THE KINEMATIC EQUATIONS: AN ANALYSIS OF STUDENTS' PROBLEM-SOLVING SKILLS

by

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Abstract

The problem-solving skills of first year university physics students were analysed by first administering a questionnaire, after which a workshop intervention was employed to ensure reliability, validity and richness of data collected. The problem-solving behaviour of these students was documented using think-aloud sessions, pen-and-paper solution of problems, observations and interviews. The students individually solved physics problems on kinematics. Fourteen activities which constitute physical and cognitive actions performed by students during problem-solving are identified and described. These activities are documented in order to provide further insight into the problem-solving process. It has been found that when solving problems, students used a variety of general methods and strategies for the fourteen activities identified. This research illustrates the large gap that exists between the "protoconcepts" with which most students come to the study of kinematics, and their grasp of the physical constructs put forth in text and lecture presentations. It has also been established that students appear to lack the critical knowledge necessary to apply the appropriate kinematic equations that ultimately result in the solution of a problem. In addition, their cognitive skills necessary for successful problem-solving are inadequately developed.

Declaration

I declare that this dissertation, titled

THE KINEMATIC EQUATIONS: AN ANALYSIS OF STUDENTS' PROBLEM-SOLVING SKILLS

is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references.

It is being submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

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Sam Mabune Ramaila
February 2000

Dedication

I dedicate this dissertation to my wife, Bahupileng, and my son, Moholla, for their constant inspiration, encouragement and patience.

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It is my pleasure to thank all those people without whom this dissertation could not have been possible. First, to my wife and son I express my heartfelt appreciation for their constant support and inspiration. My special thanks go to Mr M. Stanton, my supervisor, for his cheerful spirit in the face of challenges, diligence, attention to detail, good sense of humour, intellectual leadership and professional guidance he has shown throughout the entire process. Finally, it is indeed my pleasure to thank all colleagues who have in one way or another contributed to this dissertation.

Last, but certainly not least, I thank God of Almighty for giving me courage and strength to cope with this work.

TABLE OF CONTENTS

LIST OF REFERENCES 112

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

UNIN = University of the North

t = time

v = velocity

a = acceleration

s = seconds Not to be confused with:

s = displacement

v = speed

d = distance

m = metres

h = hour

km = kilometres

max = maximum

g = gravitational acceleration

CHAPTER ONE

ORIENTATIVE INTRODUCTION

1.1. INTRODUCTION

1.1.1. Problem-Solving

Problem-solving ability is widely accepted as a core skill in the physical sciences, technology and applied mathematics. However, definitions of what constitutes a problem vary. Problem-solving is a complex, multi-layered skill, and not one that most students can be expected to develop unaided. Even with carefully graded problems, students commonly reach the sort of impasse from which they need to be rescued by the instructor. Kahney's (1986) classification distinguishes between *well-defined problems*, in which the goal, starting point and legal operations are clearly set out, and *ill-structured problems* in which the task is expressed in only the vaguest terms.

The creativity required to solve problems is idiosyncratic, and certainly cannot be reduced to a simple set of rules or procedures. No two students are likely to tackle a problem in exactly the same way, even though they may arrive at the same solution. Moreover, although there are some general approaches that can be useful for a wide variety of problems, specific types of problem may yield only to particular techniques. The challenge for course designers is indeed to provide a general structure that helps students to order their thinking about a particular problem, without stifling their creativity.

While solving problems, students do not use any single strategy in isolation, but rather employ a combination at any one instant (Dhillon, 1995). It is therefore important to understand the problem-solving process in terms of the fundamental components that constitute any strategy or set of strategies. For instructors to provide appropriate help to students and have a meaningful interaction with them, a knowledge of these micro-components performed within the macroscopic problem-solving strategies is required.

In this study an activity is classified as any minute physical or cognitive action performed while solving a problem. A strategy is seen as an overview or plan of action. It consists of blocks of knowledge used to arrive at the solution to the problem. These knowledge blocks are applied through a series of sequenced activities performed during the problem solution. Thus, a strategy is commenced with an activity, constitutes a series of activities, and is concluded with an activity. Within each strategy an activity or set of activities can be performed repeatedly.

