this
time. He gathered as much information as possible using his previous knowledge of physical nature or principles and then tried to relate them to get the required answer.

There was no problem with #3. In problem #8, M measured distances from top of bridge to (1) water surface (7.9 m), (2) feet of Clara (5.9 m), and (3) feet of Jim (3.1 m). He set up an equation, \( x = -\frac{1}{2}gt^2 - 7.9 \), and then substituted the two remaining distances into the equation. He got time traveled of Clara (.63 second) and of Jim (.98 second) then subtracted them. At additional interview session, the interviewer pointed out that the time he calculated for Clara's traveling was less than the time for Jim.

(after seeing -7.9) That's why (there) may be a mistake. Origin is water surface. When time is going, \( x \) is decreasing. That's why maybe I got this answer. Now I'll get the correct answer.

M changed the negative sign to positive sign of 7.9 in the equation. He did not notice that the \( t^2 \) value is negative following his change.

L.7 CONFIDENCE

The mistake M made in solving the quadratic equation did not hurt his confidence rating for problem #4, even though M doubted the person's speed:

8 m/s is quite high for noble person, it is strange for me. He can do it, but physically it's problem unless he has good motivation.
It might have built up his confidence on his answer, the person could not catch the train. M liked this problem because it was fun and not too difficult.

M was very confident about his answer in problem #1. He liked this problem because he knew everyone else would do it wrong. For him this problem was easy, but it could be hard for average students because:

Half of students are gone at using the formula and the other half are gone at finding time travelled. They will just divide by 2.

He was puzzled by the time variable given in problem #5 and did not have a high confidence in his approaches using work done by the force.

Maybe the work is not that, may be a mistake, maybe this is not the work to pull back the band. So acceleration, if this is not the work done to pull back then this acceleration is used to find down the velocity in terms of acceleration.

He was not very confident of his solution because everything was not clear such as the work and energy conservation.

I use the number but I'm not sure.
I don't see any way to do it.
If I have two or three ways to do it, then my confidence will be lower, say 2 or 3.

Because he learned something, he liked this problem. This was a hard problem for him.
He was pretty sure about his solution to problem #7, even though he did not understand the question exactly. He liked this problem because all different kinds of things worked for him. When he first looked in problem #6, M said:

This is a typical exercise when I see figure like this. There's no doubt about it, don't have to think about it (because) they have everything.

He expected to be asked the distance to the highest point, not the final velocity at bottom. He indicated a confidence rating of 8 concerning his solution, because he could make mistakes in problems like this. M was confident about not using the frictional coefficient.

I don't see friction.
I didn't use it because (I) didn't need it.
It expresses everything without using it.
I think it is put to confuse people because we don't need kinetic friction.

M liked this problem because it was nice and nothing really difficult, but he rated this problem as medium in difficulty.

M was confused by problem #2 because the initial velocity of the bullet was not given. He indicated a rating of 7 for his confidence in the first solution because there were many concepts he did not use. For the second attempt to solve the problem, he was not sure about the collision among the three stages. He could not figure out the phys-
ics principles during the collision and was not sure about the equations on elastic collision. During a long process of computation, M sometimes lost subscripts of variables. It also hurt his confidence. As he saw the three velocities of the bullet at the different stages, he calculated the heat energy. His confidence on the answer was unchanged because the answer was too big. But he understood some numbers were not always so simple in physics problems. After correcting his substitution error, his confidence rating increased to 8. He loved this problem; although it was very hard, it was very interesting.

Although M initially failed to correct the units in problem #3, he did see it later, corrected it, and got very high confidence on his solution. He liked this problem because of the interest in knowing how much time would be required. This problem could be rated as:

medium in reasoning.
(It's) hard to know what you have to do. Once you have equations and you know it goes to (same) time, (it's) not so hard, it's tricky.

