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Problem Solving Characteristics of Relative  
Novices and Experts within an Intermediate  
Range of Expertise in Linear Kinematics

Christine Lorraine Blais

Thesis submitted to the School of Graduate Studies  
of the University of Ottawa  
in partial fulfillment of the requirements  
for the Degree of Doctor of Philosophy in Education.



Christine Blais-Kerr, Ottawa, Canada, 1990



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ISBN 0-315-60597-9



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YOU SEE THINGS; AND YOU SAY, "WHY?"  
BUT I DREAM THINGS THAT NEVER  
WERE; AND I SAY, "WHY NOT?"

George Bernard Shaw

### Acknowledgement

Having worked with continuous pandanorium, I would like to acknowledge the ongoing support of my husband, Robert, for the thousands of diapers he has changed and the babies he has rocked. I would also like to thank my advisor, Jean-Paul Dionne, who through these many years has provided guidance and direction.

### Abstract

Within the context of this study, expertise is used to describe the range of skills (a continuum) which lies between those of novice and expert. Although some of these expert-novice differences have been identified, what is less understood is how an individual becomes an expert: the transition from novice to expert. As the study tests a specific hypothesis and seeks information related to a specific objective, it has both confirmatory and exploratory components. The independent variables were context, level of expertise and Problem Type and the dependent variables were solution time and solution patterns. There were two categories of context (familiar and unfamiliar), two levels of expertise (novice and expert) and two Problem Types (simultaneous and successive movement). Solution time was analyzed within a confirmatory framework and solution patterns within an exploratory framework.

An information-processing approach to problem-solving was used. From 108 university students an inventory of contexts was compiled to produce familiar and unfamiliar isomorphic problems. The level of expertise of a second group of 57 subjects was based on educational background and produced Concept Map. From this process, two intermediate groups of subjects were identified as relative experts or novices. Each

subject was presented with eight isomorphic problems, four in familiar and four in unfamiliar contexts, were presented to each subject. The subjects were presented with one of two Problem Types reflecting Simultaneous or Successive movements as defined by Piaget. The problem solutions were recorded using the technique developed by Ericsson and Simon (1984), were divided into 5-second intervals, and then evaluated using a Coding Grid developed for this study. Thus, the data submitted for analysis was based on a total of 224 problems.

While the subjects in this study did represent two distinct levels of expertise, they did not evidence those characteristics associated with the extremes of the expert-novice continuum. There were no significant differences between experts and novices in their problem solution times, but the relative expert subjects did demonstrate some of the 'traditional' expert traits. In particular, experts evidenced an improved ability to recognize key information and, thereby, improve the accuracy of their performance. The more expert problem solver also used more conceptual, as distinct from computational, types of strategy. Overall, while there were no significant differences in solution time, many expert-novice distinctions arose when examining the processes whereby these solutions were achieved. In particular, while the experts tended to show an analytical approach, the novices were more speculative.

## Table of Contents

chapter	page
List of Tables.....	vii
List of Figures.....	ix
I. Introduction.....	1
Conceptual Framework.....	2
Objectives.....	6
Hypotheses.....	7
Educational Implications.....	8
Definition of Terms.....	8
II. Review of Literature.....	11
The Role of Knowledge and Expertise.....	12
Problem Categorization.....	28
Context.....	35
Articulation of the Problem.....	49
III. Methodology.....	55
Assessment Techniques.....	55
Inventory of Contexts.....	55
Concept Mapping.....	59
Problem Solving Tasks.....	63
Preparation of the Data.....	69
Coding Grid.....	76
Design.....	82
IV. Presentation of Results.....	83
Research Hypothesis .....	83
Exploratory Objective.....	103
V. Discussion.....	125

VI. Summary, Conclusions and Recommendations.....	134
References.....	140
Appendices .....	155
A Inventory of Contexts Questionnaire.....	156
B Relative frequency of transportation and sport activities for each choice.....	159
C Concept maps of Subjects 9 and 17.....	161
D Subject Instructions for Concept Mapping.....	172
E Cue Words for Verbal Protocols.....	174
F Instructions for Verbal Protocols.....	176
G Isomorphic Problems.....	178
H Order of Presentation of Verbal Protocols.....	187
I Simple Main Effects for Context x Episode interaction for Simultaneous and Successive movement.....	189
J Verbatim Protocols Timed and Coded.....	191
K Summary of Tukey tests for Components.....	205
L Simple Main Effects for Components.....	208

## List of Tables

	page
1. Frequency of contexts identified by subjects in questionnaire (N=108).....	57
2. Description of Simultaneous and Successive movement and their associated subtasks.....	67
3. Category rating of subjects.....	71
4. Correspondence between the categories and rankings according to the concept maps and verbal protocols of the maps.....	73
5. Comparison of categories and educational experience in physics of 57 subjects.....	74
6. Coding Grid developed for this study.....	79
7. Descriptive statistics and analysis of variance for solution time (sec) on Simultaneous movement.....	85
8. Descriptive statistics and analysis of variance for solution time (sec) on Successive movement.....	86
9. Expertise x Context x Episodes analysis of variance on solution time (sec) for Simultaneous movement with repeated measures on the last two factors.....	88
10. Means and standard deviations of time spent (sec) on Episodes with Simultaneous movement.....	89
11. Mean differences for solution time (sec) between Episodes for Simultaneous movement.....	91
12. Expertise x Context x Episodes analysis of variance on solution time (sec) for Successive movement with repeated measures on the last two factors.....	93
13. Mean differences for solution time (sec) between Episodes for Successive movement.....	94
14. Means and standard deviations of time spent (sec) on Episodes with Successive movement.....	96

15.	Expertise x Context x Components analysis of variance on solution time (sec) for Simultaneous movement with repeated measures on the last two factors.....	98
16.	Means and standard deviations for time (sec) spent on Components with Simultaneous movement.....	100
17.	Expertise x Context x Components analysis of variance on solution time (sec) for Successive movement with repeated measures on the last two factors.....	101
18.	Means and standard deviations for time (sec) spent on Components with Successive movement.....	102
19.	Frequency on Sub-components of Reading.....	104
20.	Frequency of Problem Representation component.....	106
21.	Frequency of Recognition of key information.....	108
22.	Frequency of conceptual and computational strategies used by novices and experts during problem solution.....	110
23.	Frequency of types of Response component.....	111
24.	Frequency of Evaluation of performance component...	113
25.	Frequency of use of Self-Directed Activity.....	114
26.	Correct Final Responses and errors.....	116
27.	Average frequency of forward and backward movements between Episodes.....	118
28.	Frequency of solution patterns for levels of expertise.....	120
29.	Frequency of solution patterns as affected by Context.....	122

List of Figures

page

1.	Four examples of Concept Maps for the same topic Genetic Continuity.....	60
2.	Means of time spent on Episodes for Simultaneous movement.....	90
3.	Means of time spent on Episodes for Successive movement.....	97

## Chapter 1

### Introduction

An underlying motivation for research in education is the desire to make learning more effective. From the objectives of such differing disciplines as philosophy, psychology, computer science, linguistics and neuroscience, a consensus has evolved that learning leads to a change in the meaning of experience. Learning is seen as an active process, one where individuals reflect upon their own experience and construct new and more powerful meanings. Any educational program should provide learners with the basis for understanding why and how new knowledge is related to what they already know, and give them the assurance that they have the capability to use this new knowledge in new contexts (Novak & Gowin, 1984).

There is a need to move from the expectation that it is the educator who should produce learning to a recognition that it is the learner who must initiate and maintain learning. For this change to occur the educator needs to understand both the meaning and goal of what is being taught, and also must be able to provide the learners with workable strategies to help them learn. As Novak and Gowin

(1984) note, the educator must help the students learn to take charge of their own learning. With this overriding goal in mind, an attempt is made to add one piece to a very complex human puzzle by focusing on the impact of differing levels of expertise on problem solving.

An information-processing approach to problem solving is adopted. An information processing model centers attention on a particular person at work on a particular problem or task. Mitchell and Chi (1986) have emphasized that solving an actual problem, or thinking through how it is solved is actually the preferred method for getting some indication of the dynamics of the process involved. The purpose of the present study is to analyse the cognitive processes that are involved in the performance of tasks within the context of linear kinematics. Specifically, relationships between context familiarity, level of expertise and the information processing components are examined. This is achieved by using problem solving situations based on the concepts of displacement, time and velocity.

### **Conceptual Framework**

Context and level of expertise represent two facets central to this study. Although the effects of context and level of expertise on problem solving processes has been researched, the study of their combined effect has been

neglected. This study represented an attempt to consider the effect of these two facets on problem solution processes for differing levels of expertise.

In terms of context, Anzai and Yokoyama (1984) and Hayes (1976) have shown that, both the way in which subjects name objects and the way in which they structure the internal problem representation are determined in part by the language in which the instructions are written. Subjects initially adopt the naming conventions and representations that follow most directly from a parsing of the instructions. Hayes and Simon (1977) have also noted that for any particular problem, it is usually easy to construct isomorphs - that is, problems whose solutions and moves can be placed in a one-to-one relationship with the solutions and moves of a given problem. However, the fact that two problems are isomorphs does not guarantee that they are of equal difficulty for the subjects (Hayes & Simon, 1977). Kotovsky, Hayes and Simon (1985) and Hayes and Simon (1977) have shown that changing the written problem instructions, without disturbing the isomorphism between problem forms, can affect the difficulty of the problem (e.g., the time required by the subjects to solve it). As well, Smith and Goodman (1984), when examining how people understand and use written instruction, found that the subjects' performance was better when the same instructions were written in an explanatory schema (instructions that

describe the structure of the task) rather than a linear one (instructions that describe a linear sequence of steps to be executed). This effect is explained by the hypothesis that different problem instructions may influence subjects to adopt different problem representations, even when the problems are formally isomorphic.

Within the framework of problem representation a cognitive component is an elementary information process that operates on internal representations of objects or symbols. A problem representation is defined as a cognitive structure associated with a problem, constructed by a solver on the basis of domain-related knowledge and organization (Chi, Feltovich & Glaser, 1981). To date, it is known that the quality of a problem representation influences the ease with which a problem can be solved (Hayes & Simon, 1976; Newell & Simon, 1972; Larkin, 1985).

de Kleer (1977) has also shown that the expert's representation is superior because it contains a great deal of "qualitative" knowledge. Further, Chi, Feltovich and Glaser (1981) suggest that experts are able to "see" the underlying similarities in a great number of problems, whereas the novices "see" a variety of problems based on surface features.

Schoenfeld and Herrmann (1982), Chase and Simon (1973a/

1973b) and Hinsley, Hayes and Simon (1977) indicate that at one end of a spectrum the correct representation of a problem may cue access to a problem "schema" that suggests a straightforward method of solution or a more or less automatic response. At the other end of the spectrum, an incorrect problem representation may send one off on a "wild goose chase".

A related question is how solvers categorise problems. The inclusion of problem types in the categorization process was proposed by Novak and Araya (1980: cited in Chi, Feltovich & Glaser, 1981). Categorization of a problem as a particular type should cue associated information in the knowledge base. This knowledge base is arranged around "problem schemata", each of which contains information necessary to solve a specific category of problems, for example, when a given physics problem is categorised as a specific type (Reif, 1979).

The above overview of some of the work in the areas of context, problem representation and knowledge base has raised some interesting research questions. For example, how does the context in which a problem is presented influence the problem solving processes? This linkage becomes plausible if one assumes that the way in which a problem is presented (by category) may cue access to problem schemas (which suggest methods of problem solution)

and the knowledge base is organized around problem schemas as proposed by Reif (1979).

### Objectives

The first objective of the study is to investigate the effects of context (familiar and unfamiliar) and level of expertise (novice and expert) on problem solving activity (solution time) in the specific area of linear kinematics.

The second objective refers to the effect of context (familiar and unfamiliar) and level of expertise (novice and expert) on problem solving activity i.e., solution patterns. Experts tend to categorize problems into types according to their deep structures whereas novices tend to focus on the problem's surface structure. The expert's ability to solve problems is likely to be less affected by the context in which the problem is presented since the expert in a sense, can 'see through' the cover story. It seems that the novice, on the other hand, tends to use context to cue relevant information or useful strategies in semantic memory.

Repeatedly research has shown expert's performance on problem-solving tasks to be superior to that of novices. However, little is known of the transition from novice to expert. Although the terms novice and expert refer to poles of the expertise continuum, the terms are also used to

differentiate two intermediate groups in level of expertise, one being more expert than the other. The expert/novice terminology will be used in the remainder of the report.

### **Hypotheses**

While this study deals with the area of linear kinematics, the main purpose is to investigate the effect of context and level of expertise on the problem solution process. It will be argued that the hypothesis could be stated as:

For isomorphic problems, the solution time is a function of the context of the problem and the level of expertise of the subject.

For comparison with previous studies, an exploratory phase will be added focussing on processes rather than product giving rise to an exploratory objective which can be stated as follows:

For isomorphic problems, the problem solution patterns displayed by subjects are a function of the context of the problem and the level of expertise of the subject.

In order to operationalize the hypothesis and objective several techniques were used. Concept maps (Novak & Gowin, 1984) were used to determine levels of expertise. Verbal protocols (Ericsson & Simon, 1984) were used to collect information about solution patterns of two different types of problems in linear kinematics: Simultaneous and Successive movement. As well, four isomorphic versions of each problem (2 familiar and 2 unfamiliar) are presented in

order to examine the effect of context on solution patterns.

### **Educational Implications**

The aim of an educational program should be to provide learners with the tools by which they can learn and an understanding of how these tools can be used to solve alternative problems. In particular, the question remains as to what extent, if at all, context and level of expertise are influential variables in the problem solving and/or can shed some light on the process.

### **Definition of Terms**

Within the context of this study -

category - the combination of attributes most characteristic of a class (Johnson, 1972).

chunk - any stimulus or group of stimuli that has become familiar from previous exposure and hence is recognizable as a single unit (Simon, 1981).

cognition - a generic term referring to such higher mental processes as representational learning, concept acquisition, meaningful problem solving, thinking, meaningful retention, judgment, and so on (Ausubel, Novak & Hanesian, 1978).

cognitive component - an elementary information process that operates on internal representations of objects or symbols.

cognitive structure - the total content and organization of a given individual's ideas; or, in the context of subject-matter learning, the content and organization of her or his ideas in a particular area of knowledge (Ausubel et al., 1978).

concept - objects, events, situations, or properties that

possess common criterial attributes (despite diversity along other dimensions or attributes) and are designated by some sign or symbol, typically a word with generic meaning (Ausubel et al., 1978).

deep structure - the underlying physics laws applicable to the problem, i.e., representations of general categories.

expert - the individual who has attained the higher level of skill or knowledge in linear kinematics within the intermediate group.

expertise - the range of skill or levels of knowledge that lie between and include the two extremes of novice and expert.

familiarity - the degree to which the subjects felt they already had the knowledge background or were acquainted with the item presented.

induction - a process that encompasses all inferential processes that expand knowledge in the face of uncertainty (Holland et al., 1986).

meaningfulness - the relative degree of meaning associated with a given symbol or group of symbols as opposed to their substantive cognitive content, as measured by degree of familiarity, or frequency of contextual encounter (Ausubel et al., 1978).

mental models - rules and rule clusters that operate in such a way as to 'simulate' the effects of possible states and actions in the world (Holland, Holyoak, Nisbett & Thagard, 1986).

novice - the individual who has a lower level of skill or knowledge in linear kinematics within the intermediate group.

problem representation - cognitive structures corresponding to a problem, constructed by a subject on the basis of their domain-related knowledge and its organization.

problem solving - a form of directed activity or thought in which both the cognitive representation of prior experience and the components of a current problem situation are reorganized,

transformed, or recombined in order to achieve a designated objective; involves the generation of problem-solving strategies that transcend the mere application of principles to self-evident exemplars (Ausubel et al., 1978).

problem type - represents categories of problems which share similar attributes for example, problems dealing with velocity can be represented by  $v=d/t$ , as contrasted to problems dealing with acceleration which can be represented by  $a=v/t$ . For the present study, problem types are characterised by involving Simultaneous and Successive movement.

procedures - operations that are adapted to achieve particular goals (Holland, Holyoak, Nisbett & Thagard, 1986).

referent solution path - the proposed "optimal" sequence of processing stages as based on "expert" evaluations.

schema - (operationally defined) is a set of assumptions and rules for interpreting new information that is triggered when certain conditions are satisfied. A likely trigger is the presence of information that confirms a threshold number of the schema's assumptions, but more refined trigger mechanisms are probably learned with practice.

or - a kind of organized knowledge for a concept or procedure sometimes represented by rule clusters (Holland et al., 1986).

solution path - the flow or movement across the processing stages which represents how the subject moved from the initial presentation of the problem to its final solution.

surface structures - (a) the objects referred to in the problem; (b) the literal 'physics' terms mentioned in the problems (i.e., relations among physical objects).

## Chapter II

### Review of Literature

What kind and how much knowledge is necessary to attain good problem solving performance? In an attempt to respond to this question, attention will be focused on problem solving in basic physics: specifically linear kinematics. Reif and Heller (1982) noted that this scientific domain (physics - linear kinematics) represents one which is realistically complex, requires flexible problem solving based on special knowledge, and is representative of other quantitative fields. Linear kinematics is sufficiently simple, however, to permit an analysis of the underlying cognitive processes. Judgments of distance, time and velocity are part of every day life, whether it is the appraisal and resolution of external movement (e.g., crossing the street against a light) or the decision of where and how fast to move. As a result of this type of intuitive experience, subjects entering a problem solving situation have an established reference point. Consequently, this may permit the examination of the underlying cognitive processes with more tools than we previously thought were at our disposal.

With this in mind, this chapter provides a focused review of literature in regard to some of the factors involved in the underlying cognitive processes necessary for a good performance in problem solving situations involving linear kinematics. The review is divided into four sections. In the first section the role of knowledge and expertise in problem solving is discussed. The second section explores the idea of problem type. A third section debates the effect of context on problem solving performance. The final section is an articulation of the problem.

### **The Role of Knowledge and Expertise**

Induction involves reasoning - drawing inferences in order to generate hypotheses that extend one's knowledge. In turn, reasoning involves the use of both rules about events in particular domains, and higher-order, more abstract rules termed inferential rules. Inferential rules include heuristics, or problem-solving strategies (Holyoak & Nisbett, 1988). Induction is often used in problem solving as well as being used as a basic theoretical framework for problem solving (Newell & Simon; 1972).

Holyoak and Nisbett (1988) asked the questions: "What are the cognitive units in which knowledge is expressed, and how can these be modified by experience?" They suggested that an individual's knowledge is greatly influenced by

experience. Before knowledge can be extended, it must be coded in such a way that a person can use it both to understand events and to make predictions about future events. As well, they proposed that knowledge develops from simple innate cognitive units that serve as "building blocks"; these are combined through the operation of innate inductive mechanisms to form more complex units. In turn, these higher-order units may themselves be transformed and recombined (as may the inductive mechanisms), so that knowledge grows in an ever increasing fashion, ever more responsive to the environment and less dependent on the innate units (Holyoak & Nisbett, 1988).

Two basic types of knowledge are modified by induction; concepts and procedures. Concepts are representations of general categories, such as number, dog, cat, and of more specific categories and instances, such as number 5, Fido, etc. Procedures are operations that are adapted to achieve particular goals. Concepts and procedures are closely interrelated. Concepts and procedures are often learned together; new concepts enable one to construct new procedures that apply to these concepts (Riley, Greeno, & Heller, 1983). As well, Anderson (1976, 1982) proposed a framework for the development of cognitive skill whereby knowledge is converted from a declarative to a procedural form.

How can concepts and procedures be represented? One proposal is that knowledge is encoded in condition-action rules, "if-then" rules; also known as production rules (Anderson, 1983; Newell, 1973). An important concept will typically play a role in a number of procedures, just as an important procedure will apply to a range of concepts. Both concepts and procedures, therefore, are often represented not by a single rule but by interrelated conditions or actions. Sometimes rule clusters represent the kind of organized knowledge often referred to as a schema for a concept or procedure. Holland, Holyoak, Nisbett and Thagard (1986) have described how these rules and rule clusters operate as "mental models" that mentally "simulate" the effects of possible actions in the world (the mind's eye).

The changes that take place as expertise is acquired can best be explored by longitudinal studies. Due to the operational problems involved in such a design an alternative starting point has been developed, i.e., looking at expert-novice differences. The induction framework may be useful in understanding what underlies the differences between the expert and the novice.

According to Larkin, McDermott, Simon and Simon (1980a, 1980b) two important tasks in the examination of expert-novice differences were 1) to assess the quantity of the

expert's knowledge and 2) to determine the form in which it was held in long-term memory (LTM). The most obvious difference between the expert and the novice was that the expert knew a great many things the novice did not know, and the expert could rapidly evoke the particular items relevant to the problem at hand. In other words, although a large body of knowledge is prerequisite to expert skill, knowledge must be filed (indexed) as patterns that, on recognition, guide the expert quickly to the relevant parts of the knowledge store.

The importance of knowledge organization has been demonstrated in many different domains and, in particular, that some forms of organization (hierarchical ones) are more effective than others in facilitating performance on complex tasks. Bower, Clark, Lesgold and Winzenz (1969) have shown that memory for items hierarchically organized was two to three times better than memory for random lists of words. Larkin (1980), Larkin and Reif (1979) have shown that experts, unlike novices, have their knowledge organized hierarchically. Similarly, Thro (1978) has shown that students who perform better on physics problems have clustering structures more hierarchically organised.

Larkin and Reif (1979) and Reif and Heller (1982) have indicated that experts rapidly redescribed problems presented to them, often used qualitative arguments to plan

solutions before elaborating them in greater mathematical detail, and made many decisions by first exploring their consequences. Furthermore, the underlying knowledge of such experts appeared to be tightly structured in hierarchical fashion. By contrast, novice students commonly encountered difficulties because they failed to interpret problems adequately. They usually did little prior planning or qualitative description. Instead of proceeding by successive refinements, they tried to assemble solutions by stringing together miscellaneous mathematical formulas from their repertoire. The underlying knowledge of the novice often consisted of a loosely connected collection of such formulas.

De Groot (1966) and Simon and his colleagues (Chase & Simon, 1973a, 1973b; Simon & Barenfield, 1969; Simon & Gilmarin, 1973) have compared expert to novice chess players and shifted the emphasis from a quantitative expert-novice paradigm to include qualitative comparisons. The results of their work provided a profile of the expert as an individual who had a "large vocabulary of recognizable configurations".

More specifically, they found that chess masters used much larger chunks of information than novices. In addition, 75% of all the chunks could be sorted into only three categories. Use of large chunks, and few of them, resulted in very low memory demands for master players. Simon (1980)

estimated a master possessed close to 50,000 chunks. This vocabulary of categories was built up over years of practice and hundreds of games of chess. It is estimated that to become a master requires approximately 10 years of on-hand experience. This research on the game of chess has suggested that expertise arises from having a greater domain of specific knowledge - a large vocabulary of recognizable configurations - rather than a superior memory. Simon (1981, p.80) defined a chunk as "a maximal familiar substructure of the stimulus", i.e., familiarity permits the creation of larger chunks of information. DeGroot (1966) noted that it was the intermediate level chess player who did more thinking ahead rather than the expert or novice. In addition, it was the intermediate player who tended to follow up on the consequences of bad moves as well as good ones.

It is also possible to consider the contributions of knowledge at a less specific level, namely, general vocabulary. Curtis and Glaser (1983) have attempted to discover why extensive and readily accessible word knowledge was important in the overall acquisition of reading skill and in other areas of verbal competence. Curtis and Glaser (1983) undertook the task of determining the specific vocabulary capabilities that distinguished the highly verbal person from the less skilled. Their basic findings were that the highly verbal person not only knew the definitions of more words, but also had more knowledge that related to

each known word. Thinking of human knowledge as a network of conceptual relationships, their results showed that the highly verbal person had more words tied into their network and also had more links, on the average, for any given word's encoding to other concepts.