The information gathered on the activities performed during problem-solving is also required to determine the suitability of an interactive constructivist-*cum*-transmission environment for problem solving. It should be clarified that the constructivism adhered to here does not refer to radical constructivism (von Glasersfeld, 1993), but rather to interactive constructivism, which proposes that learners use prior knowledge or past experiences in trying to make sense of the world. It sees the learner as an active participant in the construction of knowledge. The sense made of any event is seen to be dependent, not only on the situation itself, but also on the individual's purpose and active construction of meaning (Driver & Oldham, 1986).

1.1.2. Local Context

In South African schools, there exists a tradition of problem-based learning, particularly in mathematics and science. The aims of such approaches include the enhancement of learning key concepts and development of critical thinking and decision-making skills. However, in technology education programmes, the focus is on the development of problem-solving capability for which a variety of skills (such as planning, designing, decision-making and appraisal) and conceptual knowledge are means to the end of achieving desired products or ways of doing things.

The nature of processes involved in solving technological problems has been the focus of inquiry, particularly in recent years as technology education has emerged in all levels of schooling. Many models for problem-solving or design-and-make activities have been published and a selection of these are reviewed by Johnsey (1995). Most have similarities to a guided design model developed for engineering students by Wales & Stager (1972), which sets out six stages: define the situation; state the goal; generate ideas; prepare a plan; take action; and look back. Such heuristics have been critiqued on the basis that they portray problem-solving as a fixed linear or cyclical sequence (Hennessy & McCormick, 1994; Johnsey, 1995; Kimbell *et al.*, 1991) and imply that all problems are basically alike and can be solved in much the same way.

Counter arguments emerging from contemporary debate about the situated nature of learning (Brown *et al.*, 1989) suggest that the expertise required to solve one type of problem does not necessarily transfer to another problem (Custer, 1995). And, as Hodson (1996) has pointed out, the 'transferability [of skill] depends on familiarity with the relevant concepts, and so a demonstrated capacity to perform a skill in a particular context is no guarantee of skill in a conceptually different context' (p. 126).

The practical action entailed in solving technological problems is clearly a consequence of knowledge derived from accumulated practice and expertise (Custer, 1995). So how do teachers prepare and present classroom opportunities which will generate such accumulated practice? Despite the introduction of a considerable number of technology programmes in schools, the pedagogical frames for classroom implementation do not explicate the relationship between knowing and doing. Linear or cyclic models of problem-solving fail to reflect the iterative relationship of knowledge and action.

Students at the University of the North (UNIN), in the Northern Province of South Africa, encounter difficulties with the study of motion, particularly kinematics. The difficulties encountered in this area of mechanics include the following:

- the synthesis of information given explicitly or implicitly
- the identification and labelling of variables
- the conversion of a 'real-world' situation into a 'model' that is amenable to quantitative analysis
- the selection of relevant principles or laws
- basic mathematical and/or computational skills
- the use of approximations or order of magnitude estimates
- the exploration of alternative approaches and their use in checking solutions
- interpretation skills (e.g. checking solutions against experience)

It is the belief of this researcher that this area should be investigated:

(i) to help students to actively build their own understanding and to consolidate this through the application of basic concepts to the analysis of a wide variety of situations.

(ii) to raise students' awareness of good problem-solving techniques and to facilitate the transfer of these skills to other courses and other areas.

(iii) to increase the percentage of students who become proficient at solving problems.

(iv) to help weaker students by giving them some security so that they can focus on some of the higher-level skills that can make problem-solving easier.

The broad goal of this study is to undertake an analysis of students' problem-solving skills with a view to identifying the factors that impede a meaningful mastery of these skills in kinematics.

1.2. DEFINITION OF TERMS

The terms alternative conception, problem solving, problem-solving strategy and model will be used in this study. It is therefore appropriate that some preliminary discussion and definitions be given now.

1.2.1. Problem-Solving

Problem-solving is an investigative task whereby the solver explores the solution path to reach a goal from given information. Ausubel (1968) refers to problem-solving as involving the cognitive representation of prior experience and the components of a current problem situation reorganised to achieve a designated objective, popularly termed the solution. He considers problem-solving as learning that bridges the gap between the learner's existing knowledge and the solution to the problem through transformation of information by analysis, synthesis, hypothesis formulation and testing, rearrangement, recombination, translation, and integration.