Although it was an easy problem, M was not happy about problem #8, because "it was not a physics problem" and it was too easy for him. Even though he made a mistake in the frame of reference, his confidence rating was 9. He remembered problems similar to this one and was relatively confident in solving this kind of problem. M did not like this one:
M: Because (it's) stupid, there's nothing in it. Just writing down equation and make some measurements. Spend your whole life making these measurements (laugh). This is the kind of form I don't like. This is not physics, that's nothing. For C (grade) students, yes (it is physics), they understood something and very happy, but that's all.

I: You look angry.
M: Because I expected the last problem to be something hard to solve.

L.8 CHARACTERISTICS

In problem #7 after having just looked at the problem sentence and the diagram, M said:

Aha, this is nice.

Later M explained his thoughts at that time.

Because I knew that I will have to solve first for a in case what's happening in A and B, then plug in. It's not straight forward application of the formula. What we'll have to do is basically work-energy theorem and we'll have to apply it twice solving it for v and I think we'll get right answer. So let's say that the stone is shot pt A to pt B, height h, basically the work-kinetic energy theorem.

In problem #4, M checked to see if his answer worked or not. He also tried to make sense of the problem; for example he thought it was physically hard for a person to run at 8 m/s. However in problem #7, he did not check his answer because the solving process was too simple, so he did not doubt his solution. From the start until the end of his solving problem #5, M was suspicious of the time
variable. After thinking about the two velocities between the time difference, M was fairly confident about his solution. M also considered getting half credit in problem #2.

If this is test, I put this equals to that. (By doing that) at least I'll get half credit. That's (a) big number, that's really (a) big number, I guess. velocity .. that's physics I don't discuss (laugh).

M felt that it was hard to figure out what was going on in problem #3. That might be because of his language problem.

Diagram may help, picture doesn't help. Picture is the same as word problem.
Part I

I am interested in your ideas about science and physics. Please tell me what you really think. Write your answer in the space below each question.

1. What is science?
A science is a game. We look at a group of objects (or elements...), we study their behavior, we try to determine rules that determine these behavior to be able to predict further behaviors.

2. What is physics?
It is a science. Its objects are the physical particles (electrons, particles, objects).

3. Is science created or discovered?
I have been created and discovered.
Science is created by men.

4. How much of your ability to do physics shows up when you take physics tests?
I go.

5. What can you do if you get stuck while doing a physics problem?
I start all over again.

6. How important is memorizing in learning physics? If anything else is important, please explain how.
Memorizing (formulas and experience only - not routines) is very important. It helps learn what they'll ask you to do what is more important is to relate formulas together and for this we must learn them all.
Part II

Please state whether you agree or disagree with the following statement. Then briefly explain your reasons for agreeing or for disagreeing. Two to four sentences should be enough to make your reasons clear. If you cannot agree or disagree, then explain why a choice is not possible for you.

1. Scientists should be concerned with the potential effects (both helpful and harmful) that might result from their discoveries.

   __ agree _____ disagree _____ can't tell

   Reasons: Because it's by the effects that scientists make their final judgment.

2. Although advances in science and technology may improve living conditions around the world, science and technology offer little help in resolving such social problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war.

   __ agree _____ disagree _____ can't tell

   Reasons: What about modern technologies? Powder mills, digital empires, finger print. To name a few. Plus, economics is also a science, not rocket science, but a science.
3. When scientific investigations are done correctly, scientists discover knowledge that will not change in future years.

agree □ disagree □ can't tell
Reasons: Scientific knowledge always change, because experiments are done.

4. Many scientific models (such as a model of the atom or of DNA) are metaphors or useful stories; We should not believe that these models are duplicates of reality.

agree □ disagree □ can't tell
Reasons: Because it's the
Physical models are a simplification of reality.

5. The best scientists are those who do not lock themselves into following the steps of the scientific method, but instead use any approach that might help them.

agree □ disagree □ can't tell
Reasons: Sometimes scientific method help you avoid many errors.
6. Communities or government agencies should tell scientists what problems to investigate; otherwise scientists will investigate only what is of interest to them and not necessarily investigate the problems of interest to the country.