Two studies which considered subjects with expertise in baseball showed a more anticipatory, or top-down, capability. Chiesi, Spilich and Voss (1979) asked subjects to write down all of the possible outcomes they could think of for a specific baseball situation. They found that high-knowledge individuals knew more possible outcomes and could better specify which ones were likely to occur. They were, at any point in reading a passage, more likely to expect what would come next in the text. Voss, Vesonder and Spilich (1980) asked subjects to produce a narrative account of a half inning of a fictitious baseball game. Two weeks later, the subjects were asked to recall what they had written. The low-knowledge subjects were able to reproduce less of the basic action sequence, and remembered less game-relevant details than the high-knowledge group. These studies led to the following basic account of the effects of knowledge on expertise: 1) experts could use their knowledge to keep track of the information they were being given when they read, 2) their short-term memory (STM) was more effective, especially for main-plot information, 3) their knowledge of the kinds of events that could occur in their domains of

expertise allowed them to remember complicated events more easily.

Voss, Greene, Post, and Penner (1984) have suggested some of the changes that take place in the course of acquiring expertise in a particular domain in which problems are wide ranging and solutions not easily verified, such as political science. They noticed that graduate students in this area showed three differences from undergraduates in their protocols. The graduate students 1) had some knowledge of sub-problem interactions; 2) descriptions of the problem situation were more abstract; and 3) reasoning in support and evaluation of their plans was more extensive. These differences led Voss and his colleagues (1984) to conclude that the graduate students had more complete knowledge networks, containing more explicit causal knowledge that was organized more hierarchically. Experts, they concluded, presented even more knowledge development, as well as refined discipline-specific and domain-specific strategies for using such knowledge. Voss and colleagues noted the importance of 'flexibility' in the expert's use of knowledge.

The Larkin and Reif study (1979) suggested that the problem solving process of experts, unlike those of novices, exhibited two characteristics: 1) the knowledge of experts was organized more coherently, rather than merely into individual principles or equations, 2) experts

approached problem-solving by a process of successive refinements. Thus they tended first to consider gross problem features, describing them rather vaguely by words or pictures. Only later did experts consider a problem in greater detail by using more mathematical language. Correspondingly, the experts' knowledge was structured so that the same information was multiply described at various levels of detail in appropriate symbolic forms.

Larkin (1981) argued that problem solving in "formal domains" (i.e., mathematics and the hard sciences) was impossible without a knowledge base in the area, that is, without domain-specific knowledge. Indeed, Greeno (1980) emphasized that there was no sharp distinction between problem solving and knowledge based performance. Shavelson (1972), Eylon and Reif (1984), Larkin (1981), Reif and Heller (1982) also observed that it is not only the content of this knowledge base which was important but how it was structured or organized. Indeed special concepts and associated principles in the quantitative sciences are the basic building blocks of the knowledge used to deduce important outcomes (Reif, 1985).

Also crucial for the development of domain-specific knowledge is the type of knowledge modified by induction, i.e., concepts. However, an important property of rule-based mental models (induction) is that rules can be useful even

if they are fallible. More general rules generate fallible but useful "default expectations", which can nonetheless be overridden by more specific rules that capture exceptional conditions under which the default does not hold. A mental model represented by layers of default and exception rules is termed a default hierarchy (Holland, Holyoak, Nisbett & Thagard, 1986). A subject can use these default hierarchies in two ways. The first is that they allow for the 'exception to the rule'. The second, is that they can allow for misconceptions to develop. The following studies explored this property.

diSessa (1982), Clement (1983), Hewson (1985), McCloskey, Caramazza and Green (1980), Trowbridge and McDermott (1980), McCloskey and Kohl (1983), McCloskey (1983), Champagne, Gunstone and Klopfer (1985) have examined people's misconceptions about motion. Knowledge of individual scientific definitions and principles is clearly a necessary, although not sufficient, prerequisite for scientific problem solving. Furthermore, the underlying knowledge required to interpret and use any particular definition or principle is considerable and merits detailed analysis. Deficiencies in such knowledge have led to many of the commonly observed errors and misconceptions exhibited by students (Reif & Heller, 1982). However, students do not come to the study of mechanics with a blank slate. They come with prior experience and with practical understanding of

how objects move. They usually have some idea about the general principles underlying motion. Many students having studied physics concepts and been familiar with them for some time, may nevertheless lack the supplementary knowledge needed to use such concepts reliably.

Green, McCloskey and Caramazza (1985) attempted to delineate the nature of people's misconceptions about motion. They argued that a cognitive account of the problem solving behaviour of students must rest on a description of their knowledge about motion. Scientific knowledge is of two sorts, knowledge of certain facts, principles and laws, and knowledge of procedures for applying the relevant factual knowledge to the problem situation. This is equivalent to the distinction between "knowing that" and "knowing how". Students must know 'that' force equals mass times acceleration and must know 'how' to determine the force acting on a body and the nature of the acceleration.

Lesgold, Feltovich, Glaser, Wang (1981: cited in Lesgold, 1984), investigated the way in which physicians acquired the organized bodies of knowledge (schemas) that constitute radiological anatomy, the science of relationships between variations in anatomical structure and patterns seen in x-ray plates. Two findings emerged. First, the use of schemata was an important means by which knowledge could be organized. A 'schema' being a set of assumptions and rules

for interpreting new information that was triggered when certain conditions are satisfied. Second, a likely trigger was the presence of information that confirmed a threshold number of the schema's assumptions. Glaser (1984) added that experts, in general, not only had knowledge about their subject matter, but knowledge about the application of what they knew.

Thus, the second 'type' of knowledge defined by Holland, Holyoak, Nisbett and Thagard (1986), procedures, is also an important part of problem solving ability. The following paragraphs outline a few of the studies which describe how this procedural knowledge differentiates novices from experts.

In regard to the differences between novices and experts in the domain of physics, many studies (Chi, Glaser, & Rees, 1983; Larkin, McDermott, Simon, & Simon, 1980a, 1980b; McCloskey, Caramazza & Green, 1980) have shown that representing the problem was a central part of problem solving for experts. Novices tended to invoke equations quickly, selecting those that included both what was given and what was to be found. In contrast, experts concentrated first on understanding the problem. Experts were more likely to draw diagrams, for example, and more problem solving time elapsed before they wrote down any equations. Once the representation was built, the solution methods also differed.

Simon and Simon (1978) found that novices were more likely to use a "working backwards" strategy when solving physics problems, while experts were more likely to use a "working forward" strategy.

According to Larkin, McDermott, Simon and Simon (1980a, 1980b) the most obvious difference between their subjects was that the expert solved the problems in less than one-quarter of the time required by the novice and with fewer errors. A second difference, verified from their worksheets and the thinking-aloud protocols they produced, was that the novice solved most of the problems by working backward from the unknown problem solution to the given quantities, while the expert usually worked forward from the givens to the desired quantities.

Another difference between expert and novice was that novices mentioned equations they were about to use, then substituted into them the values of the independent variables. The expert usually mentioned aloud only the numerical results of the substitution, not the original literal equation. This may have been merely a difference in verbalization: the expert, simply did not have time to verbalize everything. Another interpretation would be that the experts had stored directly an entire procedure for obtaining a desired value from related known values: they then applied this procedure and stated only the results they

obtained. The novice, in contrast, had stored the knowledge that particular equations could be used to obtain values of certain variables. Hence, the verbalized result of their recognition was the equation itself (Larkin, McDermott, Simon & Simon, 1980a, 1980b).

A general difference between expert and novice found in the literature (Larkin, McDermott, Simon, & Simon, 1980a, 1980b; Simon & Simon, 1978; Chi, Feltovich & Glaser, 1981) is that experts engaged in qualitative analysis of the problem prior to working with the appropriate equations. Chi et al. (1981) speculated that this method of solution for the experts occurred because the early phase of problem solving (the qualitative analysis) involved the activation and confirmation of an appropriate principle-oriented knowledge structure, a schema. The initial activation of this schema could occur as a data-driven response to some fragmentary cue in the problem. Once activated, the schema itself specified further (schema-driven) tests for its appropriateness (Bobrow & Norman, 1975). When the schema was confirmed, that is, the expert had decided that a particular principle was appropriate, the knowledge contained in the schema provided the general form that specific equations to be used for solution would take. Such initial qualitative analysis would naturally lead to a more forward-working character of problem solving for the expert, in that the equations used depended more on the way the problem was

represented than on the "unknown" (Larkin et al, 1980a, 1980b). Hence, analogous to the way that a chess expert's initial classification yielded a small set of "good" alternative moves, which must then be investigated analytically (Chase & Simon, 1973a, 1973b), the physics expert's initial categorization restricted the search for a particular solution to a small range of possible operations.

According to Larkin, McDermott, Simon and Simon (1980a, 1980b), there was ample evidence that for the novice frequent tests had to be performed to determine the sequence of actions and that the testing process consumed considerable time. The expert, on the other hand, had "automated" many sequences, so that they could be carried out without the need for recurrent testing. For the expert the process of identifying the right equation, substituting the values in it, and solving for the dependent variable were carried through to the end as a single step. Another difference between expert and novice indicated by evidence from the think-aloud protocols was that the novice often used a process of direct syntactic translation, whereas, the expert seemed to generate some sort of physical representation, in which accelerations produced velocities and velocities produced distances travelled (Larkin, McDermott, Simon & Simon, 1980a, 1980b).

Reif and Heller (1982) have specified explicit rules and

procedures to accomplish tasks which experts may actually carry out by using tacit knowledge or pattern recognition derived from long experience. For example, experts ordinarily redescribed a problem in theoretical terms very rapidly and without conscious effort. Experts often chose suitable principles, automatically without explicit awareness of the tacit knowledge guiding their choice.

Larkin (1977; cited in Larkin, 1980) asked a group of skilled problem solvers to solve some quite difficult problems. She found that they invariably worked in the following way: 1) They began their solution by making a qualitative representation of the problem situation (usually a labelled sketch). 2) They then tentatively selected a method and applied it to the problem to make qualitative statements about the situation. 3) They then checked these qualitative statements to assess whether any difficulties were likely to arise in applying the method. 4) Only then did these skilled problem solvers begin to apply the method quantitatively to produce mathematical equations.

There appears to be considerable evidence regarding the importance of knowledge and level of expertise in problem solving. More specifically, it has already been shown that experts know more than novices, that experts have this knowledge well indexed, that experts, unlike novices, have

their knowledge organized hierarchically, experts use larger chunks of information and fewer of them, that experts are more flexible in their use of knowledge and that experts are faster and make fewer errors. However, knowledge is not the only factor in the making of an expert. The following section, on Problem Categorization, outlines some of the characteristics regarding how experts and novices respond to different types of problems.

### **Problem Categorization**

In the research literature Problem Type and Problem Categorization are used interchangeably. Problem Type represents categories of problems which share similar attributes, for example, problems dealing with velocity can be represented by  $v=d/t$ , as contrasted to problems dealing with acceleration which can be represented by  $a=v/t$ .

Hinsley, Hayes and Simon (1977) have gathered much evidence that solvers represent problems by category (i.e., the combination of attributes most characteristic of a class) and that these categories may direct problem solving. Their results confirmed that subjects not only recognize problem categories but that they can in many cases recognize a problem's category early in reading the problem. Therefore, subjects can categorize problems without completely formulating them for solution. They also found that problem

categorization was influenced more by the problem's superficial structure - its cover story - than by its underlying algebraic structure.

There appeared to be two different procedures used by the subjects in extracting the appropriate equations from the text of the problems. With one procedure, the subject read the entire problem before formulating any equations or noting any relationships explicitly. The second procedure was a line-by-line approach which formulated equations and relationships explicitly while reading the text. In addition to the evidence of line-by-line processing, it also appeared that the subjects did classify some problems early in the course of solving them and did retrieve useful information about them from memory. Subjects made explicit statements of the problem type, such as, "Sounds like another  $x+y$ ," or "Oh, one of these! I always get confused". Not only did this show that the problem type was recognized, but so was its difficulty and/or the subject's previous experience with this type of problem. In other words, subjects had information about the problem categories which was useful for formulating problems for solution, and this included knowledge about useful equations, diagrams and procedures for making judgments.

Hinsley, Hayes, and Simon (1977) concluded that humans have two ways of approaching algebra word problems. First,

if they recognized early in the problem solving process that a problem was one of a known category, they employed special heuristics specifically useful in formulating and solving problems of that category. Second, if they did not recognize a category for the problem, they employed a general solution procedure as a fallback strategy. The evidence provided by Paige and Simon (1966), however, would indicate that this process made use of semantic information. In summary, Hinsley, Hayes, and Simon (1977) noted that problems could often be categorized into a surprisingly small number of types. Recognizing a familiar problem type not only helped people know what kinds of information to attend to, it also helped them retrieve useful solution strategies from memory. The important element was being able to identify correctly the problem type.

The hypothesis guiding the research of Chi, Feltovich, and Glaser (1981) was that the representation of the problem may be constructed in the context of the knowledge available for a particular type of problem. The knowledge useful for a particular problem is retrieved when a given physics problem is categorized as a specific type. Thus, expert-novice differences may be related to poorly formed, qualitatively different, or nonexistent categories in the novice representation. In general, this hypothesis is consistent with the "perceptual chunking" hypothesis for experts (e.g., Chase & Simon, 1973a, 1973b).

Chi, Feltovich, and Glaser (1981) hoped to determine the kinds of categories subjects (of different experience) impose on problems. Examination of their data revealed that certain similarities in the surface structures of the problems existed. The suggestion that novices categorized by surface structure was confirmed by examining the subjects' verbal descriptions of their categories. The novices use of surface features involved either keywords given in the problem statement or abstracted visual configurations, that is, the presence of identical keywords was one criterion by which novices grouped problems as similar. For experts, surface features did not seem to be the basis for categorization. There was neither great similarity in the keywords used in the problem statements, nor visual similarity apparent in the diagrams depictable from each pair of problems. Nor was the superficial appearance of the equations that could be used on these problems the same. It appeared that the experts classified according to the major physics principle governing the solution of each problem: the deep structure. There was little overlap between expert and novice categories. Although both experts and novices classified a large number of problems into four categories, there was a slight difference in the distribution of the problems across categories, which may suggest greater variability in the novices' classification. This again suggested that experts were able to "see" the underlying similarities in a great

number of problems, whereas the novices "saw" a variety of problems that they considered to be dissimilar because the surface features were different. However, with learning, advanced novices began to categorise problems by the principles with a gradual release from the dependence on the physical characteristics of the problems, although their groupings were still constrained by surface features (Chi, Feltovich, and Glaser, 1981).

In regard to the relationship between categorization and a subject's representation of problems, there appear to be at least two interpretations. The first interpretation was that after reading the problem statement, a representation was formed, and based on that representation, the problem was categorized. McDermott and Larkin (1978) proposed that subjects progressed through four stages of representations as they solve a problem. The first stage was a literal representation of the problem statement. The second stage ("naive") representation contained the literal objects and their spatial relationships as stated in the problem and was often accompanied by a sketch of the situation (Larkin, 1980). These representations were considered "naive" as they could be formed by a person who was relatively ignorant of the domain of physics. In the third stage ("scientific"), representation contained the idealized objects and physical concepts, such as force, momentum, and energies, which were necessary to generate the equations of the algebraic

representation. This stage was related to the solution method. The interpretation based on this framework is that a novices' categorization was based on the construction of "naive" representations, with some limited elements of a "scientific" representation. Experts, however, constructed a more "scientific" representation, and based their categorizations on the similarities at this third level of representation. Such an interpretation explained why experts took longer initially to classify the problems. They had to process the problems more "deeply" to a scientific representation in order to determine the principle underlying a problem.

The second interpretation for the process of representing a problem for solution was that of Chi et al (1981). This interpretation suggested that a problem representation was constructed in the context of the knowledge available for the problem type which constrained and guided the final form which the representation would take. A category and its associated knowledge within the knowledge base constituted a "schema", for a particular problem type. It was the content of these problem schemata that ultimately determined the quality of the problem representation. Because the character of problem categories was different between experts and novices, Chi et al (1981) postulated that their problem schemata contained "different" knowledge.

In chess research, it appeared that the experts'

superiority in memorizing chessboard positions arose from the existence of a large store of intact and well-organized chess configurations or patterns in memory (Chase & Simon, 1973a, 1973b). It is plausible that a choice among chess moves (analogous to physics solution methods) resulted from a direct association between move sequences and a configural (chunked) representation of the surface features of the board. Finally, from research in medical diagnosis, there has been evidence to suggest that expert diagnosticians represent particular cases by general categories, and that these categories facilitate the formation of hypotheses during diagnosis (Wortman, 1972).

Overall, two processes seem to be at work as people construct problem representations. First, people can and do selectively attend to the information presented to them. Second, they make use of prior knowledge, including knowledge about specific problem types, in solving new problems (Reynolds & Flagg, 1983).

From this review, therefore, it has been suggested that the influence of Problem Type can be expressed in several ways: the manner in which the problem is presented (visually or semantically) influenced the problem representation, that changes in the problem statement could also have important effects on the solution process, that changes in the representation of a problem could change the solution process

significantly.

## Context

In this section some of the ways in which context has been defined, and the related research, will be discussed. The term 'context' has been used in a large number of research articles (Smith, 1984; Fagan, 1984; Conrad, 1974; Fischler & Bloom, 1979; Beeson, 1981; etc.). However, 'context' does not as yet have a universally accepted definition.

Thomson (1986) proposed that the concept of context had a number of different meanings. He distinguished at least four functions that could be attributed to context, with four different meanings. In the area of sensory processes, context was implicated in the process of figure-ground differentiation. For the fields of perception, psycholinguistics and psychology, context was involved in the identification of the figure. In the research areas of episodic recall and recognition, context was thought to play a critical role in discriminating one target event from another. Finally, context may be invoked to account for selective attention. Perhaps the most important observation Thomson made was that the term context had been used in very different ways and as both a descriptive and explanatory concept.

While Bransford and his colleagues (Bransford & Johnson,

1972, 1973; Bransford & McCarrell, 1974) have been closely associated with the study of context in comprehension, they have not been clear about what they meant by context. Bransford and Johnson (1972), for example, speak of the "context picture," "appropriate semantic structures," "appropriate context", as "part of the pre-experimental knowledge," and "the context underlying a stimulus," all in relation to their general claim that "relevant contextual knowledge was a prerequisite for comprehending prose passages." Doll and Lapinski (1974) attributed to Bransford and Johnson two additional terms, "thematic context" and "referential context." Later, Bransford and Johnson (1973) spoke of "activated semantic context" or "activated knowledge structures," arguing that in general "the ability to understand linguistic symbols was based not only on the comprehenders' knowledge of the language, but also on their general knowledge of the world (pp. 383)." Still later Bransford (1979) equated "context" with "appropriately activated knowledge." What knowledge is "relevant" or "appropriately activated" Bransford never says.

Clark and Carlson (1980) have outlined a theory of context which is intrinsic to language comprehension. In doing so they reviewed the uses of the term 'context' in the experimental literature and abstracted its essential features. The six features found to be common to most of the uses they reviewed were: information, person relativity, process

relativity, occasion relativity, availability, and interactibility. To summarize Clark and Carlson, context is "information that is available to a particular person for interaction with a particular process on a particular occasion" (p. 318).

According to Sternberg (1985) "implicit theories set the context in which explicit theorizing occurs". Implicit theories are based or at least tested, on people's conceptions whereas explicit theories are based or at least tested, on data collected from people performing tasks presumed to measure intelligent functioning. Clark and Carlson's (1980) definition of context complements Sternberg's (1985) conceptual subtheory. Sternberg believes that implicit theories needed to be "discovered" because they already existed, in some form, in people's heads, whereas Clark and Carlson (1980) stipulate that context is partly intrinsic.

Bransford and Johnson (1973) found that presenting subjects with a context or a cue to a context made relatively incomprehensible materials much more comprehensible. Post-experimental interviews indicated that, when left to their own devices (no context, no topic or no cue conditions), many subjects attempted to find or generate information that would make sense of the materials. The data suggested that subjects may be better off creating their own context than

attempting to find relationships between an input and the wrong context. According to Bransford and Johnson (1973), if understanding involves relating input information to general knowledge, the semantic product resulting from this process would often include more information than that directly expressed in the input. The results of their study were consistent with the notion that the subject's understanding depended not only on what they heard, but on the implications of this information in light of prior knowledge. Therefore, the subject's performance (e.g., in a recognition memory task) was not only a function of the input information, but of what they knew. Their results indicated that the absence of an appropriate semantic context could under some conditions seriously affect the acquisition process. In general, the results of their studies indicated that simply having relevant pre-experimental knowledge was not sufficient to insure comprehension. This knowledge must be activated during the ongoing process of comprehension in order for it to be maximally useful.

The role of prior semantic information was also investigated by Dooling (1972) who suggested that it could be used to speed up the sentence comprehension process. Context speeds up the processing of the basic semantic relationships of a sentence. But, according to Dooling, the presence of context required an additional process: context sentence integration. The skilled reader was felt to have the ability

to use contextual information to short-circuit part of the semantic processing in computing the meaning for a sentence. Just as letters are not individually recognized in the perception of words, so too, sentences in context may not need full semantic analysis. Comprehending a sentence in context is a more complex task than comprehending a sentence in isolation. It requires more cognitive work to relate the meaning of a sentence to its context. Therefore, context could add to the processing load in two ways. (a) Sentences understood in context may be given a "deeper" meaning, that is, a semantic analysis that is highly specific to the context. (b) In comprehending sentences in discourse, subjects construct a "theme" or "schema", and recode the information into larger semantic units; this process takes time to perform.

The part played by prior knowledge was viewed somewhat differently by Beeson (1981), whose study showed that when students learned a hierarchy of intellectual skills in the context of an anchoring idea, more meaningful learning resulted (as demonstrated by superior performance on a test of lateral transfer). Only when the students were required to apply their newly acquired knowledge to novel situations did the anchoring idea context show its superiority. On the other hand, students who used the anchoring idea context did perform better than other students on a test of retention of final task given after approximately 7 weeks. This difference

between the results of tests given shortly after and a long time after the original test can be explained in terms of the degree of meaningfulness of the learning which occurred under the various context treatments.

Stanovich, West and Freeman (1981) were able to demonstrate that poor readers strategically relied on context in order to compensate for their weak encoding skills, and that this same reliance could be elicited in good readers if the task of word recognition was made more difficult, for example in conditions of reduced contrast. This result was supported by Juel (1980), who found that whereas poor readers always made use of context in word recognition, good readers relied on context only when the internal word cues were minimal, notably with low-frequency words which presented decoding difficulties or with words presented in upper case, when the visual information from the word envelope was reduced (Underwood & Bargh, 1982).

Bransford and Johnson (1972) viewed the role of the topic or theme as something more than a schema for generating associations. The use of a 'topic' or 'theme' appeared to help subjects create contexts that could be used to comprehend the passages. In other words, if a passage did not provide sufficient cues about its appropriate semantic context, subjects were in problem solving situations for which they had to find a suitable organization from their store of previous knowledge. In order for prior knowledge to aid

comprehension it must become an activated semantic context. It appeared that for maximum benefit the appropriate information had to be present during the ongoing process of comprehension. Overall, their results emphasized the crucial role of semantic contexts in comprehension.

Barsalou (1982) proposed two important types of properties associated with concepts: context-independent (CI) properties and context-dependent (CD) properties. CI properties were activated by the word for a concept on all occasions (e.g., unpleasant smell for skunk). CD properties were rarely if ever activated by the word for a concept and were only activated by relevant contexts in which the word appeared (e.g., floats for basketball). CI properties formed the core meanings of words. This was because they were activated by the respective word on all occasions, independent of contextual relevance. Barsalou and Bower (1980; cited in Barsalou & Medin, 1986) have proposed that properties become automatically activated by a word after being frequently associated with it during processing. Frequent pairings of a word and a property cause an automatized relation between them to be established in memory as postulated by Shiffrin and Schneider (1977) and Schneider and Shiffrin (1977).