Problem-solving requires the integration of knowledge types that can be classified as content and structure. Content can be declarative or procedural. Declarative knowledge consists of facts within a domain. Procedural knowledge determines when a piece of declarative knowledge is applicable and under which circumstances, encompassing the possible assumptions that can be made in solving problems. Procedural knowledge is sometimes referred to as ancillary knowledge which includes: the appropriate interpretation of the concept; the applicability conditions of a concept; and knowledge to prevent errors and to discriminate errors from correct situations (Reif, 1985). Structure is the interrelationship and connections between pieces of related information. This organization of knowledge enables it to be related and applied to solving problems. Problem-solving ability is strongly affected by the context in which the problem occurs. Students may appear as *good* problem solvers in one area of a subject domain and may be *poor* solvers in another. An important factor in successful problem-solving is whether students can transfer their knowledge and apply it in solving problems (Gagne, 1985).

The features which good problem solvers need to have include: learning from further experience, reconceptualizing, having general knowledge, having common sense across all dimensions, reasoning by analogy, recognizing where their knowledge is inapplicable or insufficient, the ability to check whether their conclusions are reasonable, and being able to explicate their reasoning process (Estes, 1978; Garret, 1986; Tuma & Reif , 1980). The result is that the same problem may be solved in varying ways by different individuals, due to dissimilar problem-solving steps, strategies, and knowledge.

1.2.2. Problem-Solving Strategies

General problem-solving techniques may not be evident in a learner's skill behaviour when engaged in relatively familiar tasks, but are likely to play an essential role whenever the person has to move into new territory and attempt further learning (Simon, 1980). The general methods proposed in the literature (Larkin, 1980; Newell & Simon, 1972; Pizzini, Shepardson & Abell, 1989; Reif & Heller, 1982; Rubinstein, 1975) basically follow the broad procedures described by Polya (1971) of understanding the problem, determining the connection between data and unknown quantities, finding auxillary problems if an immediate connection cannot be found, obtaining a plan of the solution, carrying out the plan, and examining the solution obtained. Most methods advocate picturing or diagram drawing as this seems to facilitate problem-solving by producing coherence between the inputs of the problem . This also helps to reduce the cognitive load because a person's processing capacity is limited.

Ten commonly used strategies reported in the literature are summarized:

1.2.2.1. *Analogy*

Analogy consists of transferring knowledge from past problem-solving episodes to new problems that share significant aspects with the corresponding past experience (Carbonell, 1986). This is often used when there is little knowledge in the domain of the problem (Gagne, 1985). The problem representation is used to access knowledge in a familiar domain relevant to the current situation and to evaluate the utility of the knowledge.

1.2.2.2. *Brainstorming*

Brainstorming is a good strategy for increasing the number and quality of solutions (Osborn, 1963). The problem is first defined, and as many solutions as possible are generated without criticism. Criteria are then developed to judge the viability or applicability of the solutions and the best solution selected (Gagne, 1985).

1.2.2.3. *Envisioning*

Envisioning involves generating a series of sequential snapshots that describe what might or could happen (de Kleer, 1977). This provides the qualitative knowledge to roughly predict what will happen at various points in a given problem situation or state. Domain-specific principles and rules are then applied to obtain a qualitative causal description of the problem situation. This knowledge is represented as transformation and analysis rules and applied to solve the problem.

1.2.2.4. *Forward Strategy*

Forward strategy takes place when the initial problem description is used to generate a solution using the knowledge base (Reif, 1985). In well-defined problems, the solution is accomplished with the application of constraint satisfaction generated from information contained in the problem. The operations one chooses to perform on the initial data are not goal-constrained and might lead in fruitless directions (Gagne, 1985). When knowledge is available, solutions usually show forward and top-down development.

1.2.2.5. *Generate and Test*

Generate and test occurs when the problem- solver simply generates solutions one at a time and tests to see their applicability. The search for solutions may be controlled by generating only those that possess at least some of the properties that define the solution (Newell & Simon, 1972). This is a good method to systematically explore all possible solutions (Sleeman, 1987). Ausubel (1968) suggests this as an inevitable method when no meaningful pattern of relationships exists.