____ agree  ______ disagree  ______ can't tell

Reasons: Scientists should investigate what
ey like to, if we want them giving good results
there will always be scientists in each field.

7. A scientist may play tennis, go to parties, or attend conferences with other scientists or with non-scientists. Because these social contacts can influence the scientist's work, these social contacts can influence the content of the scientific knowledge he or she discovers.

 ______ agree  ______ disagree  ______ can't tell

Reasons: Scientists make experiments according
to their own ideas. No one can really imagine
something that has no link with real life.
Part III

Please select the best response in your opinion for each item and mark your choice. You may mark two or more responses if they seem equally good. If you do not like any of the responses, then please add your own response.

1. The main motivation of most scientists is

- (1) earning a decent salary.
- (2) earning recognition from other scientists.
- (3) satisfying their curiosity about natural phenomena.
- (4)

2. In my mind, the primary purpose of science is

- (1) the furtherance of the well-being of humanity.
- (2) the compilation and categorization of all laws and facts about natural phenomena.
- (3) the mastery and control of nature through a set of relations that successfully predict events.
- (4) the establishment of theoretical structures which integrate and explain.
- (5)
3. Which of the following is the best description in your judgement of a scientific law?

(1) It is an exact report of a set of observations.
(2) It is a generalized statement of relationships among natural phenomena.
(3) It is a theoretical explanation of a natural phenomenon.
(4) It is dictated by nature and cannot be violated.
(5) ____________________________________________________________________

4. Of the following, which is the best statement about the objectivity of the scientist in your judgement?

(1) The scientist is basically objective because he is indifferent about the conclusions and outcome of his work.
(2) The scientist is objective because making progress and achieving answers is a matter of grinding things out via the scientific method.
(3) The scientist's objectivity consists of intersubjective testability, i.e. agreement between members of the scientific community on matters of observation and verification.
(4) The scientist's objectivity is the result of the fact that science is impersonal throughout.
(5) ____________________________________________________________________
5. When a new theory replaces an older theory, it is frequently incompatible with its predecessor in the sense that

(1) successive theories often change the meaning of familiar terms and/or add new postulates.

(2) the old theory is erroneous and the new theory is a correction of former mistakes.

(3) a new battery of experimental apparatus must be designed.

(4) The premise is false; new theories are not usually incompatible with their predecessors.

(5) ____________________________________________________________

6. Concerning the verification of a scientific theory, I think that

(1) experimentation and observation proves the correctness of a theory.

(2) a theory can be enforced or weakened by new data, but not proven or falsified.

(3) theories are sometimes conclusively verified without recourse to experimentation or observation.

(4) a theory is usually discarded as soon as a piece of experimental evidence is found which falsifies it.

(5) ________________________________
7. The concept 'demons' is not part of the repertoire of science because it
   ____ (1) lacks explanatory power.
   ____ (2) involves appeal to unfamiliar qualities.
   ____ (3) is non-observable.
   ____ (4) fails to be testable.
   ____ (5) _________________________________________________________

8. The fields of natural science and social science in my view
   ____ (1) are similar in that the chief goal of both is the discovery of universal laws.
   ____ (2) are different in that the judgements of natural science are objective because the investigator does not interfere with the object, but observation and interpretation in social science are influenced by the values and actions of the investigator.
   ____ (3) are similar in that both seek to establish connections between particular events and make use of generalizations in understanding events.
   ____ (4) are different in that the phenomena of natural science are recurrent, reproducible, and regular, but the phenomena of social science are nonrecurrent, unique, and erratic.
   ____ (5) _________________________________________________________
9. Getting a good or bad grade in physics depends upon

   (1) my effort
   (2) the teacher
   (3) luck
   (4) the test
   (5) _____________________________________________________

10. The physics that I learn in school is

    (1) mostly facts and procedures that have to be memorized.
    (2) thought provoking.
    (3) just a way of thinking about mechanics, thermodynamics, and electricity.
    (4) _____________________________________________________