It is well established that context facilitates word recognition (Tulving & Gold, 1963), and there is a considerable body of work suggesting that some of these

effects are due to semantic priming (Fischler & Goodman, 1978; Meyer, Schvaneveldt, & Ruddy, 1975). Several proponents of what have become known as top-down models of the reading process (Goodman, 1976; Smith, 1971) have hypothesized that contextual information can speed ongoing word recognition during reading, because the contextual redundancy reduces the number of visual features that must be extracted from each word. Furthermore, it has been argued (Smith, 1971) that as fluency develops, the reader is increasingly reliant on contextual information during ongoing recognition. Thus, the fluent reader is less reliant on visual cues because of his efficient use of contextual redundancy. However, the prediction of the top-down models, that the word recognition performance of better readers will be more dependent on prior context than the performance of less-skilled readers, has been challenged. Schvaneveldt, Ackerman, and Semlear (1977) found evidence that, within each grade, the poorer readers made relatively greater use of context. West and Stanovich (1978) also conducted a developmental study that employed incomplete sentences as contexts, and produced results that were highly consistent with those of Schvaneveldt et al (1977).

Early experiments on reading indicated that subjects' familiarity with written material greatly enhanced their capacity to "see" the word, phrase or letter combination (Solso, 1979). The experimental data on word familiarity and word recognition has generally supported the notion that

familiarity facilitates recognition. A study by Howes and Solomon (1951) addressed this issue. They asked subjects to identify words presented for varying times. Some of the words were common, some familiar, and some rare. The results showed that, as the frequency of occurrence of a word increased, there was a decline in the time required to "see" (or recognize) it (threshold value); or conversely, that we require more time to "see" unfamiliar words (Solso, 1979, p. 100).

An experiment that demonstrated the importance of familiarity within an information-processing context was conducted by Miller, Bruner, and Postman (1954). They used familiar words which could be identified from minimal perceptual cues, and developed a list of pseudo-words that approximated the natural occurrence of letter sequences. Their data supported earlier findings, in that higher-order approximations (more familiar) took less time to identify than lower-order (less familiar) approximations. From this, the authors concluded that the amount of information carried by a symbol is related to the number of possible alternatives. The higher the redundancy, the fewer the possible alternatives, and the less information. In terms of information load, or the relative amount of information carried by each letter, the implication of these results is that even though more letters were reported among the high-frequency combinations, each letter of such combinations carried fewer bits of information because of redundancy.

Similarly, in the solution of anagrams the effect of familiarity is large, but this effect pertains to the solution word rather than to the anagram presented as a problem. On the assumption that words which appear frequently in ordinary reading matter must be more familiar on the average to a large group of subjects, Mayzner and Tresselt (1958) selected words that were very frequent, such as chair; frequent, beach; infrequent, cobra; and very infrequent, ghoul. When they rearranged many such words as anagrams and gave them to college students to solve, the effects of the familiarity of the solution word, as well as letter order, were very large. Furthermore, it has been demonstrated that if anagrams had three solutions and the subjects had to get all three, the solutions written first had the highest word frequency and those written last had the lowest (Johnson & Van Mondfrans, 1965).

One way to view these experiments is in terms of a combination of communication theory and signal detection theory. When information about words is stored by subjects, then that information may make the receiver component of their "system" more sensitive to certain kinds of information. Thus when familiar signals are presented, the subject is able to perceive them readily, not because they are less "noisy" or stronger signals, but because the subject's receiver capabilities have been altered (Solso, 1979).

For signal detection theory it has been suggested that

judgments are based on values of X, but what is X? It has been called 'memory strength' or 'familiarity'. Given a particular value of X (familiarity) resulting from an item on a particular trial, the problem is to decide whether it is in the familiarity range of 'old' items, or whether it is so low as to be in the range associated with 'new' items (Sanford, 1985). The familiarity of the materials of the problem has a generally helpful effect, but familiarity with potential solutions, from exposure in the past or present, has a much greater effect, facilitating judgment as well as solutions (Johnson, 1972).

Even for signal detection theory the most important problem for a subject is the need to distinguish between 'signal' and 'noise'. Atkinson and Juola (1973) used signal detection theory to create a model that shows that signal detection theory is not limited to situations in which the observer's problem is to identify a pure sensory event. The principles of detection theory can be applied to decisions based on non-sensory attributes of stimuli (i.e., words). In Atkinson and Juola's model (1973), the relevant non-sensory attribute is the familiarity of the test items in a recognition experiment. According to this model, a test item's familiarity is determined by how often and how recently it has been experienced, and sometimes subjects can determine whether the test item came from the 'positive set of words' by how familiar it is without searching their

memory of the positive set (Lachman, Lachman, & Butterfield, 1979). In other words response decisions based on the familiarity of the stimulus alone can be made very quickly and the subject is able to achieve a stable level of performance, matching the speed and accuracy of responses to the demand characteristics of the task (Atkinson and Juola, 1973).

Studies in memory and comprehension, which often use context to study comprehension, may help explain the relationship between familiarity of words and context. Several models of comprehension and long-term memory have been developed. Semantic network models and semantic features models (Collins & Quillian, 1969; Katz, 1972) describe sentence meaning as the construction of associations among the abstract, dictionary like lexical meanings of the words in the sentences. An alternative model, the Generative model (Wittrock, 1974), bases predictions about sentence comprehension and its long-term memory upon the following hypothesis: meaning for sentences involves more than the sum of the semantic, syntactic, phonetic and episodic characteristics of words. These characteristics and the sentence context serve to reduce uncertainty in the identification of distinctive previous experiences stored in long-term memory. After uncertainty is reduced, it is possible to generate from memory one or more distinctive representations of an event or relation consistent with the

words of the sentence. The actively constructed representation induced from memory of prior events is the psychological meaning of the sentence. The model emphasizes the context bound, distinctive nature of sentence meaning.

Researchers, using different tasks and different populations, have found that problem-solving performance is affected by the context (Cox, 1978; Siegler, 1977; Simon & Hayes, 1976). Different specific explanations were provided for their results, but a common thread was that better problem solvers were more successful in one critical aspect of the problem-solving process. This critical aspect refers to the close relationship between the problem context and an individual's knowledge or experience with that context which may enable the person to overcome a particularly difficult step in the problem-solving process. This, in turn, leads to the development of strategies for solving the problem. The problem solver may develop a context-specific strategy and be unable to transfer this strategy to problems that are structurally the same but contextually different. On the other hand, if the context of the problem is unfamiliar, the problem solver may have to think in more general terms and generate a transferable strategy (Steinberg, 1983).

How successfully a person is able to solve a problem may also depend on its complexity. Solving a problem can mean getting the right answer to a particular problem or generating

a strategy that will enable the individual to get the right answer to a succession of such problems. Polich and Schwartz (1974) found that students used different strategies, such as tabular charts or sentences, to represent the information given in the problem. Students tended to maintain those representations even with larger size problems of the same type. Only one of the representations was actually useful for solving the larger problems (Schwartz & Fatellah, 1972). Only subjects who used that representation succeeded in solving the larger as well as the smaller problems (Steinberg, 1983).

In other words, the complexity of a problem is determined, in part, by (a) the number of components, and (b) the problem solver's familiarity with the context of the problem. A person is more likely to solve a problem if it involves a small number of components (Polich & Schwartz, 1974; Reed & Abramson, 1976); Simon & Reed, 1976). Performance is also better when the person is familiar with the context of the problem (Siegler, 1977; Simon & Hayes, 1976).

The evidence to date suggests that 1) context itself has eluded a stringent definition (Thomson, 1986; Bransford & McCarrell, 1974; Clark & Carlson, 1980); 2) subjects are sometimes better off creating their own context as a framework in which to work (Bransford & Johnson, 1973); 3) familiarity with the context aids comprehension (Dooling, 1972; Bransford & Johnson, 1972); 4) the degree of

meaningfulness aids in LTM test performance (Beeson, 1981); 5) context facilitates word recognition (Tulving & Gold, 1963); 6) familiar contexts reduce information load (Miller, Bruner & Postman, 1954); 6) response decisions based on the familiarity of the stimulus alone can be made to achieve a stable level of performance (Atkinson & Juola, 1973); 7) better problem solvers show a close relationship between their knowledge or experience with that context (Cox, 1978; Seigler, 1977; Simon & Hayes, 1976); 8) problem solvers may develop context-specific strategies to problems that are structurally the same but contextually different, that is, if the context is unfamiliar the problem solver may think in more general terms and generate transferable strategies (Steinberg, 1983).

### **Articulation of the Problem**

Most human activities require substantial training if they are to be performed efficiently and with precision. While some forms of expertise are to be found only in the role of the specialist, others are part of every day roles. In general, an 'expert' is defined as the individual who has attained a high level of skill in a particular field. As well, the term 'novice' is used to indicate the individual who has a low skill level in that particular field. Therefore, expertise is used to describe the range of skills (a continuum) which lies between those of novice and expert.

Numerous researchers have compared the respective behaviours of experts to novices on specific tasks and have extracted some clear differences: 1) experts know more than novices (Larkin, McDermott, Simon & Simon, 1980a, 1980b), 2) experts are faster and make fewer errors (Larkin, McDermott, Simon & Simon, 1980a, 1980b), 3) the expert's representation of the problem is more efficient than that of a novice (Chi, Glaser & Rees, 1983; Larkin, McDermott, Simon & Simon, 1980a, 1980b; McCloskey, Caramazza & Green, 1980), 4) experts use larger and fewer chunks of information (DeGroot, 1966; Chase & Simon, 1973a, 1973b; Simon & Barenfeld, 1969; Simon & Gilmartin, 1973; Simon, 1980), 5) theoretically, at least, the expert's ability to solve problems is less affected by the context in which the problem is presented (Stanovich, West & Freeman, 1981), 6) experts are more flexible in their use of knowledge (Voss, Greene, Post & Penner, 1984), 7) experts possess not only a broader knowledge base but one which is better organized (Larkin & Reif, 1979; Greeno, 1980; Larkin, 1981; Shavelson, 1972; Eylon & Reif, 1984; Reif & Heller, 1982; Reif, 1985), 8) experts, unlike novices, have their knowledge organized hierarchically (Larkin, 1980; Larkin & Reif, 1979; Thro, 1978), 9) experts tend to categorize problems into types according to their deep structures whereas novices tend to focus on the problem's surface structure (Larkin, McDermott, Simon & Simon, 1980a, 1980b; Chi, Feltovich & Glaser, 1981), 10) experts show superior performance in

both recognition and recall tasks Tulving & Gold, 1963; Miller, Bruner & Postman (1954), 11) experts not only have knowledge about their subject matter, but knowledge about the application of what they knew (Glaser, 1984). However, knowledge is not the only factor in the making of an expert.

Researchers, using different tasks and different populations, have found that problem-solving performance is affected by the context (Cox, 1978; Siegler, 1977; Simon & Hayes, 1976). Different specific explanations were provided for their results, but a common thread was that better problem solvers were more successful in one critical aspect of the problem-solving process. This critical aspect refers to the closeness of the relationship between the problem context and an individual's knowledge or experience with that context. The less experienced problem solver may develop a context-specific strategy and be unable to transfer this strategy to problems that are structurally the same but contextually different, that is, the same problems presented in different ways (isomorphs) influence the difficulty of solution. Alternatively, more expert problem solvers tend to abstract the structure of the problem and free themselves from the particular context (Steinberg, 1983).

Although some of these expert-novice differences have been identified, what is less understood is how an individual becomes an expert: the transition from novice to expert. What

do novices need in order to increase the level of expertise they possess? In the present study, an information-processing approach to problem-solving was used, where attention was focused on a particular person at work on a particular problem or task (Clark & Carlson, 1980).

Overall, the study attempts to relate the level of expertise of the subjects to how they solve isomorphic problems. As the study tests a specific hypothesis and seeks information related to a specific objective, it has both confirmatory and exploratory components.

While this study deals with the area of linear kinematics, the main purpose is to investigate the effect of context and level of expertise on the problem solution process. The research question deals with the time taken to solve problems in linear kinematics and how the solution time may be related to the context of the problem and the level of expertise of the subject. Specifically, we would expect those subjects with lower levels of expertise to take longer to solve problems and/or exhibit more incorrect solutions. At the same time the literature would suggest that those subjects with higher levels of expertise would be less influenced by the problem context and exhibit more consistent performance.

The hypothesis being tested in this study is as follows:

For isomorphic problems, the solution time is a

function of the context of the problem and the level of expertise of the subject.

In addition to this confirmatory process the study also has an exploratory component. Solution times and response accuracy provide a measure of overall performance, but if we are to understand the process by which the solutions were achieved, it is necessary to examine the various operations which were utilized. The literature suggests that experts are better able to identify the problem structure and, therefore, would tend to emphasize those operations which lead more directly to problem solution. Alternatively the less expert subjects may be expected to spend more time searching for relevant information and less time verifying the accuracy of their responses.

The exploratory component was described by the following objective:

For isomorphic problems, the problem solution patterns displayed by subjects vary with problem context and level of expertise of the subject.

This study is concerned with how people use knowledge, whereas the focus of the educational process is how people acquire knowledge. Put simply, the purpose of any educational program is to facilitate the learning process. However, while learning may require students to solve particular problems, it is important to realize that the solution process is not simply a function of the problem itself, but also may be

influenced by the context in which the problem is placed and the expertise which the student brings to that situation. Hence, any information which might add to our understanding of how these variables interact may, in turn, enhance our ability to facilitate the learning process.

## CHAPTER III

### METHODOLOGY

This chapter is divided into three parts. How the various contexts for the isomorphic linear kinematics problems were chosen is described in part 1. The second part is concerned with the process of concept mapping and the determination of the subject's level of expertise in the area of linear kinematics. The third part includes the methodology for collecting the verbal protocols as the subjects attempted to solve the isomorphic linear kinematic problems.

The specific instruments used to gather data will be described in the sequence that they were used within the study. The three instruments were 1) Inventory of Contexts, 2) Concept Mapping, and 3) Problem solving tasks.

#### Inventory of Contexts

The objective of this first phase was to compile an inventory of contexts related to or involving the concepts of displacement, time and velocity in order to construct familiar and unfamiliar isomorphic problems. The degree of

familiarity was based on the frequency with which the particular contexts were identified by subjects.

An adaptation of a technique employed by Sternberg (1985) yielded an inventory of contexts. One hundred and eight (48 males and 60 females, 41 anglophones and 67 francophones) university undergraduate students were asked to identify in writing as many different contexts as they could involving the concepts of time, displacement and velocity. All but nine students had previously attended one High School physics course or the equivalent. A one page questionnaire (see Appendix A) was developed by the experimenter to facilitate data collection. The average time required to complete the questionnaire was 20 minutes. From these responses a list of 'contexts' was compiled.

A summary of the responses to the question

"If you had to describe to someone situations where one or several of the concepts of time, displacement and velocity are involved, what kind of examples would you use? List as many as you can."

can be seen in Table 1.

Automobiles and running were the most popular or familiar categories identified when people were asked to provide specific examples, although modes of transportation and sports in general scored high on the list. In the sports category, projectile sports appeared to be the preferred choice. As observed in Table 1 the least frequently mentioned categories were movement of the earth and molecules, cooking, flying a

TABLE 1

Frequency of contexts identified by subjects (N = 108).

Context	1st choice	2nd choice	3rd choice	4-7th choice
sports	62	54	41	37
transportation	41	31	26	25
construction	1	1	2	0
cooking	0	1	0	1
molecules	0	1	0	2
mvt of the earth	0	0	0	2
flying a kite	0	0	1	0
falling stars	4	3	2	1
elevators	0	1	0	0

kite and elevators.

All subjects included either an item of transportation or a sports activity in their list. A complete list in both of these categories is presented in Appendix B.

Of the 41 subjects who chose transportation as their first choice 23 of them chose automobile transportation as the most familiar and 10 indicated 'transportation in general'. As a second choice in this category, automobile (16) was chosen over 'transportation in general' (7). Consequently, it would seem safe to state that transportation by car was most familiar.

The category with the highest number of first choices of examples was that of sports (62). However, this may be due to two factors. First, many of the people interviewed were from the departments of Kinanthropology or Physical Education and thus influenced by their background. A second reason may be related to the wide range of sports and physical activities available to people: it is something these students experience every day. On closer examination of this category the three most popular choices were running (20), projectile sports (6) and sports in general (17). The second and subsequent choices tended to follow the same pattern as the first choice.

Therefore, the 3 groups of contexts that appeared to be the most familiar to this population were (1) transportation

by automobile, (2) sports in general which could include or exclude the other popular choices of (3) running and projectile sports. These three groups were chosen to form the basis for the context of the isomorphic problems that would represent the familiar contexts of this study.

The unfamiliar or less frequently identified contexts as seen in Table 1, were 'cooking' (2), 'molecules' (3), 'movement of the earth' (2), 'kite flying' (1), and 'elevators' (1).

In order to obtain distinct categories, the decision was made to use two very different contexts. The first unfamiliar context, representing movement on a very small scale, was molecules in the form of blood flow. The second choice for unfamiliar contexts was comets, since it provided an example of very large scale movement in regard to moving between the earth and other planets.

### Concept Mapping

Few functional tools useful in evaluating what the learner actually knows have been identified. Novak and Gowin (1984) believe concept mapping to be such a tool since it was developed specifically to tap into the learner's cognitive structure and to externalize what the learner already knows. They do not claim that concept mapping is a complete representation of the relevant concepts and

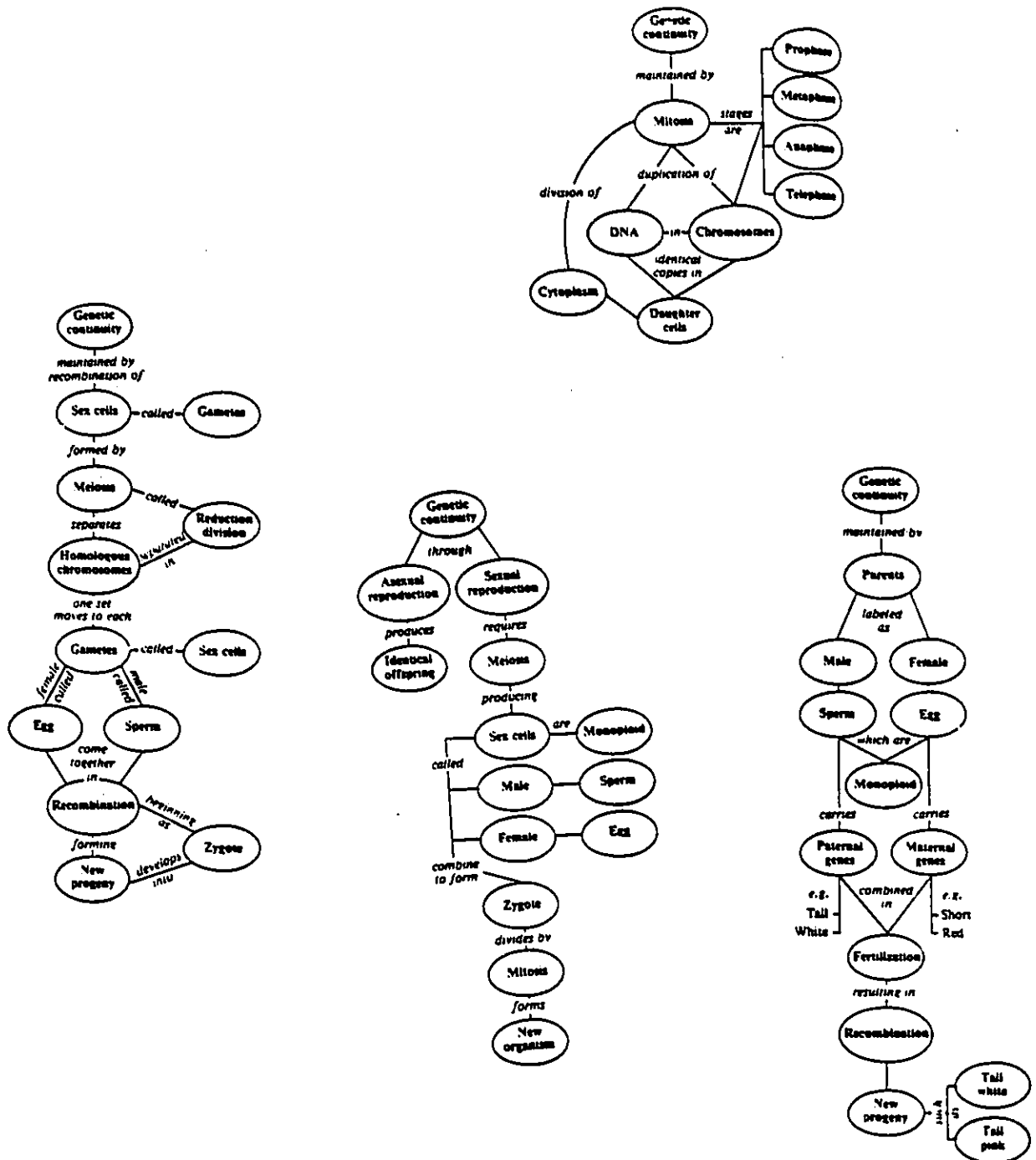


Figure 1 : Four examples of Concept Maps for the same topic - Genetic Continuity ( Novak & Gowin, 1984, p. 80 - 81 )

propositions the learner knows, but suggest that it is at least a workable approximation (Novak & Gowin, 1984).

A concept map may be described as a schematic device for representing a set of concept meanings embedded in a framework of propositions (see Figure 1). Novak and Gowin (1984, p. 4) define concept as "a regularity in events or objects designated by some label". The regularity represented by the concept label is given additional meaning through propositional statements that include the concepts. Thus, a proposition is seen as a meaning relationship between two concepts. The concept map may be likened to a visual road map which shows some of the ways a person may connect the meanings of concepts by propositions (see Appendix C).

The schematic nature of concept maps offers two advantages besides the obvious one of providing indicators of what the person already knows. The first is that it helps single out why a particular propositional linkage is good or valid. The map may illustrate either the linkages between concepts that lead to correct or false propositions and/or linkages that miss the key idea relating those concepts. The second advantage is that the same set of concepts may be represented in two or more valid forms. Concept mapping, therefore, may be useful in helping to understand how individuals rather than groups respond to particular problems.

Subjects were asked to describe their understanding of

movement in the form of a concept map. Fifty-seven undergraduate students from the University of Ottawa (31 males and 26 females) volunteered to participate in this study. The mean age for the females was 22.26 years  $\pm$  2.30. The mean age for the males was 22.83 years  $\pm$  2.61. Prior to testing subjects were asked to identify their preferred sport or activity (Bransford & Johnson, 1973).

All subjects completed a single test session lasting from 45 minutes to 1 hour 15 minutes. The order of presentation of testing instruments (concept map and the problem solving tasks) was the same for every subject.

The subject was seated at a table across from the experimenter. The experimenter read a standard set of instructions to the subject. The subject had an identical copy of the instructions and followed along with the experimenter (see Appendix D). The subject was shown two alternate ways of completing the concept map during a 10 to 15 minute training session on how to use the technique. The subject was encouraged to ask questions during the training session. Once the subject felt comfortable with the technique, several blank pieces of paper plus a separate sheet of paper with a list of 7 cue words were placed before the subject (see Appendix E). The experimenter then asked if there were any additional questions and reminded the subject to keep talking at all times. The concept mapping session lasted on

average 20 minutes.

The verbal protocols of the concept mapping session were recorded on a JVC MK-100 tape recorder using TDK AD60 tapes. When the testing was completed the verbal protocols of the concept mapping were transcribed verbatim and timed. The drawings made during the process of creating the concept maps were included with the verbal protocols for judging.

### Problem Solving Task

The third part of the study involved collecting the verbal protocols as the subjects attempted to solve the isomorphic linear kinematic problems. High-level encoding of verbal information, particularly encoding that abstracts from the substantive content of the protocols, can only be carried out if certain basic assumptions about human information processing are made. Ericsson and Simon (1984) identify three such assumptions. The primary assumption is that any cognitive process can be described in terms of the sequence of information processes that are attended to during its course. Their second assumption is that attending to information takes time. It is assumed that the time interval between two acts of a) just previously attended to information and b) accessing or generating the current information, corresponds to the time taken by the corresponding information process.