1.2.2.6. *Heuristic Search*

Heuristic search is the process of using operators to guide the search in a problem space (Newell & Simon, 1972). The search can go depthwise or breadthwise, and can continue in different directions. If the problem space is large then it is usually transformed into a more manageable form by first using problem decomposition. Knowledge of possibilities and constraints is necessary to generate trial solutions and to guide the search for the solution respectively. Guessing or plausible reasoning is also used. Kolodner (1984) mentions that sometimes a search for related operators or information, called alternate context search, is required, especially when the operator being searched is too obscure.

1.2.2.7. *Means-end Analysis*

Means-end analysis occurs when an assessment is made between the current state of knowledge of the problem and the desired goal state (Newell & Simon, 1972). This assessment is used to select and apply an operation or operator to reduce the difference. This is done recursively until the goal state is reached, or all the operators in the problem space have been used. This strategy applies to problems for which there are no specific or better methods.

1.2.2.8. *Problem Abstraction*

Problem abstraction is the process of concentration on a generalized representation of the most important elements of a problem (Rolston, 1988). This allows the solver to construct a simplified representation by ignoring the minor details and to focus on the problem by retaining certain central features (Larkin, 1980). The successive refinement or modification of the abstraction of the problem by including more features in steps facilitates the search and allows one to focus on a couple of features at a time.

1.2.2.9. *Problem Decomposition*

Problem decomposition is the decomposition of a large, complex problem into a collection of smaller subparts (Rolston, 1988) or subproblems. A subproblem is any problem whose solution facilitates that of the original problem (Reif, 1985). The process of successive decomposition is continued until all the resulting subproblems are readily solvable. These separate pieces are then combined to form the solution to the original problem.

1.2.2.10. *Working Backward*

Working backward is a goal-directed strategy in which a tree of intermediate quantities is constructed, starting with the goal state, until one arrives at the quantities specifically as given in the problem (van Weeren, 1983). Rules acquired as a result of previous problem-solving experiences are used to consider only those paths that might potentially lead to the solution. The problem is that there are no specific guidelines as to the process of acquiring the rules or of then selecting them appropriately. This strategy requires knowledge of the goal state.

1.2.3. Model

The development of a suitable model is arguably the key step in problem-solving, and one to which the students' attention is repeatedly directed. An important aspect of purposeful modeling is knowing how to check that the model is responding sensibly to changes in conditions; Glaser and Chi (1988) have identified one of the key characteristics of expert performance as the conscious execution of such 'self-monitoring' skills.

Some physics educators have argued that students' evolution from folk realism to scientific realism can take place, at any level, only when the structure of the physics theory and physicists' mental processes are represented explicitly (Eylon & Reif, 1984; McDermott, 1993; Mestre, Dufresne, Gerace, Hardiman & Touger, 1993). This evolution may best be realized in <u>model-based instruction</u>. Some findings are worth noting in this regard:

- Students can learn the content of scientific knowledge meaningfully when it is presented in the form of models (Clement, 1989; White, 1993). This facilitates the development of scientific inquiry skills, especially critical thinking (Clement, 1989; Stewart, Hafner, Johnson & Finkel, 1992; White, 1993). Students' scientific discourse improves significantly, in particular when they are asked to defend the validity of their models (Stewart *et al.*, 1992; White & Frederiksen, 1990).
- Physics students engaged in model-based instruction are far more successful than their peers in resolving incompatibilities between their folk conceptions and physics theory (Halloun & Hestenes, 1987; Wells, Hestenes, & Swackhamer, 1995; White & Frederiksen, 1990).
- Modeling skills are generic. Physics students can successfully transfer modeling skills that they develop in specific situations into novel situations, within and outside the domain of instruction (Clement, 1989; Halloun & Hestenes, 1987; White, 1993; White & Frederiksen, 1990).
- Physics students who are initially of average or low competence benefit the most from model-based instruction (Halloun & Hestenes, 1987; White, 1993).

Schematic modeling is an epistemologic framework for physics instruction. This framework of instruction is founded on two tenets:

- *Models* occupy the content core of physics (or any science for that matter). A model in physics represents a set of physical systems in some respects, and serves well-defined purposes.

- *Modeling* is a systematic activity for developing and applying scientific knowledge in physics (or any science).

Consequently, the pedagogic expectation is that by learning how to structure the content of physics theory around models, and how to solve problems by modeling, students will reach a meaningful understanding of physics.