11. The reason I try to learn physics is

    (1) to help me think more clearly.
    (2) it is required for my program.
    (3) it is interesting.
    (4) _____________________________________________________
1. Write an equation to represent the following statements.

   a) "In a classroom there are five times as many boys as girls."
   Use B for the number of boys and G for the number of girls.
   \[ B = 5G \]

   b) "A country sells four times as much wheat as corn."
   Let W represent the amount of wheat and C represent the amount of corn.
   \[ W = 4C \]

   c) "There are six times as many students as professors at this university."
   Use S for the number of students and P for the number of professors.
   \[ 6S = P \]
   \[ S = \frac{P}{6} \]

   d) "At Mindy's restaurant, for every four people who ordered cheesecake, there are five people who ordered strudel."
   Let C represent the number of cheesecakes and S represent the number of strudels ordered.
   \[ \frac{C}{4} = \frac{S}{5} \]
   \[ 5C = 4S \]
2. There are two plastic cylinder containers of equal height but with different diameters. A given quantity of water rises 4 units in the wide container and rises a corresponding 6 units when poured into the narrow container. Using the same plastic containers, if 11 units of water are poured from the narrow cylinder to the wide cylinder, the level in the wide cylinder will be \( \frac{11}{2} \) units. Why?

3. If the 100 gram weight is hung at 4 cm on the left side of the balance at which position will the 50 gram weight have to be placed on the right to balance the arm? Why?

\[ 8 \text{ cm} \]
4. A biologist did an experiment to find out how many frogs lived in a pond. He did not have enough time to catch and count all the frogs. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to spread themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg. Using all of this information, how could the biologist figure out about how many frogs are in the pond?

\[ \frac{12}{55} \rightarrow \frac{55 \times 72}{12} = \frac{52}{1} \times 6 \]

5. Walking back to my room after class yesterday afternoon, I noticed my six-foot frame cast a shadow eight feet long. A rather small tree next to the sidewalk cast a shadow eighteen feet long. My best guess of the height of the tree would be \( \frac{27\frac{1}{4}}{8} \).

\[ \frac{6\text{ft}}{8} \rightarrow \frac{8\text{ft}}{18} \times \frac{18 \times \frac{1}{8}}{\frac{1}{8}} = \frac{27}{2\frac{1}{4}} \]
Computational Skill Test

1. Fill in the blank.
   a) 106 Cm - (   ) m   b) 4 g - (   ) Kg

2. Calculate the following expressions.
   a) \( \frac{1}{3x23} ((16 \times 10^2)^2 - (7 \times 10^2)^2) \)
   b) \( \frac{\sqrt{2x7x10^2}}{\sqrt{5x10}} \)
   c) \( \frac{\sqrt{4x0.57}-\sqrt{3x0.29}}{\sqrt{4x3}} = \frac{\\sqrt{2.36} - 0.57}{\\sqrt{27.2}} = 0.23 \)
   d) Sin 37°
   e) Cos 37°

3. Solve the following equations.
   a) Solve for \( x \).
\[ 2x^2 - x - 6 = 0 \]
\[ 2(x^2 - \frac{1}{2}x - 3) \]
\[ \Delta = 1 + 4(-2) = 7 \]
\[ \frac{1 \pm \sqrt{7}}{2} = 2; -\frac{3}{2} \]
\[ x = 2 \text{ or } x = -\frac{3}{2} \]
b) Solve for $x$ and $y$.