Their final assumption is that the number of symbols, or

amount of information, that can be attended to and held in STM simultaneously is severely limited, and independent of the particular content and type of information. [The amount of information that subjects can hold in STM will, therefore, be a direct function of how much information they can encode in a single symbol (chunk).] This assumption suggests that we abstract from the verbalized information the maximum number of different patterns, or chunks, into which it is encoded. These three assumptions (sequence, time and chunking) provided the framework for the examination of the problems.

A review of the literature revealed no readily available categorization of Problem Types in linear kinematics involving the concepts of time, distance and velocity. However, three procedures were available.

The first of the three procedure available in the literature involved the categorization of problems according to the concept in question (i.e., distance, time, velocity). However, within each category there existed a large variation in the degree of difficulty, the result of which may have been to mask the information gained by the use of context/degree of familiarity.

The second procedure would have been to obtain an expert's (a physics instructor) interpretation of kinematic concepts, i.e., based on operational definitions and precise verbal and mathematical articulations. This would involve the use

of five basic equations. However, there could be a problem with this type of categorization since non-experts are likely to have a wide variety of somewhat vague and undifferentiated ideas about motion based on intuition, experience, and their perception of previous instruction (Trowbridge & McDermott, 1980, 1981; DiSessa, 1982; Green, McCloskey & Caramazza, 1985; McCloskey & Kohl, 1983; McCloskey, Caramazza & Green, 1980; White, 1983; McCloskey, 1983). The concern with this categorization system was that this wealth of information may be lost in the mechanics of the solution of equations.

The third alternative to developing 'Problem Types', was to use a Piagetian approach. This involved an extension of some of the Piagetian tasks on motion. Trowbridge and McDermott (1980, 1981) used Piagetian tasks on motion (Piaget, 1946, 1971) and supplemented these by information obtained from written examination questions. The four types were referred to by Piaget as "speed in synchronous movements," "speeds of movements in succession travelling unequal distances in unequal times," "conservation of uniform speeds," and "uniformly accelerated movement". Conservation of uniform speeds and uniformly accelerated movement were considered to be more advanced concepts involving acceleration. Therefore, two of these four tasks were used in the present study as a basis for the categorization of problems into "types" i.e., synchronous and successive movements. The intent was to establish

whether any effects seen in one Problem Type would be common across Problem Types rather than specific to a particular Problem Type. The Piagetian tasks of synchronous or simultaneous movement and sequential or successive movement, were broken down into their four subtasks as identified in Table 2.

More specifically, Piaget's simultaneous movement subtasks attempt to address four subtasks : Movement a, b, c and d. Movement a describes one object catching up to the other. For example, one car starts off from a point placed some distance behind the starting point of the second car, both move off simultaneously and reach the same stopping point together. Movement b is the same as the first movement but the first car does not quite reach the second car. Movement c describes 'overtaking'. It is the same as the first movement but the first car overtakes the second. Movement d describes one car moving towards another from the opposite direction and crossing over (each car sets off from a point facing the other).

The relative speed of movements occurring in succession, as described by Piaget, addresses the question of what happens when, instead of perceiving both movements at the same time, the individual can only see them one after the other. In other words, how skillful is the individual in comparing equal/unequal distances covered in equal/unequal

Table 2

Description of Simultaneous and Successive movement  
and their associated subtasks

Problem Type	Movement a	Movement b	Movement c	Movement d
Simultaneous Movement	one object catches up to the other	one object does not catch up to the other	overtaking	crossing- over
Successive Movement	movements in equal time and equal distance	movements in equal time and unequal distance	movements in unequal time and equal distance	movements in unequal time and unequal distance

times. Therefore, the 4 subtasks of successive movements are: movement (a) refers to movements that occur one after the other where both objects travel equal distances in equal times. Movement (b) refers to movements that occur one after the other where one travels farther than the other but in the same total time. Movement (c) is the opposite of Movement (b) in that they both travel the same distance but one is faster than the other. Finally, Movement (d) describes two movements occurring one after the other but neither travels the same distance nor do they cover it in the same amount of time.

Problems were written for each of these 8 movements (Problem Type x Movement: 2 x 4) in each of the 4 contexts (driving, activity or sport, blood flow, comets) for a total of 32 problems (or 8 movements with 4 isomorphs each). For the context of activity or sport, the problem was modified such that it was expressed in the terminology of the particular activity or sport identified by the subject.

Following the concept mapping the subjects were asked questions concerning their background studies in physics, mathematics, biomechanics or other related areas. The subjects were arbitrarily assigned to one of the two Problem Types, simultaneous movement or successive movement. These two groups were balanced for gender and educational background. The testing procedure for the third part of the study was the same for every subject. A standard set of instructions

(see Appendix F) were read aloud to the subject. The subjects were asked if they had any questions.

The problem solving task consisted of 8 isomorphic problems representing familiar and unfamiliar contexts, i.e., 2 in driving situations and 2 in the sport or activity of their choice, 2 isomorphs in a blood flow context and 2 isomorphs in a comets context (see Appendix G).

The order of presentation of the 8 problems, (2 from each context), was counterbalanced (see Appendix H). This required a minimum of 12 subjects for each Problem Type. An additional 12 subjects per Problem Type was also required to balance for a reversal in the order of presentation. The entire problem solving session was recorded on TDK AD60 tapes. The experimenter did not interfere except to remind the subject to keep talking.

#### Preparation of Data

Once all the concept map protocols and problem solving protocols were collected the tapes were transcribed verbatim. The concept map protocol in its transcribed form, the total time for each concept map protocol and the diagram that was made during the concept mapping were organised as a package. The verbal protocols of the 8 isomorphic problems were transcribed onto separate pages. Each protocol was then divided into 5 second intervals to facilitate the analysis. The total

time for problem solution was noted and the diagram (or blank page) accompanying each problem solution was assembled and given a new code. This was done so that there was no possibility of associating the results of the concept mapping category or rank with one the 456 problem solving protocols and thus bias the results in any way.

The four judges chosen to evaluate the 57 concept maps and protocols were from varied backgrounds. One judge had a Ph.D. in the area, the second a Ph.D. in History, the third a B.A. in Sociology and the fourth an M.Sc. in Kinanthropology. This selection of judges, although not required methodologically, provided a mix of different perspectives in terms of how the task would be viewed. The judges were given a 3 1/2 hour training session and were asked to meet as a group the following day. Each of the judges was asked to categorize, individually, the 57 maps and protocols into one of five categories. The categories are outlined in Table 3. This task took approximately 8 1/2 hours. Then, the judges reviewed their evaluations as a group and attempted to reach consensus on their categorizations (time 3 1/2 hours). The next day the judges ranked each of the 57 subjects. The judges worked independently for the first 3 hours, and then for the next 4 hours they discussed these rankings in order to reach a consensus position. In total four judges devoted 22 1/2 hours each to this phase of the study.

The guideline that was used to arbitrate disagreements

Table 3

## Category rating of subjects

Category	Description
1	In this category the subject does not understand the concepts involved.
2	In this category the subject shows very little understanding of the concepts.
3	In this category the subject shows some understanding but may (or may not) show evidence of misconceptions.
4	In this category the subject shows evidence of understanding the concepts in general, but may be a little vague on specifics.
5	In this category the subject shows definite evidence of understanding: uses more specifics.

in terms of the categorizations was that discussion would continue until an agreement of at least 3 of the 4 judges was reached. For the 57 concept map protocols and diagrams the consensus of the judges on the categorizations was 85.97%. For the ranking procedure the basis for agreement was when at least 3 of the 4 judges gave a subject the same ranking. If following discussion consensus was not reached, the subject was assigned the average rank and added to the nearest category.

The categorizations and rankings are contrasted in Table 4. With the exception of subject 42 the categories and rankings were in agreement. It should be noted that one subject (#11) was dropped because of a faulty tape. The categories and rankings were then summarized and compared to the subject's educational experience (see Table 5). No relationship between the category and mathematical or biomechanical (academic) background of the subjects could be found. However, when grouping subjects who had no physics and/or grade 12 physics only against subjects who had taken grade 13 and/or a 1st year university physics course, a pattern emerged. As can be seen in Table 5, only those subjects with more advanced courses in physics were categorized as level 4 and 5.

Of the eight subjects in categories 4 and 5, seven subjects had completed 1st year university physics, seven subjects had 1st year university mathematics, and seven had at least one biomechanics course. Category 3 subjects, with

Table 4

Correspondence between the categories and rankings according to the concept maps and verbal protocols of the maps.

* Categories	** Rankings
1	42, 45 - 57
2	20 - 41, 43, 44
3	9 - 19
4	4 - 8
5	1 - 3

\* Where category 1 represents those subjects with the least expertise and category 5 those with the most expertise in the area of linear kinematics

\*\* Where ranking 1 is the subject with the highest level of expertise and ranking 57 represents the subject with the least expertise

Table 5  
 Comparison of categories and educational experience  
 in physics of 57 subjects

Physics Background	Category of Expertise				
	1	2	3	4	5
	*				
Sim	3	4	1	0	0
No physics					
	**				
Suc	3	6	1	0	0
Sim	1	10	2	3	3
Physics					
Suc	6	4	7	2	0

\* Where Sim refers to Simultaneous Movement and  
 \*\* Suc refers to Successive Movement

the exception of 2 subjects (subjects 37 and 39) had completed 1st year university mathematics. Seven of the category 3 subjects had completed 1st year physics and 2 subjects had grade 13 physics: two of the subjects had not taken any biomechanics courses.

Subjects in category 1 and 2 fell into 2 groups. Sixteen of the subjects had no physics or grade 12 only educational experience in physics. However, 13 subjects in categories 1 and 2 had completed 1st year university physics and 8 subjects in category 1 and 2 had at least grade 13 physics. The categorization level of this latter group of 21 subjects did not correspond to their educational background.

There were no true experts and novices chosen to participate in this study since it was originally intended to study the intermediate range of expertise. However, in order to have well defined groups it was decided to divide the subjects into two groups: a lower level of expertise and a higher level of expertise and, therefore, collapse categories 1 and 2 to represent the group with a lower level expertise and collapse categories 3, 4, and 5 to represent the group with the higher level of expertise. The smallest cell size was 7 subjects (no physics, categories 1 and 2) for the simultaneous movement group. Seven lower level expertise subjects were chosen at random from those subjects in categories 1 and 2 who were in the successive movement

group. Similarly, 14 subjects (7 subjects per Problem Type) were chosen at random from those subjects in categories 3, 4 and 5 who had sufficient educational experience. Therefore, 28 subjects were identified for the final analysis. There were two Problem Types each with 14 subjects; that is 7 with a lower level of expertise (novice) and 7 with a higher level of expertise (experts). Since each subject solved 8 problems, there was a total of 224 problems on which to base the analysis.

#### **The Coding Grid**

Many authors have suggested that transcripts of verbal protocols of problem solving sessions must be handled with care lest the interpretation of data distort, neglect or even enhance some aspects of behaviour (Schoenfeld, 1985; Rowe, 1985; Ericsson & Simon, 1984). According to Newell and Simon (1972) and Rowe (1985) objective data analysis from "thinking aloud" protocols is possible if behaviour categories and processes are determined from the data, rather than imposed on the data.

Although grids for coding verbal protocols already exist (Schoenfeld, 1985; Rowe, 1985), there was a concern that an available framework might restrict the information which might be gained in the present study. The decision was made to base the classification of the problem solving behaviours manifested in the protocols obtained in the present study on

an adaptation of several authors (Schoenfeld, 1985; Rowe, 1985).

The models developed by Schoenfeld (1985) and Rowe (1985) provided the appropriate terminology for the solution model for this study. The Coding Grid was devised as a means of examining the ways individuals solve problems. According to Schoenfeld (1985) decisions at the control level are those that affect the allocation or utilization of a substantial amount of problem solving resources (including time). Schoenfeld partitioned protocols into macroscopic chunks of consistent behaviour called Episodes. An Episode is a period of time during which an individual is engaged in one large task, or a closely related body of tasks with some goal in mind.

According to Schoenfeld, after a small amount of training, partitioning protocols into Episodes is a rather straightforward process: reliability in parsing protocols is quite high. For the purposes of the present study the following Episodes were identified: Reading, Analysis, Planning, Implementation, and Verification/Monitoring. These Episodes were adapted for the present study.

The Reading Episode begins when a subject starts to read the problem statement aloud, and ends when the problem statement has been read in its entirety. In the Analysis Episode, the subject attempts to fully understand the problem, to select an appropriate problem representation and reformulate the problem in those terms. The problem may even

be simplified. For the purposes of this study, Analysis includes an exploration component in terms of the subjects' search for relevant information. Analysis also includes the recognition of previously unnoticed information during the search. During the Planning stage the subject introduces for consideration whatever principles or mechanisms might be appropriate for problem solution, that is, the subject outlines a strategy to be used in order to solve the problem. It should be noted that the absence of any overt planning does not necessarily indicate the absence of a plan. Implementation involves the actual mechanics (calculations) and/or interpretation of the data to give a final response. The final Episode, that of Monitoring/Verification, involves such activities as assessing or evaluating the process or final response; or an assessment of confidence in the results.

The Rowe (1985) classification system of problem solving strategies provided the model for some of the components which were associated with appropriate episodes. For example, the activity-filled pause and the component of self-directed activity were added to the Coding Grid as a result of Rowe's model. However, to a large extent, the Coding Grid was determined by the subjects' verbalizations. The observation of a particular behaviour led to the identification of a category in the grid. The final Coding Grid used for the present study can be found in Table 6.

Table 6 : Coding Grid

EPISODE	COMPONENT	SUB-COMPONENT	CODE	DEFINITION
Reading	Reads question	Reads entire question	RQE	The reading episode begins when the subject starts to read the problem statement aloud and reads through to the end right away.
		Reads the question in part	RQP	The reading episode begins when the subject starts to read the question but breaks off the reading to do another task and returns to read the next part of the question and so on.
Analysis	Problem representation	Explicit	EPR	A representation of the problem is clearly outlined as a drawing which reflects the problem itself. EPR1 - correct drawing, EPR2 - partly correct or partial drawing, EPR3 - incorrect drawing.
		Not explicit	<u>EPR</u>	There is evidence of problem representation but it is not explicitly stated.
		No evidence	NPR	There is no evidence of a problem representation.
		Highlights information	HI	This includes going back to the problem statement in order to reformulate the problem, or pick out relevant information.
		Questions experimenter	QE	Asks questions of experimenter in order to clarify some aspect of the problem statement or to seek information in order to understand the question.
	Search for relevant information	Experimenter comments	EXC	Experimenter comments/requests subject to speak louder or to explain further.
		Related activity filled pause	AFP	This includes pencil-tapping, and verbal statements (i.e., "let's see, I...er") if there is some indication that it is done during a period of reformulation or simplification of the problem.
		Recognition	RDI	Recognition or deduction of information (RDI), incorrect recognition or deduction of information (RDI2).
			RII	Recognition of irrelevant information.
			RE	Recognition of an error
Planning	Statement of assumptions	Analyses	AN	Analyzes what is happening in the problem statement as in a reenactment of the game situation.
		Insight	I	All of a sudden the subject perceives an apparent answer to part or whole question.
		SFP	A continuous pause of 5 seconds or more.	
		SA	States an assumption correctly (SA1), incorrectly (SA2), unrelated (SA3).	
		SI	Identifies a plan/strategy	Outlines a computational strategy, i.e., makes comparison of the data.

EPISODE	COMPONENT	SUB-COMPONENT	CODE	DEFINITION	
Implementation	Computation	Identifies a problem type	IPT	Outlines a conceptual strategy, i.e., recognizes in the problem a clearly outlined problem type such as $v=d/t$ .	
		Computes v	CV	Calculates velocity explicitly; calculates correctly (CVC), calculates incorrectly (CVI).	
	Interpretation/Justification	Interprets	INT	Interpretation congruent with calculations/comparisons (INT1), congruent with statement of assumptions (INT2), incongruent with calculations/comparisons (INT3), incongruent with statement of assumptions (INT4).	
		Interpret/re-evaluate	IRE	Attempts to interpret and proposes an incorrect answer which then triggers a re-evaluation.	
	Response	Answers	RES	Response congruent with calculations/comparisons (RES1), congruent with or supported by statement of assumptions (RES2), congruent with interpretation (RES3), incongruent with calculations/comparisons (RES4), incongruent with statement of assumption (RES5), incongruent with interpretation (RES6), blank statement (RES7).	
		Final response	FR	Final response correct (FR1), incorrect (FR2), correct but inappropriate solution path (FR3), no final response (FR4).	
	Monitoring/Verification	Evaluation	Encounters obstacle	EO	Encounters a piece of information and is unsure of how it fits into the framework of the problem.
			Expresses doubt	DBT	Doubt is expressed about the correctness of the solution path or of the final response.
		Re-evaluates	REE	The response is reviewed in part or whole and re-evaluated and found to be correct (REE1), or incorrect (REE2).	
		Self-directed activity	ACC	Expresses feeling of accomplishment about his/her performance.	
	Task difficulty	DIFF	Comments on difficulty of task or process.		
	Self-criticism	CRIT	Comments on personal ability to accomplish the task.		
	Unrelated comments	UC	Unrelated comments.		

The Coding Grid itself was developed as a 3 step process. In the first step two experts (true experts) provided suggestions regarding appropriate methods of solution for the various problems. In other words, they solved the problems in the most efficient manner in order to provide the coders with a 'referent solution path' (the proposed 'optimal' sequence of processing stages).

In step two, two judges were provided with the Coding Grid developed to date and compared it with the suggestions put forward in step one. The Grid was revised accordingly (Schoenfeld's Exploration Episode was combined with the Analysis Episode). For the final step, the judges reviewed the subjects' protocols while referring to the Coding Grid and produced the final Grid.

The two judges, working independently, were then asked to code the 224 protocols using the final Coding Grid. As the transcribed verbatim protocols had been divided into 5 second intervals, the judges calculated the time (in seconds) the subject had allocated to each sub-component. Subsequently the frequencies and total times for the Episodes and Components were noted.

Although reliability in parsing protocols is quite high (Schoenfeld, 1985), once the protocols were coded, the judges reviewed each protocol and discussed where their decisions differed and resolved any differences. The coded data was

used as a source of data for statistical analysis. As an illustration of the use of the Coding Grid as a coding system, sample protocols and their respective coding are given in Appendix J. The strokes (/) indicate 5 second breaks and 5 seconds between two successive strokes (//).

### Design

The independent variables were Level of Expertise (novice and expert) and Context (familiar and unfamiliar). The two Problem Types (Simultaneous and Successive movement) were used to see if the effects of Context would hold true across Problem Type. Each Problem Type was composed of four different movements. The nature of the movements which constituted each Problem Type differed (Simultaneous and Successive) and, as such, they could not be compared directly (see Table 2). Consequently, two individual analyses were performed. Within each Problem Type the 4 movements were collapsed across Context to produce a single dependent variable (solution time or solution pattern).

Therefore, four groups of subjects (n=7) were established: for each Problem Type (Simultaneous and Successive) there was a novice and an expert group. Each subject was presented with 8 problems, 4 of which were presented in a familiar context and their 4 isomorphs in an unfamiliar context. Thus, the 28 subjects attempted to solve a total of 224 problems.

## Chapter IV

### Presentation of Results

This chapter describes the results of the analysis of the problem solutions. The results are presented as they relate to the research hypothesis, which represents the experimental question, and the objective which refers to the exploratory component of this study.

#### Research Hypothesis

The hypothesis was stated as follows:

For isomorphic problems, the solution time is a function of the context of the problem and the level of expertise of the subject.

In this section an examination of the solution time data will be presented. In particular, there will be a focus on the time the subjects devoted to the components of this process (i.e., Episodes).

Since the tasks involved in Simultaneous and Successive movement problems are not directly comparable it was decided to analyse the two Problem Types separately. Data for each Problem Type were analyzed separately using a Group x Context

analysis of variance with repeated measures on the last factor. The dependent variable was solution time and the independent variables were level of expertise and context.

The Cochran test applied to the solution time data, for both Simultaneous and Successive movement led to the conclusion that the variances were homogeneous at the 0.05 level of significance. Based on the Lillifors test (Marascuilo & McSweeney, 1977, p. 249-250) the normality of solution time data is not violated.

The results of the analyses are presented in Tables 7 and 8. The  $p < 0.05$  level of significance was adopted throughout in order to facilitate comparisons with previous literature. For both Simultaneous and Successive movements there were no significant differences between the two levels of expertise ( $(F(1,12)=0.03, p < .8653)$  and  $(F(1,12)=0.23, p < .6375)$  respectively). A significant Context effect was found for the Simultaneous movement ( $F(1,12)=5.70, p < .0343$ ), however, for the Successive movement no such significant effect was observed ( $F(1,12)=1.71, p < .2153$ ). When the responses of the two groups were examined separately it was observed (from the means and standard deviations of Tables 7 and 8), that for Successive movement, the solution times of the more expert group evidenced a smaller increase from familiar to unfamiliar isomorphic problems. However, it was not enough to produce a significant

Table 7

Descriptive statistics and analysis of variance for solution time (sec) on Simultaneous movement

Level of Expertise	Context	
	Familiar	Unfamiliar
Novice		
Mean	122.86	165.86
SD	55.69	120.79
Expert		
Mean	128.57	173.86
SD	51.50	79.69

Summary of Anova

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	<b>13</b>				
Expertise(G)	1	329.14	329.14	0.03	0.8653
Error-between	12	131444.60	10953.72		
<b>Within Ss</b>	<b>14</b>				
Context(C)	1	13640.14	13640.14	5.70	0.0343*
C x G	1	9.14	9.14	0.00	0.9517
Error-within	12	28729.72	2394.14		
<b>Total</b>	<b>27</b>	<b>174152.80</b>			

\* significant at the .05 level

Table 8

Descriptive statistics and analysis of variance for solution time (sec) on Successive movement

Level of Expertise	Context	
	Familiar	Unfamiliar
Novice		
Mean	96.42	122.42
SD	29.65	27.73
Expert		
Mean	98.85	106.00
SD	16.28	57.18

Summary of ANOVA

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	<b>13</b>				
Expertise(G)	1	343.09	343.09	0.23	0.6375
Error-between	12	17617.76	1468.15		
<b>Within Ss</b>	<b>14</b>				
Context(C)	1	1922.29	1922.29	1.71	0.2153
C x G	1	622.28	622.28	.55	0.4710
Error-within	12	13478.43	1123.20		
<b>Total</b>	<b>27</b>	<b>33983.86</b>			

interaction. The non-significant Context effect for Successive movement could be attributed to the type of problem which was observed to be easier.

Having analysed the overall impact of Context, the next step is to consider a refinement into Episodes. As was previously discussed the coding of the think-aloud protocols was accomplished according to a grid adapted for the study. Each protocol was divided into Episodes: reading, analysis, planning, implementation and monitoring/verification according to the Coding Grid. The time spent on these Episodes was analysed using a Group x Context x Episode analysis of variance with repeated measures on the last two variables for Simultaneous movement, and again for Successive movement.