1.2.4. Alternative Conceptions

Alternative conceptions, at least those most deeply rooted, are associated with intuitive ideas or preconceptions acquired prior to school learning (Driver, 1986). For some authors (Preece, 1984), these ideas are not just learned from experience but built into the hardware of the brain.

One of the most important outcomes of research on alternative conceptions in science has been, undoubtedly, a better understanding of learning difficulties and the awareness of the necessity for profound changes in the teaching and learning process, to improve meaningful learning. Particularly important in this sense have been conceptual change strategies (Hewson, 1981; Posner, Strike, Hewson & Gertzog, 1982), based on the assumption that many difficulties in science learning have their origin in the knowledge students have acquired prior to instruction and in the ignorance of this knowledge by instructors.

The idea of science learning as a process of *knowledge construction*, starting necessarily from prior knowledge, appears more or less explicitly in recent research (Driver, 1985; Gil, 1983; Novak, 1987; Osborn & Wittrock, 1983; Posner *et al.*, 1982). As Novak (1986) points out: " The exciting thing that is happening now is that we are beginning to do the kind of research and instructional innovation that builds on our new psychological and epistemological insights and is leading to promising new educational programmes.... We are moving towards research that shows the important interplay between thinking and feeling and the parallels between the construction of meaning by learners and that done by creative mathematicians" and - it can be added - scientists.

Some experimental results (Hewson & Hewson, 1984) seem to suggest that an instructional strategy based on the model of conceptual change causes a much better acquisition of scientific conceptions than the usual mere transmission or reception of knowledge. Nevertheless, other authors (Fredette & Lockhead, 1981; Shuell, 1987) stress that conceptual change is often very difficult, even when prior conceptions are explicitly considered.

Alternative in "alternative conception" refers to the fact that students' knowledge about how the world works is *different* than that of the physicist. The use of "student conception," therefore, is synonymous with alternative conception. These terms contrast with "misconception," which is believed to be inappropriate for referring to students' alternative conceptions because it ignores the rational basis of those conceptions; they are rationally based on the students' experiences with the world and prove adequate for the person-on-the-street to accomplish most everyday tasks. Such conceptions cannot, therefore, simply be written off as wrong.

1.3. ANALYSIS OF THE PROBLEM

In a review of research on physics problem-solving, Maloney (1994) stated that although the research to date in physics problem-solving is informative, one of the key issues in need of investigation is the role of problem-solving in learning physics concepts. It is known from previous research that preparing students to become effective problem solvers and helping students to understand concepts are both difficult goals to achieve.

Numerous studies of problem-solving indicate that even after instruction, many physics students still have difficulty solving problems and continue to use novice problem-solving techniques rather than more advanced problem-solving techniques (Maloney, 1994). Likewise, numerous studies of conceptual understanding indicate that even after instruction, many physics students continue to have the same alternative conceptions they had before instruction (Wandersee, Mintzes & Novak, 1994).

One instructional method that has been used to address both problem-solving performance and conceptual understanding is explicit problem-solving instruction. Explicit problem-solving is instruction that directly teaches students how to use more advanced techniques for solving problems. Textbook problem-solving, on the other hand, often provides only a general outline of steps to follow for solving problems and does not usually provide explicit instruction on how to apply those steps.

Textbook problem-solving also tends to emphasize primarily the quantitative aspects of problem-solving, while explicit problem solving tends to emphasize both the qualitative and quantitative aspects of problem-solving. This emphasis on qualitative aspects may help students, not only to improve their problem-solving performance, but also to better understand the concepts and principles of physics.

Students often attempt to solve physics problem (a) by trial and error, (b) backward from a numerical answer provided in a textbook, or (c) by invoking a solution presented in class to a problem that they wrongly assume to be similar to the one on which they are working (Arons, 1981; Halloun, 1995; McDermott, 1993; Novak, 1987, 1994; Reif & Larkin, 1991; Strnad, 1986). They tend to view solving a physics problem mainly as a task for selecting mathematical formulae to relate variables in the problem (Halloun, 1995; Hammer, 1994).