$2x + 5y = 2$

$3 + 30x = -20y$

\[ b) \quad 2 \cdot ab = c^2 - d^2 + 100, \quad \text{where } a = -200, \quad c = 5 \times 10^2, \quad d = 30. \quad \text{What is the value of the b?} \]

\[ b = \frac{c^2 - d^2 + 100}{2} = \frac{2 \times 100 - 9 \times 10^2 + 100}{-4 	imes 10^2} = -\frac{620 - 700}{-400} = -\frac{620}{-400} = \frac{620}{400} = \frac{31}{20} \]

\[ d) \quad \frac{x^2}{3} - 2.7x - \frac{5}{2}x^2 \]

\[ e) \quad \frac{at^2}{2} + ab = \frac{1}{3} (\cdot \cdot \cdot )^2 \quad a + ab(t + 2), \quad \text{where } b = 4. \]

What is the value of the $t$?

\[ t \geq 0 \quad \frac{t^2}{2} - t - \frac{5}{3} \cdot 10^{-2} + a(t + 2) \]

\[ t^2 - 2t - \frac{5}{3} - 16 = 0 \]

\[ t^2 - 8t + \frac{265}{3} = 0 \implies t = \frac{8 \pm \sqrt{8^2 - 4 \cdot \frac{265}{3}}}{2} \]

\[ t = \frac{8 \pm \sqrt{64 - 4 \cdot 265}}{2} = \frac{8 \pm \sqrt{-1056}}{2} = \frac{8 \pm 32.5}{2} \]

\[ t = -16.04, \quad t = -6.04 \]

4. What are the values of $y$ and $z$ in terms of the $x$ and $\theta$?

\[ \theta = \frac{2}{3} \quad \text{and} \quad \theta = \frac{2}{3} \times \theta \]

\[ y = x \cdot \theta \]

\[ \theta = \frac{2}{3} \quad \text{and} \quad \theta = \frac{2}{3} \times \theta \]

\[ \theta = \frac{2}{3} \times \theta \]
1. A juggler plays with seven identical balls. At time $t$, the seven balls are in the air at the same height, on trajectories shown in dashed line in the figure. Also shown are the velocity vectors of the balls at this instant. Are the forces acting on the balls at this instant the same or different? Are some the same and others different? Justify your answer. (Neglect air resistance.) Are the potential energies of the seven balls the same or different?
2. A bowling ball weighing 16 lbs. hits a bowling pin weighing 4 lbs. Compare the force the ball exerts on the pin with the force the pin exerts on the ball.

\[ \bar{F}_1 = -\bar{F}_2 \]

3. Three boxes are stacked on top of each other with the lightest on the bottom and the heaviest on the top. Think about whether the top and bottom blocks A and C exert a force on the middle block B.

\[ A \rightarrow B, \quad \overrightarrow{W_A} \quad \downarrow \quad b-u = -\overrightarrow{W_A} \quad \uparrow \]

\[ C \rightarrow B, \quad -\overrightarrow{W_C} \quad \uparrow \quad b-u = +\overrightarrow{W_C} \quad \downarrow \]
4. A suitcase slides from a ramp onto the steel floor of the baggage area at an airport. Explains why the suitcase will stop?

Lost of energy in the work done by friction only.

5. Twenty large books are stacked in a pile in Roger's garage, and Roger wants to read the black one in the middle. He tries to pull it horizontally out of the pile without taking the books above it off, but can't move it. Explains the primary reason why this is happen?

As the coefficient of static friction is high enough to make the friction force greater in magnitude than the force he's applying.
6. A coin is tossed from point A straight up into the air and caught at point B. On the dot to the left of the drawing, draw one or more arrows showing the direction of each individual force acting on the coin when it is at point B. (Draw longer arrows for larger forces.) Explain your drawing.

7. A body is dropped freely from position A to reach the position 1 on level XY. The body is projected from A with different horizontal velocities such that it successively reaches the position 2, 3, 4 as the projecting velocities increase. What is the change in total energy for each body as it reaches each position?

\[
\begin{align*}
\Delta E &= 0 \\
F &= ma \\
g &= a \\
v_x &= v_0 \\
v_y &= -gt + v_{0y} \\
z &= x + vt \\
z &= -\frac{1}{2}gt^2 + v_{0y}t + \frac{1}{2}at^2 \\
E &= K + U \\
\Delta E &= \Delta K + \Delta U \\
1, 4 &\rightarrow 2
\end{align*}
\]
Ball A travels with uniform motion from left to right while ball B travels in the same direction, starting with an initial velocity greater than that of ball A. As ball B travels up a gentle incline, it slows down and eventually comes to rest. Ball B first passes ball A, but later ball A passes ball B. Do these two balls ever have the same speed? Explain your choice.