The analysis for the Simultaneous movement showed no significant difference in solution time for the two levels of expertise ( $F(1,12)=0.08, p<.7859$ ). However, there was a significant difference (see Table 9) between Contexts ( $F(1,12)=6.19, p<.0286$ ), and between Episodes ( $F(4,48)=17.70, p<.0000$ ). Solution times were longer for unfamiliar problems, and the two Episodes that accounted for the largest amount of time were Analysis and Implementation (see Table 10 and Figure 2). The Tukey post hoc revealed significant differences at the .05 level between Reading and Analysis, Analysis and Planning, Planning and Implementation, Analysis and Monitoring/Verification, and between

Table 9

Expertise x Context x Episodes analysis of variance on solution time (sec) for Simultaneous movement with repeated measures on the last two factors

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	13				
Expertise(G)	1	188.04	188.94	0.08	0.7859
Error-between	12	29230.99	2435.92		
<b>Within Ss</b>	14				
Context(C)	1	3295.58	3295.58	6.19	0.0286*
C x G	1	45.43	45.43	0.09	0.7752
Error-within	12	6390.80	532.57		
Episodes(E)	4	42578.59	10644.65	17.70	0.0000**
E x G	4	2577.13	644.28	1.07	0.3812
Error-within	48	28871.54	601.49		
C x E	4	2818.39	704.60	3.24	0.0196*
C x E x G	4	584.26	146.06	0.67	0.6143
Error-within	48	10424.52	217.18		

\*\* significant at the .01 level

\* significant at the .05 level

Table 10

Means and standard deviations of time spent (sec) on Episodes with Simultaneous movement

Degree of Familiarity	Episodes	Novice	Expert	Total
Familiar	Reading	22.14* 4.62**	23.35 4.11	22.75
	Analysis	49.29 35.16	39.82 20.20	44.55
	Planning	8.93 5.07	16.11 11.78	12.52
	Implementation	33.29 21.43	40.00 23.04	36.64
	Monitoring/ Verification	9.25 5.26	9.50 9.20	9.38
Unfamiliar	Reading	25.18 4.28	23.89 3.45	24.54
	Analysis	79.86 69.22	62.29 31.88	71.07
	Planning	9.96 7.49	21.25 18.04	15.61
	Implementation	43.43 38.65	51.64 24.66	47.54
	Monitoring/ Verification	7.29 10.70	23.93 33.18	15.61

\* Mean

\*\* Standard Deviation

FIGURE 2  
MEANS OF TIME SPENT ON EPISODES  
FOR SIMULTANEOUS MOVEMENT

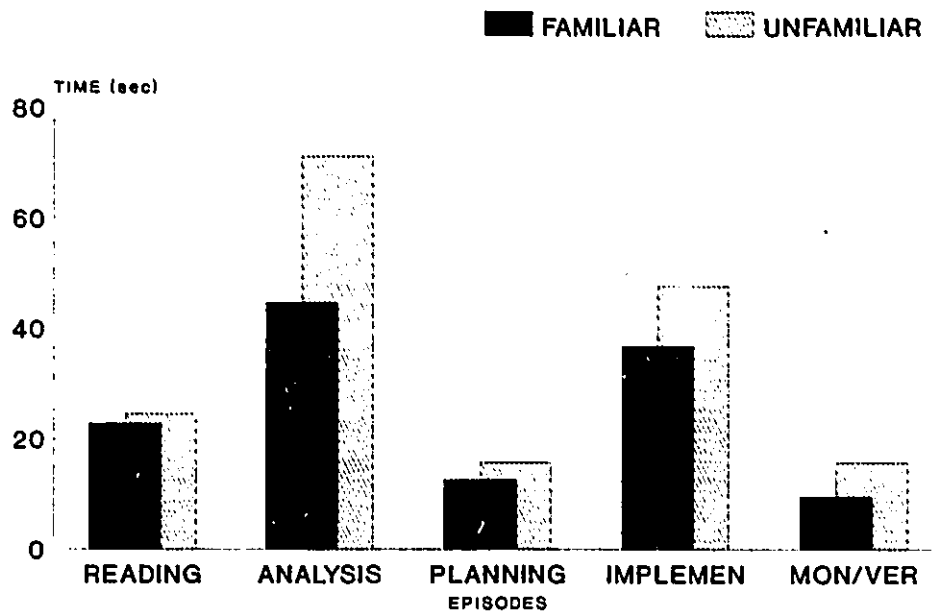


Table 11

Mean differences for solution time (sec) between Episodes  
for Simultaneous movement

Episodes	Means	A	I	R	P
Analysis (A)	(57.81)	--			
Implemen- tation (I)	(42.09)	15.72	--		
Reading (R)	(23.64)	34.17*	18.44	--	
Planning (P)	(14.06)	43.75*	28.03*	9.58	--
Monitoring/ Verification (M/V)	(12.49)	45.32*	29.60*	11.15	1.57

\* significant at the .05 level using Tukey's criterion.

Implementation and Monitoring/Verification (see Table 11).

A Context x Episodes interaction was also found to be significant at the .05 level ( $F(4,48)=3.24, p<.0196$ ). The Simple Main Effects performed on the Context x Episode interaction showed that the only significant difference between the familiar and unfamiliar contexts was for the Analysis episode ( $F(1,12)=6.04, p<.0301$ ) (see Appendix I). This may have resulted from the disproportionate amount of time (mean = 79.9 sec and SD = 69.2 sec) given by some novices to the Analysis Episode in the unfamiliar context. Although there was no significant difference between expert and novice, Table 10 shows that while the experts spent more time than the novices on most components, they did spend less time on Analysis in both the familiar and unfamiliar contexts. It is interesting to note that it is during the Analysis Episode the subjects were attempting to understand the problem and build their problem representation.

For Successive movement the pattern was generally similar. There was no significant difference in solution time between levels of expertise ( $F(1,12)=0.63, p<.4432$ ) or between Contexts ( $F(1,12)=1.07, p<.3222$ ) (see Table 12). As for Simultaneous movement there was a significant difference between Episodes ( $F(4,48)=30.81, p<.0000$ ). In terms of time spent on individual Episodes, the results of the Tukey test, shown in Table 13, underlined that the major difference was between the Analysis

Table 12

Expertise x Context x Episodes analysis of variance on solution time (sec) for Successive movement with repeated measures on the last two factors

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	13				
Expertise(G)	1	162.86	162.86	0.63	0.4432
Error-between	12	3107.86	258.99		
<b>Within Ss</b>	12				
Context(C)	1	202.80	202.80	1.07	0.3222
C x G	1	52.22	52.22	0.27	0.6099
Error-within	12	2283.01	190.25		
Episodes(E)	4	30076.23	7519.06	30.81	0.0000**
E x G	4	243.31	60.83	0.25	0.9087
Error-within	48	11715.09	244.06		
C x E	4	2493.89	623.47	6.08	0.0005**
C x E x G	4	680.51	170.13	1.66	0.1748
Error-within	48	4920.08	102.50		

\*\* significant at the .01 level

Table 13

Mean differences for solution time (sec) between Episodes  
for Successive movement

Episodes	Means	A	R	I	P
Analysis (A)	(47.49)	--			
Reading (R)	(23.70)	23.79*	--		
Implemen- tation (I)	(21.78)	25.71*	1.92	--	
Planning (P)	( 8.56)	38.94*	15.15	13.23	--
Monitoring/ Verification (M/V)	( 6.45)	41.05*	17.26	15.34	2.11

\* significant at the .05 level using Tukey's criterion.

Episode and the other four Episodes.

A Simple Main Effects was performed to analyse the significant Context x Episode interaction ( $F(4,48)=6.08, p<.0005$ ) (see Appendix I). As Table 14 and Figure 3 support, the only significant difference between familiar and unfamiliar contexts was for the Analysis Episode ( $F(1,12)=6.37, p<.0267$ ) (see Appendix I). As for Simultaneous movement, this may have been due to the disproportionate amount of time spent by some novices on the Analysis Episode in the unfamiliar context.

In terms of the hypothesis, while Context was observed to be a contributing factor, the level of expertise (as defined in this study) did not influence solution time.

In order to provide a frame of reference with regard to the previous analysis of the Episodes it was felt that an assessment of the time given to the various subcomponents of the Episodes might help locate some of the previously noticed effects. In regard to the breakdown of the solution process (Coding Grid), nine components were identified as part of the individual Episodes. The data for Simultaneous movement was, therefore, submitted to a Group x Context x Component analysis of variance with repeated measures on the last 2 factors (see Table 15). The analysis revealed no significant Group difference ( $F(1,12)=0.77, p<.40$ ) or Context effect ( $F(1,12)=4.35, p<.059$ ): the experts and novices performed

Table 14

Means and standard deviations of time (sec) spent on Episodes with Successive movement

Degree of Familiarity	Episodes	Novice	Expert	Total
Familiar	Reading	29.43* 17.79**	23.96 7.15	26.70
	Analysis	36.07 15.20	40.50 13.97	38.29
	Planning	10.29 10.15	9.50 5.68	9.89
	Implementation	24.54 16.24	17.25 6.91	20.89
	Monitoring/ Verification	4.00 3.53	8.43 9.06	6.21
Unfamiliar	Reading	19.57 4.79	21.86 4.38	20.71
	Analysis	63.43 20.32	49.96 36.34	56.70
	Planning	7.93 3.98	6.54 3.02	7.23
	Implementation	24.54 13.06	20.82 11.00	22.68
	Monitoring/ Verification	7.00 6.24	6.39 14.31	6.69

\* Mean

\*\* Standard Deviation

FIGURE 3  
MEANS OF TIME SPENT ON EPISODES  
FOR SUCCESSIVE MOVEMENT

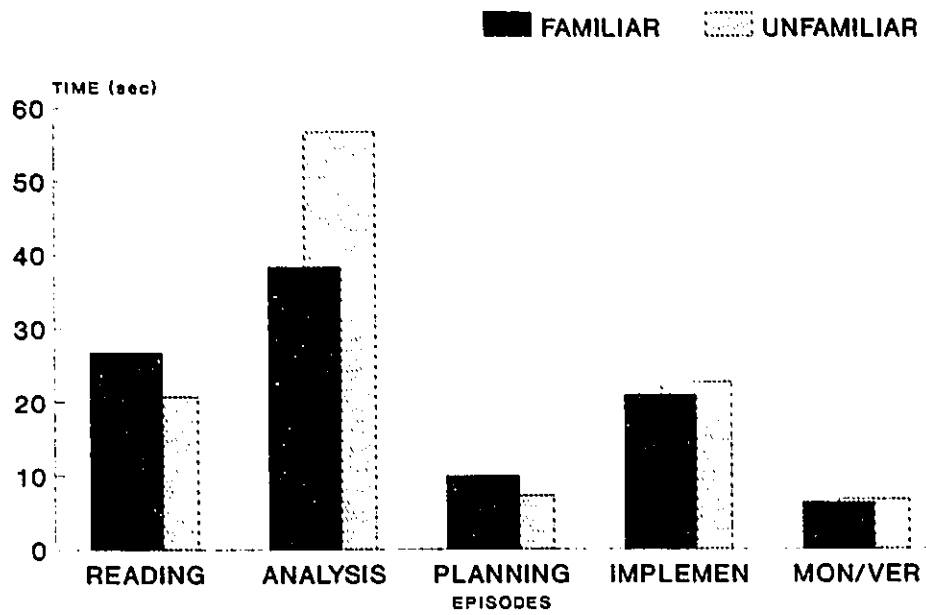


Table 15

Expertise x Context x Components analysis of variance on solution time (sec) for Simultaneous movement with repeated measures on the last two factors

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	13				
Expertise(G)	1	494.20	494.20	0.77	0.3970
Error-between	12	7687.56	640.63		
<b>Within Ss</b>	14				
Context(C)	1	472.05	472.05	4.35	0.0590
C x G	1	318.71	318.71	2.94	0.1122
Error-within	12	1301.50	108.46		
Component(P)	8	20570.17	2571.27	20.98	0.0000**
P x G	8	1962.12	245.27	2.00	0.0543
Error-within	96	11764.74	122.55		
C x P	8	932.73	116.59	2.12	0.0415*
C x P x G	8	554.25	69.28	1.26	0.2751
Error-within	96	5290.48	55.11		

\*\* significant at the .01 level

\* significant at the .05 level

similarly in both familiar and unfamiliar contexts. There was, however, a Component effect ( $F(8,96)=20.98, p<.01$ ) and a Context x Component interaction ( $F(8,96)=2.12, p<.05$ ): Table 16 presents means and standard deviations. A Tukey test showed that Reading and Search for Relevant Information were the two main contributors to the Components effect. Search for Relevant Information being significantly different ( $p<.05$ ) from all other Components (see Appendix K).

Simple Main Effects for the Context x Component interaction showed significant differences between Familiar and Unfamiliar Contexts only for Problem Representation ( $F(1,12)=10.64, p<.01$ ) and Response ( $F(1,12)=8.55, p<.05$ ) (see Appendix L).

Results for Successive movement were very similar. A Group x Context x Component analysis of Variance with repeated measures on the last two factors was performed (Table 17). Although there were no significant Group ( $F(1,12)=0.23, p<.65$ ) or Context differences ( $F(1,12)=1.77, p<.21$ ), there were significant differences for Components ( $F(8,96)=20.25, p<.01$ ) and a significant interaction between Context and Component ( $F(8,96)=3.12, p<.01$ ). Again the major Components, in terms of occupying the largest amount of time, were Reading and Search for Relevant Information (see Table 18 for Means and S.D. and Appendix K for Tukey test). The Context x Component interaction arose mainly from the difference between contexts evidenced by the Search for Relevant Information Component.

Table 16

Means and standard deviations for time (sec) spent on Components with Simultaneous movement

	FAMILIAR			UNFAMILIAR		
	Novice	Expert	Total	Novice	Expert	Total
Reading	22.14* 4.60**	23.36 4.11	22.75	25.18 4.28	23.89 3.45	24.54
Problem Representation	12.68 12.12	10.79 12.60	11.73	24.57 18.57	22.71 16.39	23.64
Search for Relevant Info	36.61 25.73	29.04 12.62	32.82	32.75 12.28	39.57 19.85	36.16
Statement of Assumption	8.93 5.07	15.79 11.17	12.36	8.07 4.38	21.25 18.04	14.66
Computation	12.86 7.39	21.50 29.14	17.18	7.39 9.43	29.14 20.67	18.27
Interpretation/Justification	10.68 4.32	6.71 2.69	8.70	8.07 3.70	7.82 3.48	7.94
Response	10.32 5.29	11.79 6.78	11.05	17.57 7.00	15.36 6.80	16.46
Evaluation	6.11 2.60	6.86 6.22	6.48	2.39 2.73	6.11 7.68	4.25
Self-directed Activity	3.18 3.76	2.64 3.82	2.91	1.89 2.05	7.49 12.78	4.69

\* Mean

\*\* Standard Deviation

Table 17

Expertise x Context x Components analysis of variance on solution time (sec) for Successive movement with repeated measures on the last two factors

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	<b>13</b>				
Expertise(G)	1	36.76	36.76	0.23	0.6421
Error-between	12	1940.71	161.73		
<b>Within Ss</b>	<b>14</b>				
Context(C)	1	218.68	218.68	1.77	0.2083
C x G	1	70.99	70.99	0.57	0.4633
Error-within	12	1484.02	123.67		
Component(P)	8	21026.25	2628.28	20.25	0.0000**
P x G	8	600.52	75.06	0.58	0.7933
Error-within	96	12457.82	129.77		
C x P	8	1502.46	187.81	3.12	0.0035**
C x P x G	8	428.71	53.59	0.89	0.5276
Error-within	96	5777.11	60.18		

\*\* significant at the .01 level

Table 18

Means and standard deviations for time (sec) spent on Components with Successive movement

	FAMILIAR			UNFAMILIAR		
	Novice	Expert	Total	Novice	Expert	Total
Reading	22.89* 7.35**	23.96 7.15	23.43	19.57 4.79	21.86 4.38	20.71
Problem Representation	7.71 8.01	17.71 12.83	12.71	20.18 14.16	16.82 17.19	18.50
Search for Relevant Info	26.64 15.16	22.79 12.89	24.71	43.25 8.27	33.14 35.08	38.20
Statement of Assumption	10.29 10.15	9.50 5.68	9.89	7.93 3.98	6.54 3.02	7.23
Computation	4.36 11.53	5.75 7.69	5.05	2.54 6.71	3.96 5.86	3.25
Interpretation/Justification	7.25 4.66	5.61 2.27	6.43	9.82 5.03	5.57 1.94	7.70
Response	12.93 9.55	5.89 2.35	9.41	12.18 10.07	11.64 9.36	11.91
Evaluation	.86 2.05	4.43 5.56	2.64	1.86 1.23	1.29 2.31	1.57
Self-directed Activity	3.21 3.07	3.18 4.91	3.20	5.14 6.59	5.21 12.27	5.18

\* Mean  
\*\* Standard Deviation

### Exploratory Objective

This section represents the exploratory part of the study and focuses on those elements of the problem solution patterns represented by the Coding Grid developed to analyse the verbal protocols, that is, reading, problem representation, search for relevant information, statement of assumptions, computation, interpretation/justification, response and evaluation. The exploratory component of the research was proposed in the following objective:

For isomorphic problems, problem solution patterns displayed by subjects vary with problem context and level of expertise of the subject.

Descriptive data, in terms of the frequency of use of Components, was the focus. The following section includes those Components which afforded further qualitative analysis. The first step in any problem solving task is reading the problem statement. From the verbatim protocols (see Appendix J for examples) it is observed that the subjects can perform this task in two ways: they can read the complete problem statement at the beginning of the task or they can read the problem statement in sections at different times during the solution. When examining frequency data (see Table 19) novices and experts tended to read the question entirely more often than partial readings in both Simultaneous and Successive situations. Using Chi-square, comparisons were

Table 19

## Frequency on Sub-components of Reading

Problem Type	Level of Expertise	Sub-component	Context	
			Familiar	Unfamiliar
Simultaneous Movement	Novice	RQP	9	11
		RQE	19	17
	Expert	RQP	12	11
		RQE	16	17
Successive Movement	Novice	RQP	6	5
		RQE	22	23
	Expert	RQP	12	10
		RQE	16	18

where RQP means reads question partially  
RQE means reads question entirely

made of novices and experts for reading the question entirely or in part for both Simultaneous and Successive movement. Only for Successive movement was the pattern significant ( $\text{Chi-square}=5.2$ ,  $\text{df}=1$ ,  $p<.05$ ). A larger proportion of novices tended to read the question entirely before proceeding, whereas experts more frequently interspersed their reading of the problem by e.g., highlighting the information. For both movement types there was a higher frequency of reading the question entirely regardless of level of expertise.

According to the literature, novices do not have as accurate Problem Representations as experts. A summary of how the subjects used this component of the problem solving process for both types of movement is outlined in Table 20. There were 112 problems solved for the Simultaneous movement Problem Type. Seventy of those were accompanied by correct drawings (an appropriate representation of the problem), partially correct (represents some but not all key elements of the problem) or partial drawings (is an incomplete representation). Therefore 62.5% of the time, the subjects were using Problem Representations explicitly in support of their solutions. There was evidence of Problem Representation, although not explicitly stated, 35.7% of the time, and for only 1.8% of the problems, there was no evidence of Problem Representation. Similarly, for Successive movements 60 of the 112 problems were accompanied by Problem Representations

Table 20

Frequency of Problem Representation components

		Explicit and Correct	Explicit and Partly Correct	Explicit and Incorrect	Not Explicit	No Evidence
Novice	F	15	1	0	12	0
	U	11	8	0	7	2
Expert	F	11	4	0	13	0
	U	15	5	0	8	0
Total		52	18	0	40	2
Novice	F	8	3	0	17	0
	U	12	7	0	9	0
Expert	F	17	0	0	11	0
	U	11	2	0	15	0
Total		48	12	0	52	0

(53.6%), either correct or partially correct. For 37.5% of the Successive movement problems there was evidence of Problem Representation, although not explicitly stated, and 8.9% of the time there was no evidence of Problem Representation whatsoever. An interesting point is that there was not a single instance where there was an incorrect explicit Problem Representation in both the Simultaneous and Successive movements. In other words, when the representation was explicit it was also correct or partially correct. This was true for both Simultaneous and Successive movements.

Recognition of relevant information involves recognition or deduction of information as well as insight; it is also a characteristic of expert problem solvers. Table 21 outlines the frequency of recognition of the key information by each group. Overall, experts were able to recognize information twice as often as the novices (frequency = 60 vs 30) suggesting a better indexed knowledge base on the part of the experts. Neither the Chi-square for Simultaneous (Chi-square=0.55, df=1,  $p>.05$ ) nor for Successive (Chi-square=0.07, df=1,  $p>.05$ ) movement were significant.

Another factor that discriminates between levels of expertise is the type of strategy used for solving problems. For Simultaneous movement, novices tended to rely more upon computational strategies, (e.g., making comparisons of the data) whereas the experts outlined conceptual strategies

Table 21

Frequency of Recognition of key information

Problem Type	Level of Expertise	Context	
		Familiar	Unfamiliar
Simultaneous Movement	Novice	9	9
	Expert	15	23
Successive Movement	Novice	7	5
	Expert	10	12

(e.g., recognized in the problem a clearly outlined problem type such as  $v=d/t$ ). A Chi-Square test, relating the level of expertise and the type of strategy used (for both contexts), revealed a significant relationship between expertise and strategy at the .01 level for Simultaneous movement (Chi-square=35.0,  $df=1$ ,  $p<.01$ ). For the 56 Simultaneous movement problems solved by the experts, they used a conceptual strategy 62.5% of the time as contrasted with 8.9% for the novices. However, for the Successive movement, the easier of the two Problem Types, both groups relied more on the computational strategy (see Table 22). Of the 56 problems solved in Successive movement by each group the novices used the computational strategy 87.5% of the time and the experts 83.9% of the time. The Chi-square for Successive movement, relating level of expertise to type of strategy, was not significant (Chi-square = 0.29,  $df=1$ ,  $p>.05$ ). It appears that both groups rely primarily on a computational strategy where they make comparisons of the data.

Several types of Response statements were identified in the problems, but the major division was between those responses which were congruent or incongruent with the solution path. In some cases no response statements were made (see Table 23). In both Simultaneous and Successive movement the pattern was similar. The expert and the novice groups tended to give Responses congruent to the solution path that they had followed, regardless of the context of

Table 22

Frequency of conceptual and computational strategies used by novices and experts during problem solution

Problem Type	Level of Expertise	Type of Strategy	Context	
			Familiar	Unfamiliar
Simultaneous Movement	Novice	Computational	26	25
		Conceptual	2	3
	Expert	Computational	10	11
		Conceptual	18	17
Successive Movement	Novice	Computational	24	25
		Conceptual	4	3
	Expert	Computational	22	25
		Conceptual	6	3

Table 23

Frequency of types of Response components

Problem Type	Level of Expertise	Response Type	Context	
			Familiar	Unfamiliar
Simultaneous Movement	Novice	Congruent	22	25
		Incongruent	8	6
		Blank	7	5
	Expert	Congruent	27	36
		Incongruent	4	2
		Blank	2	1
Successive Movement	Novice	Congruent	27	28
		Incongruent	1	4
		Blank	5	6
	Expert	Congruent	33	29
		Incongruent	2	2
		Blank	2	4

the problem or whether the final solution was correct. Clearly, final responses were not given until subjects had achieved a reasonable degree of certainty. However, the experts did tend to make fewer incongruent Responses and/or blank statements, most particularly for Simultaneous movement (26 to 9 for Simultaneous and 16 to 10 for Successive).

In terms of Evaluating their performance (Encounters Obstacles, Expresses Doubt, and Re-evaluates) experts were found to Evaluate their performance more often than did the novices (see Table 24). Using a Chi-square test there was no significant relationship found between Expertise and Context for Simultaneous movement (Chi-square=.007, df=1,  $p>.05$ ), however, there was a significant association for Successive movement (Chi-square=7.883, df=1,  $p<.01$ ). This effect resulted primarily from the high frequency with which experts evaluated their performance in familiar contexts, whereas novices evidenced a low frequency of evaluation in either context.

The final category that was added to the Coding Grid included Self-directed activity: frequencies are seen in Table 25. Self-directed activities included expressions of accomplishment, comments on the difficulty of the task at hand, comments on personal ability to accomplish the task, and unrelated comments. A Chi-square showed a relationship

Table 24

Frequency of Evaluation of performance components

Problem Type	Level of Expertise	Context	
		Familiar	Unfamiliar
Simultaneous Movement	Novice	17	17
	Expert	25	26
Successive Movement	Novice	3	9
	Expert	16	5

Note: Evaluation combines the sub-components of Encounters Obstacles, Expresses Doubt, and Re-evaluates.