\[ \frac{dv}{dt} = \frac{\Delta v}{\Delta t} \]

\[ v_B = C_0 \]

\[ -C_1 < v_B < +C_1 \]

\[ C_1 > C_0 \Rightarrow \text{ball B had twice the same velocity (in magnitude only)} \]
9. Ball A starts with some high initial velocity, slows down, and comes to rest. Another ball, ball B, starts from rest at a point ahead of ball A. It accelerates uniformly down a gentle incline. Ball A never overtakes ball B as is shown. Do these two balls ever have the same speed? Explain your choice.

Yes. $v_A$ is decreasing from $v_A$ to 0
$v_B$ is increasing from 0 to $v_B$
They had the same velocity once.
10. Both balls start from rest and reach the same final velocity at the end of the incline just as they simultaneously enter a tunnel at the bottom. They are not released at the same point or the same time and do not travel equal distances. Ball A is released first from a point several centimeters behind ball B. After rolling a few centimeters, ball A strikes the lever and ball B is released. Do these two balls have the same or different accelerations? Explain your choice.
11. The initial velocity of both balls is zero. The two balls are rolling down inclined tracks and level tracks. Given numbers on following diagram are the length of each track and the time which the ball travels the track. Calculate the accelerations of two balls.

\[ a = \frac{\Delta d}{(\Delta t)^2} \]

**A:**

<table>
<thead>
<tr>
<th>Ball</th>
<th>Length</th>
<th>Time</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40.5 cm</td>
<td>3.0 sec</td>
<td>13.5 cm/s²</td>
</tr>
</tbody>
</table>

\[ \bar{v} = \frac{\Delta d}{\Delta t} \]

\[ \bar{a} = \frac{\Delta v}{\Delta t} \]

**B:**

<table>
<thead>
<tr>
<th>Ball</th>
<th>Length</th>
<th>Time</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>60.0 cm</td>
<td>4.0 sec</td>
<td>15 cm/s²</td>
</tr>
</tbody>
</table>

\[ a_A = \frac{27}{3} = 9 \]

\[ a_B = \frac{15}{3} + 2.7 = 7.9 \]
12. What are the dimensions of the following expressed in fundamental units?

a) \( N \) (Newton): \( [M][L][T^{-2}] \)

b) \( J \) (Joule):
\[
\begin{align*}
\text{[M]}[\text{L}][\text{T}^{-2}]
\end{align*}
\]

c) Do the "force," "work," and "energy" have the same dimension? \( N [/][L][T^{-2}] \)

\[
F \cdot t = W \quad W = E
\]

: \( F \cdot x = E \)

13. Fill in the blanks and define symbols.

a) \( v = v_0 + (\text{at}) \)  
\( \text{a}: \text{acceleration} \)  \( t: \text{time} \)

b) \( 2gs = v^2 + (-v_0^2) \)  
\( s = \Delta x = \text{distance travelled} v_0: \text{initial vel.} \)

c) \( s = v_0 t + \left(\frac{1}{2}at^2\right) \)  
\( s: \text{initial position} \)

d) \( F = \text{m} \times (\text{a}) \)

e) Kinetic Energy - \( \left(\frac{1}{2}mv^2\right) \)

f) Potential Energy - \( \left(\text{mgh}\right) \)  
\( h: \text{height} \)

g) Work - \( \left(\int P \, dx\right) \)  
\( P: \text{force} \)  \( x: \text{distance} \)

h) Frictional force on plane with \( \mu \) and \( m = \left(\frac{F}{\text{N}} - \text{mg}\right) \)  
\( \text{N: normal force} \)  \( \mu: \text{friction coeff.} \)

i) Energy loss by frictional force (\( Pf \)) - \( Pf \times \left(\frac{F}{\text{N}}\right) \)  
\( \text{a: normal force} \)  \( \text{v: velocity} \)

j) Stored energy in spring = \( \frac{1}{2} (\text{ka}^2) \times d. \)
14. How are the following quantities related?

speed, velocity, and acceleration

\[ \text{Speed} = \text{Velocity}, \quad \text{Accel} = \frac{d\text{Velocity}}{dt} \]

15. Explain the energy conservation principle and show the mathematical expression using Kinetic Energy (KE), Potential Energy (PE), and Work by friction (Wf).

The total energy of a system is always in came.

\[ \Delta E = \Delta KE + \Delta PE = Wf \]

16. Explain the momentum conservation principle and show the mathematical expression using mass (m) and velocity (v).

For an isolated system, the momentum is constant.

\[ \sum m \frac{dv}{dt} = \text{Constant} \]

17. A block is sliding down an inclined plane with \( \mu \) as the coefficient of friction. At the position shown in the figure write an expressions for each of the following.

\[ \text{a) kinetic energy} = \frac{1}{2} m v^2 \]

\[ \text{b) potential energy} = mgh \]

\[ \text{c) frictional force} = \text{mg}\sin(\theta) (\mu = \text{constant}) \]

\[ F = \mu N = \mu mg\cos(\theta) \]

\[ N = m g \sin(\theta) \]

\[ \theta = \text{angle of incline} \]
A late passenger, sprinting at $8 \text{ m/s}$, is 30 m away from the rear end of a train when it starts out of the station from rest with an acceleration of $1 \text{ m/s}^2$. Can the passenger catch the train if the platform is long enough?

\[ v_p = 8 \text{ m/s} \]
\[ a = 1 \text{ m/s}^2 \]
\[ x = \frac{1}{2} t^2 + 30 \]
\[ \frac{1}{2} t^2 - 8t + 30 = 0 \]
\[ t^2 - 16t + 60 = 0 \]
\[ a' = 16 - 60 = -44 \]
\[ t = \frac{4 \pm \sqrt{164}}{2} \]
\[ t = 4 + \sqrt{41} \]

No
A rock is dropped from a 100-m high cliff. How long does it take to fall from the mid-point (50-m high point) to the bottom?

\[ y = \frac{1}{2} a t^2 + y_0 \]
\[ x = -4.9 t^2 + 100 \]
\[ b = 50 \]
\[ -4.9 t^2 = 40 \]
\[ t^2 = \frac{50}{4.9} \]
\[ t = \frac{100}{4.9} \]

\[ 4.9 - 2.2 = 1.3 \]
Problem E

A 100-g projectile is placed in a slingshot, and a band is pulled back 0.5 m and held with a force of 60 N before being released. The slingshot takes 0.05 sec to accelerate the projectile to its final speed. What is the final speed of the projectile?

\[ W = F \cdot x = 25 \, \text{J} \]

\[ K = \frac{1}{2} m v^2 \]

\[ v_f^2 = v_i^2 + 2 \cdot a \cdot x \]

\[ v_i = 9.3 \, \text{m/s} \]

\[ \Delta v = 3.13 \, \text{m/s} \]

\[ v_f = 25.43 \, \text{m/s} \]

\[ 22.3 \, \text{m/s} \]
problem G

A stone is thrown vertically upward. On its way up it passes point A with speed \( v \), and point B, 3.0 m higher than A, with speed \( \frac{1}{2} v \). Calculate the maximum height reached by the stone above point B.

\[
\begin{align*}
\frac{1}{2}mv^2 &= mgh \\
v^2 &= 2gh \\
v^2 - \frac{1}{2}v^2 &= 2g^2 \\
v^2 - \frac{1}{4}v^2 &= 2g^2 \\
v^2 &= \frac{4}{3}v^2 \\
v &= \frac{2}{\sqrt{3}}v \\
v &= \sqrt{\frac{2}{3}}v \\
\Rightarrow \quad \text{max height} &= \frac{5}{3} \text{m}
\end{align*}
\]
problem F