Table 25

Frequency of use of Self-Directed Activity component

Problem Type	Level of Expertise	Context	
		Familiar	Unfamiliar
Simultaneous Movement	Novice	19	14
	Expert	10	30
Successive Movement	Novice	19	28
	Expert	20	23

between Expertise and Context for Simultaneous movement (Chi-square=8.013, df=1,  $p<.01$ ) but not for Successive movement (Chi-square=.338, df=1,  $p>.05$ ). From Table 25 one observes that experts show a higher frequency of self-directed activity for unfamiliar problems. This may be due to the fact that Simultaneous movement was apparently the more difficult of the two Problem Types (although not significantly so), bringing forth more comments from the experts who recognised/acknowledged the increased complexity of the unfamiliar context.

Having considered the various sub-components the next step in the process is to examine questions relating to the precision of the final response and the consistency across context, the tendency to work forwards or backwards in the problem solution, and the overall problem solution pattern at the component level.

An assessment of the precision with which the two groups performed can be gained by examining the number of errors in terms of the accuracy of the Final Response: where errors were represented as Final Responses which were not correct (see Table 26). For the purposes of this study errors included instances of a) incorrect solutions, b) no final response, or c) correct responses which arose from an inappropriate solution path (e.g., a guess). The group with less expertise (novice) had 3 times as many incorrect Final

Table 26

## Correct Final Responses and Errors

Problem Type	Response	Novice		Expert	
		F	U	F	U
Simultaneous Movements	Correct	20	17	25	23
	Incorrect	5	9	3	3
	CorIPath*	3	2	0	2
	No Final Response	0	0	0	0
Successive Movements	Correct	21	21	25	28
	Incorrect	5	2	2	0
	CorIPath	1	3	0	0
	No Final Response	1	2	1	0

where CorIPath means correct but with inappropriate solution path

Responses. Across both Problem Types (112 problems) the novices made 29.5% errors, whereas the more expert subjects made 9.8% incorrect Final Responses. As the final solution times for the two levels were equivalent, this effect was not simply a function of the novices working faster and making more errors.

In the review of current literature several expert-novice differences have been noted, one in particular was the fact that experts tend to solve problems working forward while novices tend to work backward. The Episodes listed in the Coding Grid are placed in sequential or natural order of occurrence (to represent a natural progression from reading to final solution) based on the models from which they were derived. To examine the question of working forward (where subjects follow the sequential order of occurrence) or backward (where subjects follow the reverse of the sequential order of occurrence) in terms of the 5 Episodes, the average frequencies of forward or backward movement were calculated. The mean and standard deviation for each group, based on the frequency of movement between Episodes either forward or backward, are outlined in Table 27.

While the results are quite similar for the two groups, experts did tend to work forward slightly more frequently for Simultaneous for both familiar and unfamiliar contexts.

Table 27

Average frequency of forward and backward movements between Episodes

Problem Type	Level of Expertise	Type of Movement	Context	
			Familiar	Unfamiliar
Simultaneous Movement	Novice	forward	31.50* 5.91**	30.00 2.44
		backward	17.75 5.56	16.00 3.74
	Expert	forward	34.75 10.04	35.75 7.27
		backward	21.25 8.34	22.25 4.57
Successive Movement	Novice	forward	23.25 1.89	24.00 3.91
		backward	9.25 2.06	10.75 3.09
	Expert	forward	27.75 4.27	21.50 3.41
		backward	11.50 3.51	8.75 2.75

\* means

\*\* standard deviations

Overall, for both Problem Types and regardless of context, all subjects worked forward to problem solution more frequently than working backwards.

In addition to the time spent on any particular operation or the frequency with which a particular operation is used, it is also important to evaluate the overall flow of the problem solution and attempt to identify any common patterns occurring during solution. Thus the problem solution patterns are compared in terms of the level of expertise, context, and the correctness of the final solution in order to identify the predominant patterns. As self-directed activities represent random comments rather than movements towards the final solution, this component was not included in the analysis of solution patterns.

In Table 28 it can be seen that the novices evidenced a high frequency of repetition, relative to the experts, between sub-components of the Search for Relevant Information. A second element was that, while novices tended to move to or from the Response component from the Search for Relevant Information component, experts tended to move between Response and Interpretation/Justification. In other words, prior to or immediately after giving a response the experts generally provided some interpretation of that response. The other clear difference between novices and experts appeared to be in the extent to which experts

Table 28

Frequency of solution patterns for levels of expertise

Pattern	Simultaneous Movement		Successive Movement	
	Novice	Expert	Novice	Expert
Repeated Search	142	97	105	73
Extended Search				
Search-Response or Response-Search	73	48	76	39
Reads-Assumption or Assumption-Reads	14	31	5	16
Interpret/Just-Response or Response-Interpret/Just	33	44	36	46

Repeated and Extended Search refer to situations where subjects move between sub-components of the Search for Relevant Information component. Repeated Search refers to a single repetition while Extended Search refers to a series of 5 changes within the Search for Relevant Information component.

derived assumptions from their reading of the problem.

In evaluating the effect of Context, it was observed that the most predominant pattern was the movement between the various elements within the Search component (see Table 29). The only other two patterns which showed any influence of Context were the movement between problem representation and Search for Relevant Information and between Interpretation/Justification and Response. In either case there was a greater frequency of movements between these pairs of components in the unfamiliar context. The other feature which was of note arose when the context effects were evaluated in relation to the level of expertise. At this point it became clear that the high frequency of movement between elements within the Search component was primarily a consequence of the performance of the novice subjects in the unfamiliar context. However, even for the unfamiliar context the experts tended to show a greater flow between components in their solution patterns. In addition it was observed that when starting from any component, the component most frequently moved to was for the novice (in all cases) the Search component. This was also true, in general, for the expert subjects, however, for at least three components this was not the case. The exceptions were movement from Assumptions to Computation, Interpretation/Justification to Response, and Response to Interpretation/Justification. Although few clear patterns

Table 29

Frequency of solution patterns as affected by Context

Pattern	Simultaneous Movement		Successive Movement	
	Fam	Unfam	Fam	Unfam
Extended Search				
Problem Rep-Search or Search-Problem Rep	39	60	28	63
Interpret/Just-Response or Response-Interpret/Just	28	49	34	48
Repeated Search (expert)	42	55	31	41
Repeated Search (novice)	48	94	38	67

Repeated and Extended Search refer to situations where subjects move between sub-components of the Search for Relevant Information component. Repeated Search refers to a single repetition while Extended Search refers to a series of 5 changes within the Search for Relevant Information component.

emerged, the experts tended to show more movement between components whereas novices demonstrated a high frequency of movement within components.

In order to consider the solution patterns in terms of the correctness of the final solution the previous analyses were repeated with the incorrect responses separated from the correct responses. From this procedure it became clear that as the error rate was so low (see Table 26), there was no clear impact on the solution patterns. In the correct data only those differences previously identified were evidenced (e.g., Tables 28 and 29). When limited to correct responses, the one new pattern to emerge was an expert-novice difference in terms of the movement between Reading and Search for Relevant Information. This pattern was observed to occur almost twice as frequently in the expert subjects (frequency: expert=95, novice=55). In the incorrect data no clear patterns emerged other than those which would be a shadow of those effects already noted.

With regard to the solution times for Simultaneous and Successive movements (combined), the correlation coefficient between the two levels of context (familiar and unfamiliar) for the novices was  $-.03$ . This would suggest that the novices' performance in familiar contexts was not related to their performance in the unfamiliar contexts. However, the correlation coefficient between the two levels of context

(familiar and unfamiliar) for the experts was .78. This suggests that the expert groups' performance was more consistent, that is, if they performed well on the familiar context they also tended to perform well on the unfamiliar task. Given the numbers involved, however, this result should be treated with caution.

Therefore, while the significant differences in solution times reflected primarily the effect of Context, differences between novices and experts were evidenced from an exploration of the process by which these solutions were obtained.

## Chapter V

### Discussion

The review of literature has underlined many of the known differences between expert and novice performance. Although the terms novice and expert refer to poles of the expertise continuum, the terms are also used here to differentiate two intermediates groups in level of expertise, with one being more expert than the other. In this chapter the author examines the results of this study in light of the experts' and novices' performance.

Across the 57 subjects the concept maps showed a range of expertise. In order to have a balanced design it was decided to use 28 subjects. Of these there were 7 subjects in the higher range (i.e., judged to have a greater amount and better structured knowledge as determined by the concept maps) and 7 subjects in the lower range. However, even though the concept maps showed marked differences in how their knowledge was structured, no significant group effects were found for final solution times. The judges were quite consistent in assigning subjects to categories. In terms of the main hypothesis of this study, although clear differences

in Knowledge Base were noted, the groups formed by the above process were not sufficiently distinct to produce significant differences in performance. Therefore, perhaps the association reported in the literature between Knowledge Base and performance is only appropriate when comparing true experts and novices. When working at the intermediate level, as defined by this study, the failure to find a significant relationship between performance and level of expertise may suggest that relative differences in expertise are not so clearly linked to performance.

With regard to the main hypothesis, an alternative explanation for the failure to find significant differences based on the level of expertise may be derived from the fact that all the subjects had a strong movement or sports background (Physical Education). While the Concept Mapping may capture the Knowledge Base in terms of facts and relationships, it does not tap into the perceptual and/or recognition abilities of the subjects. For the type of problems produced for the study an experiential component may have been an important factor (Reif & Heller, 1982), allowing novice subjects to see (recognize) relationships that they might not be able to explain. While students with a movement background may have been limited in their factual knowledge of linear kinematics they may have brought with them a strong experiential component. Anderson (1976, 1982, 1983) has noted that individuals may not always be

able to express verbally their knowledge of procedures. Consequently, the concept mapping procedure used to assign subjects to groups may not have provided a complete assessment of their Knowledge Base. The failure to find expert-novice differences in Final Solution Time on the surface was disappointing, but there were some noticeable differences in how they approached the problems.

The experts' representation of the problem is more efficient than that of the novices'. Experts are more likely to draw diagrams. Novices often use a process of direct syntactic translation, whereas, the experts seem to generate some sort of physical representation (Glaser, 1984; Holland, Holyoak, Nisbett & Thagard, 1986; Chi, Glaser & Rees, 1983; Larkin, McDermott, Simon & Simon 1980a, 1980b; McCloskey, Caramazza & Green, 1980). From Table 20 we can observe that of the 112 problems presented to the subjects 70 of the problem solutions were accompanied by correct drawings, partially correct or partial drawings. There were no expert-novice differences but it should be noted that the sort of problem presented lent itself to diagrams as they referred to objects which changed their position. From this, it can be seen that both these groups of subjects (novice-expert) were using problem representations as part of their problem solutions; unlike what would be expected of the truly novice problem solver.

Experts rapidly redescribe problems presented to them, often use qualitative arguments to plan solutions before elaborating them in greater mathematical detail, and make decisions by first exploring their consequences. Novices usually do little prior planning or qualitative description (Larkin & Reif, 1979). The novices in this study tended to rely more upon computational strategies (i.e., made comparisons of the data), whereas experts used more conceptual strategies (i.e., recognizes a clearly outlined problem type such as  $v=d/t$ ). There was a significant difference between groups for Simultaneous movement for the use of such strategies. However, for Successive movement, the slightly easier of the two Problem Types, the difference in strategy use was not significant with both novices and experts using primarily (85% of the problems) a computational strategy.

According to Simon and Simon (1978), Bobrow and Norman (1975), once the representation is built the novices are more likely to use 'working backwards' strategy, while experts are more likely to use a 'working forwards' strategy. While the pattern of results is quite similar for experts and novices and consistent across context, the frequency with which the subjects work backwards is greater for Simultaneous movement. For Simultaneous movement the relative frequency of forward and backward movement was 33.0:19.3, compared to 24.1:10.1 for Successive movement. However, for both Problem Types all

subjects worked forward to problem solution more frequently than working backwards, indicating that all the subjects in this study were adopting an approach similar to that normally associated with more expert subjects.

According to Larkin, McDermott, Simon and Simon (1980a, 1980b) experts solve problems faster and with fewer errors than novices. An assessment of the accuracy with which the two groups performed can be gained by examining the number of errors (see Table 26). The group with less expertise (novice) had 3 times more incorrect final responses in approximately the same time for solution as those subjects with more expertise. That is, the more expert subjects made 9.82% incorrect final responses whereas the novices made 29.46% errors. The tendency of novices to make mistakes suggests that they may feel more insecure in applying their knowledge than do the experts (by guess and by hunch rather than by calculation or intuition).

One of the characteristics of the novice group was their variability in solution times within the individual (problem to problem) and between individuals (within the same group) (e.g., see Tables 11 and 15). There did not seem to be a single or common solution path. With regard to the combined solution times for Simultaneous and Successive movements the correlation coefficient between the two levels of context (familiar and unfamiliar) for the novices was  $-.03$ . This would

suggest that the novices' performance on familiar contexts was not related to their performance on the unfamiliar contexts. However, the corresponding correlation coefficient between the two levels of context (familiar and unfamiliar) for the experts was .78. This suggests that the expert groups' performance was more consistent, that is, if they performed well on the familiar context they also tended to perform well on the unfamiliar task. This might also give support to the notion that the novices might be more likely to "make a guess" at the final solution before they are really certain, as suggested by their higher frequency of errors and of responses incongruent with their solution path.

Competent problem solvers consistently monitor and evaluate their solutions as they work; novices do not appear to be as consistent (Schoenfeld, 1985; Voss, Green, Post & Penner, 1984). From Table 24 it can be observed that experts evaluated their performance more often than did novices; this result is confirmed in the literature.

In that the subjects in this study did not respond in the manner expected of novices and experts, the results describe the intermediate group as being one which operates differently from the novices and from the experts as well. It seems that the more expert subjects in the intermediate group are adopting some of the characteristics of the true

expert, even though they are clearly at different levels in terms of knowledge base. In the process of becoming more expert it seems that one of the first characteristics to develop is that of accuracy.

Overall, for Simultaneous and Successive movement there was no significant difference in Final Solution Time but two observations stand out. The first was that there were differences in the variability (spread) of solution times: the experts were less variable, had fewer errors, and had a higher proportion of problems solved in under 1 minute. The second observation had to do with the differences in how the two Problem Types were approached. While the Analysis Episode occupied the major portion of the solution time for both types of problem, the difference between the two problem types lay in the reduced amount of time subjects gave to the Implementation process for Successive movements.

According to Bransford and Johnson (1973), Dooling (1972), Stanovich, West and Freeman (1981), Juel (1980), Cox (1978), Siegler (1977), Simon and Hayes (1976), the expert's ability to solve problems is less affected by the context in which the problem is presented. However, the expert has the ability to use contextual information to short-circuit part of the semantic processing in computing the meaning for a sentence. There was a clear Context effect for Simultaneous movement, but for Successive movement there was only a Context effect for

certain Episodes. In neither case was there a Group effect, with experts and novices responding alike to familiar and unfamiliar contexts. While the literature suggests that context would be a major variable, the break-down of the verbal protocols permitted the location of this effect; for both problem types this was primarily in the Analysis Episode. However, further analysis of the Components demonstrated that the source of the context effect in the Analysis Episode was different for each problem type: for Simultaneous movement it was the Problem Representation component while for Successive movement it was the Search for Relevant Information Component. As subjects placed more emphasis on the Search component for Successive movements, this would seem to support the notion that the Successive movement problems were easier to solve; i.e., subjects placed less emphasis on laying out the problem and more on looking for key information.

From an analysis of the solution patterns the novice subjects tended to use the Search component frequently. Even their final responses seemed to be associated with this particular component. In contrast, the expert subjects exhibited a greater tendency to move between various components within their solution patterns. There was a stronger relationship between Interpretation and Response and a more consistent tendency to relate the Reading of the problem to some other component, e.g., Assumptions or Search. Perhaps it might be suggested that, in some sense,

while the experts tended to show a more analytical approach, the novices might be characterized as being more speculative. This, in turn, may be one of the underlying reasons for the higher error rate being shown by the novice group.

In terms of problem type it was clear that while subjects found Successive movements to be somewhat easier to interpret than Simultaneous movements, the differences observed for Simultaneous movements were also present for Successive movements. However, for Successive movements these differences were not as strong. Consequently, Problem Type was not a major determining factor in either solution time or the process by which those solutions were obtained.

## Chapter VI

### Summary, Conclusions and Recommendations

The purpose of the present study was to contrast the characteristics of relative novices and experts in the domain specific area of linear kinematics with the aid of varying contexts.

Context and level of expertise represent the two central facets of this study. The study, therefore, was an attempt to consider the effect of these two facets on the problem solution process. In the research literature the experts' performance on problem-solving tasks has been shown to be superior to that of novices, also those characteristics which best describe the expert have been identified. However, little is known of the transition from novice to expert. In this study, the terms expert and novice are used to differentiate two groups within an intermediate range of expertise; one being more expert than the other.

As the main purpose of this study was to investigate the

effect of context and level of expertise on the problem solution process, the hypothesis tested was:

For isomorphic problems, the solution time is a function of the context of the problem and the level of expertise of the subject.

As well, as an exploratory component, the following objective was advanced:

For isomorphic problems, problem solution patterns displayed by subjects vary with problem context and level of expertise of the subject.

The exploratory part of the study focused on the elements of the problem solution pattern.

An inventory of contexts related to or involving the concepts of displacement, distance, time and velocity was compiled in order to construct familiar and unfamiliar isomorphic problems. One hundred and eight undergraduate university students were asked to identify different contexts involving the concepts of time, displacement and velocity. The degree of familiarity was based on the frequency with which particular contexts were identified. From this process two familiar (driving and activity) and two unfamiliar contexts (comets and blood flow) were identified.

Once the isomorphic problems were developed, a total of 57 subjects were asked to complete a Concept Map and solve eight isomorphic problems. Based on the quality of the Concept Maps obtained from the subjects, combined with an

assessment of their Educational experience, a judgment was made of their level of expertise. In order to obtain two distinct groups, 28 subjects (16 male and 12 female) were identified as relative novices or experts. For the problem solution task each subject was required to solve 4 problems in a familiar context as well as 4 problems in an unfamiliar context. Instructions were given to the subjects asking them to solve the problems aloud, and their responses were recorded on a tape recorder. This provided a total of 224 (i.e., 8 x 28) problems which were then transcribed verbatim, timed and coded according to a Coding Grid developed specifically for this study.

While the subjects in this study did not represent the extremes of the expert-novice continuum they were, however, two distinct groups. Overall, the results showed that the subjects in this study did operate differently from what would normally be expected of subjects representing the two extremes of the novice-expert continuum. It appeared that the subjects in this study were adopting some of the characteristics of the 'traditional' expert subject. The first step in this process seemed to be an improved ability to recognize key information, and thereby, improve the accuracy of their final solutions.

As has been demonstrated previously in the literature, Context does have a significant effect on more difficult

problem solving tasks (as defined by the degree of familiarity). From the performance of the expert group it was observed that as expertise develops there is an increase in the use of recognition skills. Similarly, as the level of expertise increases there is a move to working forward rather than backward towards the problem solution. With higher levels of expertise it was also observed that the more expert subjects use problem representation more frequently in order to help their understanding of the problem. In addition, there is an increase in the accuracy of final solutions with increases in the level of expertise even though the final solution time remains about the same. At the same time, it appears that the types of strategies used in problem solution change with expertise; the more experienced problem solver (i.e., the person with more domain specific knowledge) appears to use more conceptual, as distinct from computational, types of strategies. Finally, in terms of their solution patterns, the novices in this study were frequently caught in the Search component, the expert group evidenced solution patterns which highlighted a more analytical approach to the problem solution.

From an educational point of view, while there exists a clear inventory of the characteristics of an expert performer the process whereby the novice attains these characteristics is not immediately apparent. Though this study leaves many questions unanswered it does offer some

clues (e.g., the ability to tease out characteristics of differing levels of expertise) towards developing a methodology which might help clarify the overall transitory process from novice to expert. However, since the same types of response patterns were seen across Problem Type, it appears that the same strategies were applicable in both cases. This generalizability of strategies should help focus the task of the educator on strategies (learning how to learn) as well as on the domain-specific knowledge. The study provided clear evidence that the traditional method of evaluation, i.e. performance outcome, may not be the most appropriate. An alternative may be to examine how students solve particular problems, the actual process. As indicated in the data, a critical element may be the factor of recognition. If this is correct, therefore, it would be important for evaluative techniques to include this aspect.

The research implications arising from this study are directly linked to the educational implications. In Table 5 the difficulty students had with this particular domain-specific knowledge (linear kinematics) was outlined. Of the 38 subjects who had an educational background in physics, 21 (55.26%) were not been able to integrate this knowledge. A further research question, therefore, would be to compare the solution patterns of these students with the students in categories 3, 4 and 5, to see whether the problem solution patterns would provide any additional insight.

A second research question would relate to the inclusion of some type of perceptual or pattern recognition task (Green, McCloskey & Caramazza, 1985; Anderson, 1976, 1982; Glaser, 1984; Holland, Holyoak, Nisbett & Thagard, 1986; Larkin, McDermott, Simon & Simon, 1980a, 1980b; Bransford & Johnson, 1973). This may help identify the extent to which procedural, as distinct from declarative knowledge, may contribute to the problem solution process. Also, the use of more difficult problems (e.g. questions relating to acceleration) requiring a greater depth of understanding, might provide better discrimination between relative levels of expertise. Although research suggests that context is a significant variable, it did not have a major effect in this study. Consequently, the context effects would seem to be related to problem difficulty; evidencing a minor role with easy problems and a more apparent role with more difficult problems.

The use of Concept Mapping with the concurrent think-aloud procedure provides more and richer information than Concept Maps alone. This expanded methodology offers interesting potential for characterising the level of expertise in a particular domain. Further study of the classification of expertise using this revised technique of Concept Mapping should be pursued.

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**APPENDICES**

**Appendix A**  
**Inventory of Contexts**  
**Questionnaire**

Date \_\_\_\_\_

Date of Birth    /   /     
                  D   M   Y

Sex \_\_\_\_\_

The present study is concerned with the effect of "context" on problem solving activity. The first step involves a compilation of all possible contexts related to or involving displacement, time, velocity and acceleration. Please answer the following to the best of your knowledge.

1. Where have you used these concepts (displacement, time, velocity and acceleration). Check the appropriate answer(s).

- every day experience
- High school math
- High school physics
- 1st year physics (Univ.)
- any other? explain

- Engineering
- Biomechanics
- Advanced physics

2. If you had to describe to someone situations where one or several of the concepts of time, displacement, velocity and acceleration are involved, what kind of examples would you use? List as many as you can.

3. Rank the above situations in terms of their familiarity to you (1 for most familiar, 2 for next most familiar, etc.).

Thank you for you cooperation

Date \_\_\_\_\_  
Date de naissance   /  /    
Sexe M ou F

Nous désirons étudier l'effet du "contexte" sur le processus de résolution de problèmes. La première étape vise à produire un éventail de contextes associés au concepts de déplacement, de temps, de vitesse et d'accélération. A cet effet, nous vous invitons à répondre aux questions suivantes.

1. A quelle occasion vous êtes-vous servi de ces concepts (déplacement, temps, vitesse et accélération). Cochez la (les) réponse(s) appropriée(s).

- |   |  |
|---|--|
| <input type="checkbox"/> dans la vie de tous les jours                | <input type="checkbox"/> génie                       |
| <input type="checkbox"/> mathématique (école secondaire)              | <input type="checkbox"/> biomécanique                |
| <input type="checkbox"/> physique (école secondaire)                  | <input type="checkbox"/> études avancées en physique |
| <input type="checkbox"/> physique (1 <sup>ère</sup> année université) |  |
| <input type="checkbox"/> autre(s)? expliquez                          |  |

2. Si vous aviez à décrire une ou plusieurs situations où les concepts de déplacement, de temps, de vitesse et d'accélération s'appliquent, quels sortes d'exemples utiliseriez-vous? Vous êtes priés de fournir autant d'exemples que possible.