A block is moving up a 40° incline. At a point 1.8 m from the bottom of the incline (measured along the incline), it has a speed of 4.5 m/s. The coefficient of kinetic friction between block and incline is 0.15. How fast will it be going after it slides back to the bottom of the incline?

\[
\frac{1}{2}m (v^2 - v_0^2) = mg \Delta x \sin \theta - f \Delta x
\]

\[
v^2 = v_0^2 + 2gd (\tan \theta - \sin \theta)
\]

\[
v^2 = 2gd (\tan \theta - \sin \theta) + v_0^2
\]

\[
v = 5.21 \text{ m/s}
\]
$v^2 = 2gd \left( \tan \theta + \omega \sin \theta \right) - v_0^2$

$v = 8.52 \text{ m/s}$
problem B

A 5-g bullet horizontally penetrates a 1 kg block suspended at rest from a 1 m long thread of negligible mass. The bullet leaves the block from its far side with velocity 200 m/s. How much energy was transformed into heat if the block rose through a height of 0.3 m? (You may assume that the block did not rise while the bullet was inside it.)

\[ E_i = \frac{1}{2} m v_i^2 + mgh = 2.94 \text{ J} \]

\[ E_f = \frac{1}{2} (m_1 + m_2) v_f^2 \]

\[ E_i - E_f = 503.1 \text{ J} \]
\[ E_3 = \left( \frac{1}{2} M v_{1,3}^2 + mgh \right) \]
\[ \Delta E = E_3 - E_1 \]
\[ E_f = E_1 \]
\[ v_{1,2} = \sqrt{2gh} = 2.42 \]
\[ v_{2,2} = 2.43 \]
\[ h_{1,2} = \frac{1}{2} m_1 v_{1,2}^2 \]
\[ v_{1,2} = \frac{m_2 - m_1}{m_1 + m_2} v_{2,2} \]
\[ V_{1,2} = \frac{m_2 - m_1}{m_1 + m_2} V_{2,2} \]
\[ B = \left( \frac{1}{2} m_2 v_{1,3}^2 + mgh \right) = \frac{1}{2} m_2 v_{1,3}^2 \]
\[ = \frac{1}{2} \left( \frac{100}{100} \right)^2 + 2.94 - \frac{1}{2} \left( 2.43 \right)^2 = -9521.6 \text{ J} \]
\[ \frac{100}{100} + 2 \cos \theta = 1.87 = 45 \text{ J} \]
problem C

A basketball player, standing near the basket to grab a rebound, jumps 76 cm vertically. During falling from top, 0.175 second is measured in the top 15 cm of this jump. How much time does the player spend in the bottom 15 cm during the falling? Does this help explain why such players seem to hang in the air at the tops of their jumps?

\[ x = \frac{1}{2} g t^2 + 76 \]

\[ 76 - 115 = 60 \]

\[ -175 \times 2 = 2550 \]

\[ t_1 = 3.52 \]

\[ t_0 = 2.93 \]

\[ t_0 - t_1 = 0.59 s \]
As the figure shows, Clara jumps from a bridge, followed closely by Jim. How long did Jim wait after Clara jumped? Assume that Jim is 170 cm tall and that the jumping-off level is at the top of the figure. Make scale measurements directly on the figure.

\[ h_c = 170 \text{ cm} \]
\[ L = \frac{5 \times 1.7}{2} = 5.9 \]
\[ h = \frac{1}{2} gt^2 + 2.30 \]
\[ h_c - h_f = \frac{1}{2} g (t_c - t)^2 \]
\[ 28 \rightarrow 1.70 \]
\[ 120 \frac{170}{28} \]
\[ h = -\frac{1}{2} gt^2 - 7.9 \]
\[ t_c = 0.63 \]
\[ t_f = 0.98 \]
\[ J = 0.35 \]