3. Assignez un ordre de familiarité aux exemples ci-haut (1 désigne l'exemple le plus familier, 2 le suivant, etc.).

Sincères remerciements pour votre coopération

**Appendix B**

Relative frequency of transportation  
and sport activities for each choice

Relative frequency of transportation and sport activities for each choice

	1st choice	2nd choice	3rd choice	4-7th choice
Transportation	10	7	8	1
in general	(24.39%)	(22.58%)	(30.76%)	(4.00%)
automobile	23	16	7	6
walking	(56.11%)	(51.61%)	(26.92%)	(24.99%)
biking	5	2	1	0
aeroplane	(12.19%)	(6.45%)	(3.85%)	
train	2	2	5	3
shuttles, rockets	(4.87%)	(6.45%)	(19.24%)	(12.00%)
boat	1	2	2	5
Total	(2.44%)	(6.45%)	(7.69%)	(20.00%)
	0	1	2	2
		(3.23%)	(7.69%)	(8.00%)
	0	1	1	6
		(3.23%)	(3.85%)	(24.00%)
	0	0	0	2
				(8.00%)
	41	31	26	25
	(100.00%)	(100.00%)	(100.00%)	(100.00%)
Sports in	17	11	4	2
general	(27.42%)	(20.75%)	(9.76%)	(5.71%)
running	20	14	8	3
projectile sports	(32.26%)	(26.42%)	(19.51%)	(8.57%)
throwing	6	11	4	7
movement in	(9.68%)	(20.75%)	(9.76%)	(20.00%)
general	6	7	5	5
jumping	(9.68%)	(13.21%)	(12.20%)	(14.29%)
swimming	6	0	4	1
skiing	(9.68%)		(9.76%)	(2.86%)
diving	2	3	8	7
gymnastics	(3.23%)	(5.66%)	(19.51%)	(20.00%)
skating	2	3	3	3
horseback riding	(3.23%)	(5.66%)	(7.32%)	(8.57%)
	0	0	2	1
			(4.88%)	(2.86%)
	2	0	0	2
	(3.23%)			(5.71%)
	1	2	3	3
	(1.61%)	(3.77%)	(7.32%)	(8.57%)
	0	1	0	1
		(1.89%)		(2.86%)
	0	1	0	0
		(1.89%)		
Total	62	53	41	35
	(100%)	(100%)	(100%)	(100%)

**Appendix C**  
**Concept Maps**

- S - alright motion
- is comprised of velocity acceleration
  - acceleration
  - acceleration with a direction
  - velocity with a direction
  - speed expressed as a magnitude
  - displacement
  - displacement is
  - wow in difference from
  - ummm
  - distance
  - it represents
  - a very specific type of motion in that
  - ummm
  - its the shortest distance between two
  - between two areas
  - two points
  - therefore its expresed as a magnitude
  - as with speed umm
  - motion is also comprised of
  - umm
  - time
  - ummm
  - time really in an indirect way
  - time
  - can be integrated with velocity acceleration
  - this might get a little messy
  - uh
  - velocity acceleration and it integrates with speed
  - uh
  - as speed acceleration and time are really expressed in terms
  - are really expressed in terms of time
  - umm for example
  - metres per second
  - metres per sec squared
- R - ok write all this down, show me how you see this
- S - difference between velocity and speed is metres /sec with a direction
- R - where would you put direction in all this?
- uhm direction and time both integrate together
  - direction simillarly as time integrates with motion
  - just like time direction integrates with velocity it integrates with acceleration
  - not with speed it only integrates with
  - motion
  - that has a
  - a direction
  - a specific place to go
  - ummm
  - you said these are just some of the things you want me to ahh
- R - keep going, I can glue all sorts of pages together I you want
- S - motion also implies to me force
- uh force is again is integrated with a

- I'm sorry this is really messy this is just the way I page 163  
R - it's ok  
S - ok  
- force is umm  
- again integrated with time  
- its integrated with direction it also has magnitude umm  
- its unit are SI units are Newtons  
- ummm  
- which is Kg metres per sec squared  
- um umm  
- force is basically composed of acceleration and mass  
- mass is another part of motion  
- you will have a devil of a time understanding this  
R - do you want another page tapped on?  
S - ehuh  
R - up or down?  
S - doesn't matter  
- you will have the devil of a time understanding all this  
- mass  
- mass integrates with force  
- it eh  
- SI units is Kg  
- acceleration m/sec squared  
- umm whenever I think of all of these I think of them in SI units  
- thats basically because thats whats taught  
- umm force  
- motion  
- whole concept of motion  
- to me  
- mainly deals with physics  
- eh  
- motion is basically math with a direction  
- and measurement  
- write that down  
- direction  
- and measurement  
- which equals physics to me  
- ummm  
- ummm  
- its an extremely general term  
- it can be applied to umm  
- all facets of education  
- just about science side  
- umm  
- which is biomechanics  
R - where would you fit all that in, biomechanics, education, physics?  
S - ok  
- I'm not going to remember all of these but  
- there are so many  
- physics (writing)  
- deals with living things  
- which means living things  
- have motion  
- they

- if they have motion it means they have force
- they are capable of producing force velocity acceleration speed displacement page 164
- uh and all the things which are integrated with these things such as time direction magnitude
- uh
- mometum
- motion also consists of momentum  $P$
- this is also  $MV$  which is
- which is
- umm
- which integrates velocity it integrates mass
- motion also consists of energy
- energy again is uh
- a concept in itself
- energy
- again energy ummm
- of which there are several forms
- potential kinetic
- energy is integ is comprised of
- uhm mass
- velocity (writing)
- in the kinetic form
- in the potential form
- umm
- deals with
- mass gravity height or distance displacement specifically
- it it can represent anything any object that has a placed in a specific position that it might adding another sheet of paper
- be able to possess some energy such as
- $U$
- for example a simple example a cliff a ball
- thats  $U$
- ummm ummm
- energy this is one form of potential energy there are several types
- types of velocity yeah well velocity and acceleration
- talk about them both together
- can be
- one 2 3 degrees of freedom or more
- by dimensions it can be in
- linear velocity
- thats why I said direction
- it can be in a circular path
- it can be umm
- in a parabollic flight as in any
- as in a projectile
- as anything in the gravitational field of the field of the earth
- I'll do that parabollic path
- similarly with acceleration acceleration can be broken down into different types again there is constant acceleration
- as expressed in a graph here
- where
- time inreases

- uh
- acceleration is constant over time
- or umm it can be
- an increasing acceleration
- ummm
- it can be integrated with velocity
- acceleration can be expressed and seen graphically
- on a velocity
- in terms of velocity
- there is velocity on an increasing
- see it as that
- umm
- or that
- if velocity increases like that it would be
- depending on how steep that is
- it can be
- uh
- hard for me to remember here
- that would be an increasing acceleration that would be a constant acceleration that would be (writing it in)
- that's increasing
- how long do I have here is there a certain time limit or is it not told
- R - what you need
- S - speed
- vague and general just eh
- it means velocity but it can be in any
- in any direction
- uh
- when you talk about speed you just talk about magnitude of the velocity
- umm
- energy to contrast from velocity acceleration
- it has no preferred direction
- it can be in any way which is a
- particularly useful in motion because
- can be used to
- to solve problems that you cant using direction
- I'd have to write a problem
- ok
- a simple example would be
- if you have a ball here
- and rolls down here
- it will possess mgh here
- its motion will increase as gravity acts on it
- and increase increase and increase
- it undergoes a transformation of potential energy to kinetic energy at each intermediate point here
- and then leaves here but if you are just given this piece of information and the height
- uh
- using the velocity or accerlation direction equations are really useful USELESS because you cannot
- ummm

- cannot determine the velocity
- however using energy which is really a dimensionless ah thing you can say fine Mgh they have no direction
- they are all constants
- you get a magnitude
- and then give it a direction ya eventually
- gravity has a direction
- however that direction is constant and does not change these change
- motion gravity
- very important thing
- has a direction but does not change
- always down
- towards the earth
- umm
- so you can determine energy here in a potential form
- convert it into a kinetic form and eventually it'd be here would you like
- me to show it
- ok
- umm
- we'll be here all night
- motion
- ok I've talked about speed acceleration velocity force momentum
- let me see
- ummm
- got to be other forms of energy um motion
- R - concentrate on these ones for awhile
- some more on velocity acceleration ok?
- ok
- perhaps how velocity acceleration a
- and
- displacement
- integrate
- R - you use the word integrate a lot, what do you mean?
- what I mean by integrate how they all complement each other work with each other in a unified way to produce something else
- is that right?
- R - I'll tell you later
- ummm
- R - ok why have you got A here? on these graphs and V there, can you explain it?
- S - because here I'm saying as time increases endlessly the acceleration does not increase it's
- I'm showing a graphical representation of constant acceleration
- here this is actually
- well that would be a an increasing acceleration, this is an increasing increasing acceleration
- uhhh
- the
- let's see what I can remember
- DT squared V
- R - ok don't go that deep just sort of explain to me the difference between these two curves
- S - between this and this

- R - no, this one and this one where you have velocity here **apage** 167 acceleration here and yet these two curves basically are the same form.
- S - they are the same form but they  
- mean different things because they are put in a different constant in a different context  
- um acceleration  
- is increasing  
- increasing  
- at a much higher rate here  
- this same curve represented here  
- to me would a lot more steeper than that.
- R - OK
- S - uh I don't know if I'm saying all this right it's been a while since I took physics
- R - ok
- S - this just represents  
- this  
- would represent this here  
- and this would represent this here
- R - ok
- S - and that
- R - that's what I wanted to know
- S - and that's what  
- no ok that's motion, displacement, time give me some more time I'll think of some more.
- R - why don't we move on?
- S - ok

TOTAL TIME = 19 minutes 46 seconds

Motion  
Bio mechanics  
Physics  
living things

Mass

$P = mv$

direction

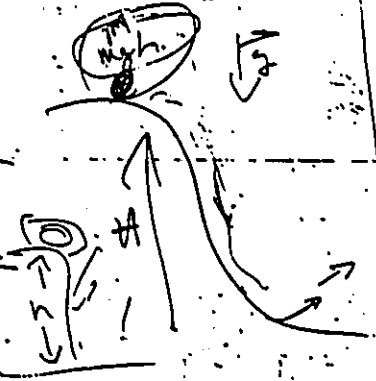
$E = \frac{1}{2}mv^2$

Vel<sup>y</sup>

Energy

Wor<sup>gh</sup>

$E_k = \frac{1}{2}mv^2$



t

MOTION

Math with direction and measurement = Physics

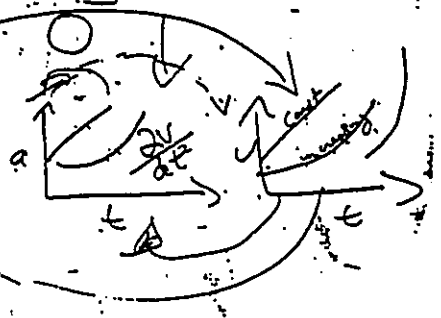
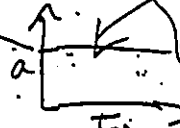
acc<sup>l</sup>

$\frac{m}{s^2}$

displacement

Speed

$\frac{m}{s}$



g  
along towards the earth

- S - ok
- feet
  - ahum
  - fast
  - slow
  - means transportation
  - oh I have to think out loud here
- R - ahum
- S - different means of transportation such as planes car train
- ahum
  - motion motion motion
  - time
  - ahum distance
  - ahum
  - ok ahum
- R - think out loud
- S - I'm havin trouble thinking of something else right now
- oh dear
  - motion motion ahum motion ahum
  - rough that's not the way I want but
  - can't think of something better than that
- R - can you in those lines there give me the reason why you picked that like motion something times motion something rough
- S - ok motion the time the motion like what the the
- the .....
  - throwing a baseball or something like that, am I doing it slow or fast like velocity well
  - no that's not what I mean or that time time motion that is ah
  - time it takes to get from point a to point b
  - ok ah distance
  - ok rough was
  - is is ahum that's what I'm trying to say it's ah
  - not a smooth motion it's not flowing at all very
  - it's choppy.
- R - could be rough
- S - yea
- distance
  - how far for example if I'm running couple miles distance in in length
  - speed how fast I do the motion
  - whether it's arm motion or foot motion
  - feet a means of locomotion
  - fast and speed they kinda go together
  - slow is the ah
  - slow slow moving
- R - motion can be slow ok
- S - motion can be slow
- different means of motion well these two right
  - that's one right here feet
  - there is another means by transportation
  - motion as in locomotive plane cars stuff like transportation
  - and we've gone around in a circle
  - you want me to go on for another the whole tape or what

- R - it's up to you  
S - ah  
R - you tell me what if your having a hard time  
S - ah ok  
- direction  
- ahum  
- varies  
- varies come on think out loud  
- varies considerably depending on  
- type of activity  
- for example if I'm playing basketball or hockey I'm going in a zig-zag fashion all the time whereas if I'm running  
- ah mile around the track its the same basic thing ok  
- ok acceleration  
- that will change again depending on the where I'm going if I'm playing golf my speed is gunna be the same constant throughout the 18 hole there's no need to rush my move my walking my walking speed if I'm playing again hockey or basketball going from slow to quick motion  
- and without unpredictably whereas golf a sport like golf or bowling is pretty predictable what speed I'm going at all the time  
- no need to accelerate in  
- in those sports ok  
- ah lord  
- (tapping on table) (long pause)  
- we're gettin stuck here  
- displacement  
- do want me to keep going for a while or you wanna I can't really go any more  
R - it's up to you you tell me  
S - na that's it

TOTAL TIME = 6 minutes 56 seconds

Subject:



**Appendix D**  
**Subject Instructions for**  
**Concept Mapping**

Subject Instructions  
For Concept Mapping

The technique used today is useful in helping people understand how knowledge is structured. The task is called Concept Mapping. For the Concept map you will be given a list of words which relate to a particular concept. These are only cue words. You don't have to use them. You may use your own words. Your goal is to explain how you see the concept and to do this by drawing a diagram. There are no right or wrong answers. You will see from the examples the same concept map can be presented in several ways. The cue words are linked together by other words. The lines which link the ideas are to explain the relationships. The other thing you are asked to do is to think out loud at all times. The only time I will interfere is to remind you of this.

**Appendix E**  
**Cue Words for Verbal Protocols**

CUE WORDS

time

displacement

distance

direction

velocity

speed

acceleration

**Appendix F**  
**Instructions for Verbal Protocols**

### Instructions for Verbal Protocols

In this experiment we are interested in what you think about when you find answers to some questions that I am going to ask you to answer. In order to do this I am going to ask you to THINK ALOUD as you work on the problem given. What I mean by think aloud is that I want you to tell me EVERYTHING you are thinking from the time you first see the question until you give an answer. I would like you to talk aloud CONSTANTLY from the time I present each problem until you have given your final answer to the question. I don't want you to try to plan out what you say. Just act as if you are alone in the room speaking to yourself. It is most important that you keep talking. If you are silent for any long period of time I will ask you to talk. Do you understand what I want you to do?

**Appendix G**  
**Isomorphic Problems**

**Problem Type: Simultaneous movement**

**Movement a : one object catches up to the other**

**Context : familiar**

- You live 30 kilometers from school (door to door) and it takes you 30 minutes to get to school each morning. Your friend lives 20 kilometers from school. If you both leave home at the same time and arrive at school at the same time, who is driving the fastest? Explain your answer.

- You can run 300 meters in 40 seconds. Your friend in a handicapped race, starts 200 meters from the finish. If you both start and finish at the same time, who is running the fastest? Explain your answer.

**Context : unfamiliar**

-Encker's comet takes 4 months to travel  $70 \times 10^6$  miles from Mercury to Earth. Danti's comet appears from behind the sun, some  $35 \times 10^6$  miles from Earth. If both appear at the same time and pass Earth at the same time, which is travelling faster? Explain your answer.

- It takes a red blood cell 3 seconds to travel the 30 cm from the ear to the heart. A white blood cell must travel 20 cm from the shoulder. If they both start at the same time and arrive at the heart at the same time, which is travelling faster? Explain your answer.

**Problem Type:** Simultaneous movement

**Movement b :** one object does not catch up to the other

**Context :** familiar

- You live 60 kilometers from school (south of the city) and it takes you 45 minutes to get to school in the morning. Your friend also lives south of the city but only 35 kilometers from school and it takes him/her 30 minutes to get to school. If you both leave at the same time in the morning will you pass each other on the highway? Explain your answer.

- In a handicapped race you must run 60 meters and your friend only 35 meters. You run the 60 meters in 9 seconds and your friend runs 35 meters in 6 seconds. If you both start at the same time will you pass your friend before the finish? Explain your answer.

**Context :** unfamiliar

- A solar wind emanating from the near side of the sun,  $34 \times 10^6$  miles from Earth takes 3 months to reach Earth. Danti's comet appears behind the sun some  $35 \times 10^6$  miles from the Earth and takes 4 months to reach Earth. If both started at the same time would the comet pass the solar wind? Explain your answer.

- It takes a red blood cell 4.5 seconds to travel the 60 cm from the elbow to the heart. It takes a white blood cell 3 seconds to travel 35 cm from the shoulder to the heart. If they both start at the same time will the red blood cell pass the white blood cell before reaching the heart? Explain your answer.

**Problem Type: Simultaneous movement**

**Movement c : overtaking**

**Context : familiar**

-You live 40 kilometers from school (door to door) and it takes you 30 minutes to get to school each morning. Your friend lives 30 kilometers from school and it takes her/him 45 minutes to drive to school. If you both leave home at the same time in the morning, who is going fastest? Explain your answer.

- In a handicapped race you must run 800 meters and your opponent 600 meters. You run 800 meters in 2 minutes and your opponent runs 600 meters in 2 minutes 30 seconds. If you both start at the same time, who is running the fastest? Explain your answer.

**Context : unfamiliar**

-The Earth is  $800 \times 10^6$  miles from Saturn and it takes Halley's comet 6 months to reach Earth. Jupiter is  $480 \times 10^6$  miles from Earth and it takes Danti's comet 8 months to reach Earth from Jupiter. Which comet is travelling fastest? Explain your answer.

- It takes a red blood cell 3 seconds to travel the 40 cm from the eye to the heart. It takes a white blood cell 4 seconds to travel the 30 cm from the liver to the heart. If they both leave at the same time, which is travelling faster? Explain your answer.

**Problem Type: Simultaneous movement**

**Movement d : crossing-over**

**Context : familiar**

- You live in the west end of the city and you want to get to the east end. The trip involves travelling 35 kilometers and will take you 30 minutes. Your friend lives in the east end and is driving into Centre town. His/her trip is a 17.5 kilometer trip. You both leave at the same time, drive past each other on the Queensway, and arrive at your respective destinations at the same time. Who was driving the fastest? Explain your answer.

While training doing wind sprints up and down the field, you sprint 50 meters to the end of the field in 8 seconds. Your teammate, starting from the other end of the field and running towards you, runs 25 meters. You start at the same time, cross-over, and arrive at the end of your run at the same time. Who was running the fastest? Explain your answer.

**Context : unfamiliar**

- Halley's comet returns from Earth, past the sun to Mercury ( $68 \times 10^6$  miles) in 6 months. A winter solar wind must travel  $34 \times 10^6$  miles to reach Earth. If they both leave at the same time, cross each other, and arrive at their journey's end at the same time, which was travelling the fastest? Explain your answer.

-A red blood cell takes 3 seconds to travel 35 cm up the vena cava to the heart. A white blood cell must travel 17.5 cm down the descending aorta from the heart. If they both start at the same time, 'pass' each other, and arrive at their respective destinations at the same time, which was travelling the fastest? Explain your answer.

**Problem Type: Successive movement**

**Movement a : movements in equal time and equal distance**

**Context : familiar**

-You live 30 km from school and it takes you 30 minutes to get to school each morning on the queensway. Your friend, who lives next door, leaves for school half an hour before you but he/she takes the parkway instead. If he/she gets to school just as you are leaving home, who is the faster driver? Explain your answer.

-In a downhill race, as the 2nd skier down the hill, it takes you 3 seconds to cover the last 30 meters from the final bend to the finish line. The 1st skier enters the final bend 3 seconds ahead of you and crosses the finish line just as you enter the final bend. Who was skiing fastest? Explain your answer.

**Context : unfamiliar**

-Danti's comet travels the  $480 \times 10^6$  miles from Jupiter to Earth in 8 months. Escanti's comet which left Jupiter 8 months earlier arrives at Earth just as Danti's comet leaves Jupiter. Which is the fastest? Explain your answer.

-It takes a red blood cell 3 sec to travel the 30 cm from the eye to the heart. A white blood cell which left 3 seconds earlier arrives at the heart as the red blood cell leaves the eye. Which travels faster? Explain your answer.

**Problem Type: Successive movement**

**Movement b : movements in equal time and unequal distance**

**Context : familiar**

-You live 30 km from school (south of the city) and it takes you 30 minutes to get to school in the morning if you leave at 7:00 am. Your friend also lives south of the city but only 20 km from school and it takes him/her 30 minutes to get to school if he/she leaves home at 7:30 am. Who is driving faster? Explain your answer.

-In a slalom you are first down the hill and it takes you 3 seconds to cover the 30 meters from the 2nd last gate to the finish line. Your opponent who is second down the hill covers the 20 meters from the final gate to the finish line in 3 seconds. Who is faster? Explain your answer.

**Context : unfamiliar**

-Halley's comet comes from behind the sun and covers  $30 \times 10^6$  miles to Earth in 3 months. The solar winds from the near side of the sun which appear after the comet cover  $20 \times 10^6$  miles to Earth in 3 months. Which is faster? Explain your answer.

-It takes a red blood cell 2 seconds to travel the 27 cm from the spleen to the heart. One minute later a white blood cell takes 2 seconds to travel the 18 cm from the liver to the heart. Which is faster? Explain your answer.

**Problem Type: Successive movement**

**Movement c : movements in unequal time and equal distance**

**Context : familiar**

-You live 45 km from school (south of the city) and it takes you 30 minutes to get to school in the morning if you leave at 7:00 am. Your friend, who lives next door, leaves for school at 7:30 am and it takes him/her 45 minutes to get to school. Who is the faster driver? Explain your answer.

-In a giant slalom, as first down the hill, it takes you 3 seconds to cover the 45 meters from the last gate to the finish line. The second skier down the hill takes 4.5 seconds to get to the finish line from the last gate. Who is travelling fastest? Explain your answer.

**Context : unfamiliar**

-In the summer the solar winds travel the  $20 \times 10^6$  miles to Earth in 3 months. Halley's comet, which comes once every 76 years, takes 4 1/2 months to travel to Earth from the sun. Which is the fastest? Explain your answer.

-It takes a white blood cell 3 seconds to travel the 45 cm from the right kidney to the heart. A red blood cell travels the 45 cm from the left kidney in 4.5 sec. If the white blood cell leaves the right kidney as the red blood cell reaches the heart, which is travelling faster? Explain your answer.

**Problem Type: Successive movement**

**Movement d : movements in unequal time and unequal distance**

**Context : familiar**

-You live 34 km from school and it takes you 30 minutes to get to school in the morning if you leave at 8:00 am. and drive on the side streets. Your friend lives 4 km closer to school than you do and it takes him/her 45 minutes to get to school in the morning using the queensway if he/she leaves at 8:15. Who drives faster? Explain your answer.

-In a dual slalom the last gate is 34 meters from the finish line and it takes you 3 seconds to cover the distance. Your opponent is 4 meters closer to the finish and takes 4.5 seconds to reach the finish line. Who is skiing fastest? Explain your answer.

**Context : unfamiliar**

-Halley's comet first appears from behind Saturn  $800 \times 10^6$  miles from Earth and takes 6 months to reach Earth. Two months later Danti's comet appears  $320 \times 10^6$  miles closer to Earth from behind Jupiter and takes 8 months to reach Earth. Which is faster? Explain your answer.

-The right kidney is 34 cm from the heart. It takes a red blood cell 3 seconds to travel to the heart from the kidney. The left kidney is 4 cm closer to the heart. A white blood cell leaves the left kidney 3 seconds later and takes 4.5 seconds to travel to the heart. Which is travelling faster? Explain your answer.

**Appendix H**  
**Order of Presentation of**  
**Verbal Protocols**

## Order of Presentation of Verbal Protocols

Cell	Simultaneous Movement	Successive Movement	Order of Presentation
1	3 *	12	act ab - driv cd - blfl ab - com cd
2	13	15	blfl ab - com cd - act ab - driv cd
3	24	14	act cd - driv ab - blfl cd - com ab
4	40	34	blfl cd - com ab - act cd - driv ab
5	18	16	act ac - driv bd - blfl ac - com bd
6	51(28)	37	blfl ac - com bd - act ac - driv bd
7	49(32)	54(41)	act bd - driv ac - blfl bd - com ac
8	21	17	blfl bd - com ac - act bd - driv ac
9	42	33	act ad - driv bc - blfl ad - com bc
10	50(25)	45	blfl ad - com bc - act ad - driv bc
11	43	31	act bc - driv ad - blfl bc - com ad
12	9	10	blfl bc - com ad - act bc - driv ad
13	27	38	driv cd - act ab - com ab - blfl cd
14	36	44	com ab - blfl cd - driv cd - act ab
15	5	4	driv ab - act cd - com cd - blfl ab
16	48	52(29)	com cd - blfl ab - driv ab - act cd
17	7(30)	6(47)	driv ac - act bd - com bd - blfl ac
18	19	20(23)	com bd - blfl ac - driv ac - act bd
19	55	56	driv bd - act ac - com ac - blfl bd
20	11	57	com ac - blfl bd - driv bd - act ac
21	1	2	driv bc - act ad - com ad - blfl bc
22	22	8	com ad - blfl bc - driv bc - act ad
23	46	53(39)	driv ad - act bc - com bc - blfl ad
24	35	26	com bc - blfl ad - driv ad - act bc

\* subject number

**Appendix I**  
**Simple Main Effects for**  
**Context x Episode interaction for**  
**Simultaneous and Successive Movement**

Effect of context for each of the 5 Episodes for both  
Problem Types

Source	df	SS	MS	F	Prob>F
Simultaneous movement					
Reading	1	24.12	24.12	1.13	0.3095
Analysis	1	4922.38	4922.38	6.04	0.0301*
Planning	1	67.58	67.58	1.81	0.2039
Implementation	1	830.58	830.58	3.54	0.0845
Monitoring/ Verification	1	271.88	271.88	0.93	0.3545
Successive movement					
Reading	1	250.50	250.50	3.88	0.0723
Analysis	1	2372.68	2372.68	6.37	0.0267*
Planning	1	49.56	49.56	1.24	0.2870
Implementation	1	22.32	22.32	0.24	0.6325
Monitoring/ Verification	1	1.63	1.63	0.05	0.8213

\* significant at the .05 level

**Appendix J**  
**Verbatim Protocols**  
**Timed and Coded**

Simultaneous Movement  
Familiar, Driving A, Novice

CODE : WAA

- 1 - Ok you live 30 km from school door to door and it
- 2 takes you 30 min // to get to school each morning //
- 3 - your friend lives 20 km from school //
- 4 - if you both leave home at the same time and arrive at
- 5 school
- 6 at the same time who is driving the fastest // // SFP
- 7 - R - talk loud
- 8 - ok so //
- 9 - one your going 30 km //
- 10 - in 30 min
- 11 - he's only going 20 km in 30 min /therefore //
- 12 - who's driving the fast //
- 13 - the person // (writing)
- 14 - who lives //
- 15 - 30 km from the school // (1:00) //
- 16 - lives 20 km from the school // //
- 17 - no 30 km from the school // //
- 18 - is driving fastest //
- 19 - R - because //
- 20 - because // (writing)
- 21 - he covers //
- 22 - 10 km more //
- 23 - more distance in the same time //
- 24 - in the same //
- 25 - 30 min //
- 26 - time period

TOTAL TIME = 1 minute 59 seconds

FR1

FRP

↓

SI

Simultaneous Movement  
Familiar, Activity C, Expert

CODE : CMG

- RQP 1 - in a special junior senior handicap cycling race
- 2 - you must travel 40 // km from start to finish
- 3 - you know th my mind really doesn't think if I talk at the same //
- MC 4 time out loud
- 5 - oops sorry ok //
- 6 - junior senior handicap cycling race you must race 40 // km from
- 7 - start to finish
- IPT 8 - so the distance equals 40 k //
- RQP 9 - your youngest opponent starts 30 km from the distance so his // d-1 is 40 d-2
- IPT 10 - equals 30 km //
- 11 - you start time equals 9 a.m.
- RQP 12 - which really doesn't // mean anything / it takes you 30 min to complete the distance
- RIE 13
- RQP 14 - so it's 30 min // and your junior cyclist takes 45 t equals 45
- HI 15
- RQP 16 - if you // both start at the same time who's cycling the fastest
- 17 - I just did the // velocity part again // (1:00) // (calculator)
- CVC 18 - 1.33 k's
- 19 - per min // minus 1
- 20 - that's 1.33 // //
- 21 - again 0.66 km // minute minus one that's minute there //
- DIFF 22 - again this is just added confirmation // that this one's going quicker because / when you look at it
- RES1 23 - um if he has longer distance // to go
- INT1 25 - and it takes him 30 min and the younger cyclist // has only 30 km
- 26 and it takes him longer.

TOTAL TIME = 1 minute 48 seconds

FR1

EPR  
↓  
IPT

Simultaneous Movement  
Unfamiliar, Blood Flow D, Novice

CODE : UZP

- RRP 1 - ok a red blood cell takes 3 seconds to travel 35 cm //  
QE 2 - ok can I split this up  
EXC 3 - R sure  
IPT 4 - ok 3 sec // to travel 35 cm //  
 5 - ok up the vena cava to the heart  
 6 - a white blood cell // must travel 17.5 cm down // a  
RRP 7 - from the heart // they both start at the same time pass  
 each other and  
 8 - arrive at their destination at the same time // which was  
 travelling  
 9 - the fastest explain your answer //  
 10 - a red blood cell red a red takes 3 sec // to travel  
 11 - to the heart  
 12 - a white blood cell must travel // mumble to the heart  
HI 13 - both start at the same time pass // each other arrive  
 at their  
 14 - destination at the same time which are which //(1:00)  
 was travelling  
 15 - the fastest  
 16 - ok it's the white blood cell  
 17 - ok // a white blood cell mumble // descending aorta  
 from the heart //  
 18 - from the heart  
 19 - vena cava // SFP //  
 20 - vena cava to the white blood cell // must travel DOWN  
 the descending  
 21 - aorta from the heart start same // time pass each other  
 and arrive at  
HI 22 - their // destination at the same time which is  
 travelling the fastest  
 23 - explain your answer //  
 24 - this one // travels 17.5 cm  
 25 - this one 35 // cm  
RDI 26 - mumble reversed  
AFP 27 - 17.5 //(2:00) cm x //  
HI 28 - they both start at the same time //  
 29 - ok  
 30 - takes 3 sec to travel 35 cm // this way up to the up  
 to the heart //  
HI 31 - a white blood cell must travel 17.5 cm down to the  
 descending //  
 32 - aorta to the heart they both start at about the same  
 time pass each  
 33 - other and // arrive at their destination at the same  
 time which was

- 34 - traveling the fastest // explain your answer
- AFP 35 - well
- 36 - well well well //
- HJ 37 - they start at the same time //
- APP 38 - mumble // SFP //
- HJ 39 - um ya they pass each other
- 40 - ok a red blood cell //(3:00) takes 2 sec to travel mumble
- HJ 41 - a white blood cell // must travel 17.5 cm down the mumble from the heart //
- 42 - the same amount of seconds
- RDI 43 - I guess ok //
- 44 - start at the same time pass each other arrive at their respective destinations // same time which was traveling the fastest
- HJ 45 - well well well // //
- APP 46 - explain your answer //
- 47 - red blood cell takes 3 sec // to travel 35 cm to the heart //
- HJ 48 - mumble //
- APP 49 - from the heart //
- 50 - mumble DOWN the descending aorta to the heart //(4:00) they BOTH start
- HJ 51 - at the same time pass each other and arrive at their destinations //
- 52 - at the same time which is travelling fast //
- APP 53 - well // obviously ok
- 54 - like ah // //
- 55 - 3 sec to travel // //
- HJ 56 - they start at the same time //
- 57 - and arrive at the same time and one // is going faster than the other //
- 58 - which one faster //
- 59 - took 3 sec for this one //
- 60 - traveled 35 cm this one mumble it took //(5:00) to travel 17.5 //
- SI 61 - see I don't know the distances in the heart and all that stuff //
- 62 - ok well I'm gunna take a wild guess and I'm gunna have to say um //
- ED 63 - ahum ahum //
- DBT 64 - as far as they go //
- APP 65 - that's 35 cm
- 66 - 35 // (using calculator) //
- 67 - 17.5 it's got to travel twice //
- INT1 68 - twice the distance //
- 69 - white blood cell must // travel 17.5 cm down the descending aorta to the heart start at the same time // one's going up one's going down //(6:00)
- 70 - so obviously due to gravity that
- 71
- 72
- 73

- SA2  
74 - would decrease the speed // of the one that's going down  
 HI 75 - a red blood cell takes 3 sec to travel UP //  
 76 - white blood cell to travel 17.5 cm to travel DOWN //  
 QZ 77 - I'm allowed to write on this eh?  
 EXC 78 - R sure //  
 79 - ok down //  
 80 - it takes 3 sec to travel up //  
 81 - different cm this gotta go DOWN //  
 INT2 82 - what's the ahh 9.8 // //  
 83 - speed of gravity //  
 84 - 9.8 isn't it? //  
 85 - ok that obviously has to do something with it //(7:00)  
 86 - plus the distance  
 87 - how do you figure that out? //  
 88 - ok (using calculator)  
 89 - .8 //  
 CUI 90 - boy // 17.5 divided by //  
 91 - 3 sec? //  
 92 - 29 well // ok //  
 93 - mumble //  
 94 - distance is 17.5 // //  
 95 - from distance  
 96 - both start at the same time pass // each other arrive  
 at destination at  
 HI 97 the same time which is travelling fastest //(8:00)  
 explain your answer //  
 98 - this one is traveling 17.5 cm DOWN the descending aorta  
 from the  
 99 - heart //  
 ED 100 - doesn't say how much time //  
 101 - this one takes 3 sec to travel 35 cm //  
 HI 102 - a white blood cell // mumble //  
 103 - both start at the same time pass each other and arrive  
 at their  
 104 - destination at the same time // traveling the fastest // //  
 EXC 105 - R - do you wanna to go to another?  
 CRIT 106 - I wanna struggle with this one //  
 EXC 107 - R - ok //  
 108 - 3 sec  
 AFP 109 - mumble //(9:00) //  
 HI 110 - which one is going faster // //  
 CRIT 111 - I don't understand //  
 HI 112 - they both start at the same time they pass each other //  
 113 - and arrive at their  
 SA2 114 - so obviously they are gonna pass each other more than  
 once //  
 115 - arrive at their destination at the same time // which is  
 HI travelling the  
 116 - fastest explain your answer (pencil tapping) //  
 DBT 117 - they pass each other more than once? //  
 118 - no they pass each other once  
 INT1 119 - let me see

- 120 - one's going up one's going down // so they can't pass each other more
- 121 - than once
- HS 122 - mumble point one's going faster //
- 123 - which is travelling the fastest //
- SA2 124 - could the a a a a an answer also be that the ah they weren't they
- 125 - were both traveling the same speed //(10:00)
- 126 - does it matter
- 127 - like ahum I don't know cause it's // half half the distance
- INT2 128 - but one's going up // one's going down
- 129 - going down's // a slower distance
- 130 - a shorter distance //
- 131 - just wait distance //
- 132 - and it's going down should be going slower //
- 133 - for it to reach the sssss same time //
- 134 - ok ahum
- 135 - the red blood cell // SFP //
- RES1 136 - um the red blood cell obviously was travelling faster // because it's
- 137 - going up
- 138 - ok
- 139 - and it's gotta fight gravity //
- 140 - and it's travelling //(11:00) a farther distance whereas the white blood
- INT4 141 - cell is going down // with gravity which would be going fast so in
- 142 - order for //
- 143 - ahum ah a white blood cell // to reach it's destination at the same
- 144 - time as the //
- 145 - red blood cell reaches it's destination
- 146 - the red blood cell must // work harder to get up to it so obviously
- 147 - going faster //
- 148 - so they both come at the same time so I would say the red blood
- 149 - cell was going faster for that reason //
- CRIT 150 - I'm sure it's wrong

TOTAL TIME = 11 minutes 38 seconds

FR3

EPR2

↓

SI

Simultaneous Movement  
Unfamiliar, Comets B, Experts

CODE : JAJ

- 1 - a solar wind emanating from the near side of the sun  
34 x 10 to the 6th
- 2 - miles from Earth // takes 3 months to reach Earth  
Danti's comet appears
- 3 - appears behind the sun some bah bah bah // miles from  
the Earth and
- 4 - takes 4 months to reach Earth the other one only  
takes 3 // if both
- 5 - start at the same time would the comet pass the solar  
wind the solar
- 6 - wind // takes 3 months to travel 34 // x 10 to the 6th  
and Danti's
- 7 - takes // 4 months to travel the 35 x 10 to the 6th so //
- 8 - a factor of one difference if one takes //
- 9 - takes 3
- 10 - this one takes 3 months and Danti's // takes 4 months  
to reach the
- 11 - Earth if both start at the same time //
- 12 - would the comet pass the solar wind //
- 13 - ah let me think now
- 14 - the wind //(1:00)
- 15 - is
- 16 - ah emanating from the near side // of the sun
- 17 - that distance from the Earth // takes 3 months to reach  
the Earth
- 18 - don't I need a speed here to figure out
- 19 - Earth // which passes which
- 20 - Danti's comet appears behind the sun some 35 // x 10 to  
the 6th miles
- 21 - from the Earth
- 22 - it takes 4 months
- 23 - oh well they yea given the time period //
- 24 - ahum //
- 25 - takes a month
- 26 - ah //
- 27 - if both started at the same time would the comet pass  
the solar wind //
- 28 - explain your answer
- 29 - the comet is travelling 34 // x 10 to the 6th miles in  
3 months //
- 30 - we'll get a reading in miles per month
- 31 - so that's // (using calculator)
- 32 - 11.3 //(2:00) miles per month and Danti's is // ah  
35 x 10 to the 6th
- 33 - miles // in 4 months

- 34 - and that's (using calculator) //
- 35 - 8.75 that's 11.3 // 8.75 miles per month
- INT1 36 - so Danti's //
- 37 - is slower than the solar wind //
- HL 38 - would the comet pass the solar wind //
- AES139 - ahum no //
- 40 - the solar wind is travelling faster so no //
- INT1 41 - the comet would not pass the solar wind

TOTAL TIME = 2 minutes 48 seconds

FR1

EPR

↓

1PT

Successive Movement  
Familiar A, Driving A, Novice

CODE : OAA

- 1 - you live 30 km from school and it takes you 30
- 2 - min to get to school each morning on the queensway //
- 3 - your friend who lives next door leaves school  $\frac{1}{2}$  hour
- RDE 4 - but
- 5 - she or he or she takes the parkway // instead if he
- 6 - gets to
- 7 - school just as you are leaving home
- 7 - who is the faster driver explain // your answer
- 8 - yea and point of it your friend who lives // next door
- 8 - leaves
- 9 - for school  $\frac{1}{2}$  hour before you
- HI 10 - but she takes the parkway //
- 11 - instead she gets to school just as you are leaving home
- 12 - who is the faster driver? //
- 13 - let's not think about the question you live 30 km
- 14 - from school
- 14 - it takes you 30 min to get // to school each morning
- IPT (writing)
- 15 - 30 km
- 16 - in // 30 min
- 17 - 1 km // per min so that's ah
- CVC 18 - 60 km // an hour that's me ahum //
- 19 - your friend who lives next door leaves school  $\frac{1}{2}$  hour
- 20 - before //(1:00)
- 21 - you but takes the parkway
- 21 - if she if he or // she gets to school just as you are
- 22 - leaving home
- 22 - who is the faster driver //
- 23 - your friend lives who lives mumble //
- HI 24 - your friend who lives next door leaves for school //
- 25 -  $\frac{1}{2}$  hour before you but takes the parkway //
- 26 - if he or she gets to school just as you do who is the
- 26 - fast driver
- RES1 27 - oh I think its equal //
- 28 - they are going the sam same distance
- 29 - and she's // //
- 30 - she gets to school just as you are leaving home //
- INT 31 - I think its the same if things are taking approximately
- 31 - the
- 32 - same time //

TOTAL TIME = 1 minute 50 seconds

FR1

EPR

↓

IPT

↓

SI

Successive Movement  
Familiar, Activity C, Expert

CODE : PZG

- 1 - in a shooting drill you start at one end of the rink  
and shoot
- 2 - when you reach the far blue line //
- 3 - on a moving start you are 40 m out and it takes you 3 sec
- 4 - to reach the blue line //
- 5 - your friend who started 3 sec before you
- 6 - before you takes // 4.5 sec to reach the blue line who is
- 7 - skating fastest //
- 8 - so lets start at (writing)
- 9 - ok // that's me and
- 10 - I start at one end of the rink //
- 11 - so //
- 12 - here's the first blue line the red line and the second  
blue line //
- 13 - so
- 14 - I skate and once I get // to the far blue line
- 15 - I shoot at the // far blue line
- 16 - on a moving start you have 45 m out and it takes  
you // 3 sec
- 17 - to reach the blue line
- 18 - on a moving start // (1:00)
- 19 - so at some point I'm already moving here so total  
distance here
- 20 - would be // 45 m
- 21 - and it takes 3 sec //
- 22 - in 3 sec //
- 23 - your friend started 3 sec before you takes 4.5 sec  
// to reach
- 24 - the blue line
- 25 - so
- 26 - friend goes // to the same blue line
- 27 - starts 3 sec // before I do //
- 28 - and reaches it //
- 29 - and it takes 3 4.5 sec //
- 30 - well he um I'm skating faster //
- 31 - R - because?
- 32 - because
- 33 - I do travel the same distance // in 3 sec as opposed  
to him
- 34 - traveling in 4.5 sec

TOTAL TIME = 1 minute 58 seconds

FR1

EPR1

↓

SI

Successive Movement  
Unfamiliar, Blood Flow D, Novice

CODE : QZP

- RQP 1 - here we go the right kidney is 34 cm from the heart //
- EPR 2 - so heart from there is 34 cm // (writing)
- EPR 3 - the right kidney //
- EPR 4 - 34 to the // kidney
- RQP 5 - it takes a red blood cell 3 sec to travel //
- RQP 6 - to the heart from the kidney ok //
- EPR 7 - heart to kidney 3 sec //
- EPR 8 - the left kidney no that's the right kidney //
- RQP 9 - ok left // kidney
- RQP 10 - is 4 cm // closer to the heart
- RQP 11 - put down 30 cm here // // (1:00)
- RQP 12 - to the heart //
- RQP 13 - a white blood leaves the left kidney
- RQP 14 - 3 sec later // and takes 4.5 sec to travel to the heart
- RQP 15 - which is traveling faster? //
- RQP 16 - ok a white blood cell leaves the left kidney //
- HT 17 - 3 sec later // (writing)
- HT 18 - 3 sec // later and takes 4.5 sec // to travel to the heart //
- 19 - which is traveling faster? //
- DBI 20 - .5 oh dear //
- 21 - the right kidney 34 cm (mumble) //
- 22 - to the heart // (2:00) from the kidney
- HT 23 - the left kidney supposedly is closer to the heart //
- HT 24 - ok a white blood cell leaves the left kidney // 3 sec later
- 25 - 3 sec later //
- RQP 26 - equals zero //
- 27 - and takes 4.5 sec to travel to the heart
- HT 28 - ok // ahum 1.5
- 29 - which is traveling faster // explain you answer
- RES 30 - ok I would say that //
- RES 31 - the right kidney to the heart is traveling faster
- 32 - I added on // 1.5 sec
- 33 - from the left kidney to the heart //
- SI 34 - which would make it //
- 35 - 1½ sec which would take 1½ sec longer //
- 36 - then the first one
- EXC 37 - R - ok give me a colour of blood cell // (3:00)
- 38 - ok the white blood cell
- 39 - will ah //
- RES 40 - oh // red ok red blood cell there
- 41 - ok the white
- 42 - the one // up here the red blood cell
- 43 - travels faster // than the white blood cell
- EXC 44 - R - because

- INT 45 - because the left kidney would take // 1.5 sec longer  
46 - to travel to the heart // oh God how many more of these?

TOTAL TIME = 3 minutes 33 seconds

FR1

EPR1

↓

SI

Successive Movement  
Unfamiliar, Comets B, Expert

CODE : LAJ

- RDP 1 - hey Halley's comet comes from behind the Sun //
- 2 - and covers 30 x 10 to the 6 miles in 3 months // (writing)
- SI 3 - 30 10 to the 6
- 4 - in 3 months //
- 5 - solar wind from the near side of the // Earth um of the Sun
- RDP 6 - which appear after the comet //
- 7 - covers 20 x 10 to the 6 in 3 months //
- SI 8 - in 3 months
- RDP 9 - which is faster //
- 10 - well the one that covers more distance in a
- INT 11 - slower time // I mean ah the same time so that's the Halley's comet
- RES 12 - is faster //
- UC 13 - two more

TOTAL TIME = 46 seconds

FR1

EPR

↓

SI

**Appendix K**

**Summary of Tukey tests for Components**

Summary of Tukey test for Components for Simultaneous movement

Means	Search for Info	Reading	Computation	Problem Representation	Response of Assumptions	Interpretation/Justification	Evaluation	Self-Directed Activities
Search for Information	(34.49)	--						
Reading	(23.65)	10.85	--					
Computation	(17.72)	16.77*	5.93	--				
Problem Representation	(17.69)	16.81*	5.96	5.93	--			
Response	(13.76)	20.74*	9.89	3.97	3.93	--		
Statement of Assumption	(13.51)	20.98*	10.14	4.21	4.18	.25	--	
Interpretation/Justification	( 8.32)	26.17*	15.33*	9.4	9.37	5.44	5.19	--
Evaluation	(5.37)	29.13*	18.28*	12.36	12.32	8.39	8.15	2.96
Self-Directed	( 3.80)	30.69*	19.85*	13.92*	13.89*	9.96	9.71	4.52
								1.57
								--

\* significant at the .05 level

Summary of Tukey test for components for successive movement

	Means	Search for Information	Reading	Problem Representa- tion	Response of Assump- tion	Statement of Assump- tion	Interpretation/ Justification	Self-Directed Activities	Computation	Evaluation
Search for Information	(31.46)	--								
Reading	(22.07)	8.76	--							
Problem Representation	(15.61)	15.85*	6.47	--						
Response	(10.66)	20.80*	11.41	4.95	--					
Statement of Assumption	( 8.56)	22.90*	13.51	7.05	6.90	--				
Interpretation/ Justification	( 7.07)	24.39*	15.00*	8.54	3.60	1.50	--			
Self-Directed Activities	( 4.19)	27.31*	17.88*	11.42	6.47	4.37	2.88	--		
Computation	( 4.15)	27.31*	17.92*	11.56	6.51	4.41	2.92	.04	--	
Evaluation	( 2.11)	29.35*	19.97*	13.50	8.56	6.46	4.96	2.09	2.05	--

\*significant at the .05 level

**Appendix L**  
**Simple Main Effects for Components**

Simple Main Effects of time (sec) on the Problem Representation component with Simultaneous movement

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>	<b>13</b>				
Expertise(G)	1	24.61	24.61	0.07	0.7999
Error-between	12	4395.56	366.30		
<b>Within Ss</b>	<b>14</b>				
Context(C)	1	993.06	993.06	10.64	0.0068*
C x G	1	0.02	0.02	0.00	0.9962
Error-within	12	1120.35	93.36		

\* significant at the .01 level

Simple Main Effects of time (sec) on the Response Component  
with Simultaneous movement

Source	df	SS	MS	F	Prob>F
<b>Between Ss</b>					
Expertise(G)	1	.99	.99	0.02	0.9007
Error-between	12	727.61	60.63		
<b>Within Ss</b>					
Context(C)	1	204.93	204.93	8.55	0.0127*
C x G	1	23.68	23.68	.99	0.3397
Error-within	12	287.48	23.96		

\* significant at the .05 level