Consequently, physics instruction suffers from (a) *low efficacy*, in the sense that students who are diagnosed before instruction as average or low-competence students remain at that level after instruction, (b) *short-term retention*, in the sense that even the best students forget most of what they learn shortly after completing a physics course (Tobias, 1990), and (c) *high attrition rates*, especially among students initially diagnosed as of low competence (Halloun & Hestenes, 1987; Tobias, 1990).

It is often considered that the embedding of problem-solving as a context for the conceptual knowledge of a discipline serves a number of functions, summarized by Hafner and Stewart (1995:111-2) as follows:

> *[it] allows to develop: (1) highly structured and functional understandings of the conceptual knowledge of that discipline; (2) general and domain-specific problem-solving heuristics; and (3) insights into the nature of that discipline as an intellectual activity.*

Within a given discipline, problem-solving ability is thus often seen, quite justifiably, as an end in its own right. However, many educational theorists have also highlighted both its general importance and its transferability. For example, Watts (1991:7) quotes the following summary from the instructional designer Bruner:

> *It is only through exercise of problem solving and the effort of discovery that one learns the working heuristic of discovery. The more one has practice of, the more one is able to generalise what one has learned into a style that serves for any kind of task one may encounter ...*

Although students may use only previously learned rules or conceptual understanding in the elementary levels of problem-solving, nevertheless they will be required to combine them in novel ways to approach a new situation. Moreover, even in this kind of restricted context, finding the solution to the problem and the new knowledge that may result can be seen as merely interim learning goals, albeit satisfying ones for the student.

What are claimed to be ideally retained from the process are 'higher order' skills (e.g., ways of analysing situations and identifying crucial factors or solution principles, the use of reasoning as opposed to the deployment of learned facts, the ability to break down a long problem into a series of smaller steps, etc.) which can lead to increased confidence in tackling similar classes of problem in the future.

Gick and Holyoak (1983) undertook a general investigation of the conditions under which problem-solving schemas prove most useful, and found that acquisition of such strategies is most likely to occur if learners are first presented with a number of analogous practice problems together with, not only their solutions, but also a statement of their common solution principle. Gick and Holyoak's conclusion does suggest that physics should be an ideal subject for the development of good problem-solving schemas, reinforcing the results of earlier experiments by Chi *et al.* (1981) which demonstrated that one of the main differences between experts' and novices' approaches to physics problems lay in the way in which they categorized problems prior to formal solutions. Novices tended to focus on 'surface' features of the problems (e.g. the presence of an inclined plane, regardless of whether the situation was static or dynamic), whereas experts grouped the problems in terms of the laws corresponding to the solution principle required.

Later studies by De Jong & Ferguson-Hessler (1986), Glaser & Chi (1988) and Zajchowski & Martin (1993) have indicated that, even among novices, the successful and unsuccessful problem-solvers can be differentiated by the way in which they sort their physics knowledge - the former doing so in a hierarchical manner according to large principle-oriented patterns and the latter in terms of surface characteristics.

Zajchowski and Martin's (1993) recommendations for instructors include:

(i) emphasizing the primacy of the information relating to the fundamental formulae and concepts

(ii) encouraging the classification of problems according to solution principles

(iii) illustrating (i) and (ii) by worked examples that present highly structured explanatory steps

(iv) minimising the use of 'non-formal' formulae

The importance of point (iii) had also been previously highlighted by Reed *et al.* (1985), who showed that learners are most likely to acquire transferable problem-solving skills if the 'practice' problems they are given to work on are accompanied by elaborated solutions. This issue has been further explored by McAllister (1995), who has pointed out that the form and order of presentation of many 'textbook' solutions to physics problems is that which is natural to the expert but often inverted from the point of view of the novice.

1.4. STATEMENT OF THE PROBLEM

Within the logistical constraints of the research situation and methodology [see sections 1.7, 1.8 and 1.9] the problem is stated as follows:
Students experience difficulties as regards kinematic equations as well as related physical quantities such as displacement, velocity, acceleration and time.

1.5. AIMS OF THE STUDY

The study aims in relation to the above problem are:

AIM 1 : To investigate whether students are able to *differentiate* between the first, second and third kinematic equations.

AIM 2 : To investigate whether students have a *meaningful understanding of the physical quantities* associated with kinematic equations.

AIM 3 : To investigate whether students are able to *interpret* and *analyse the given data* before attempting to solve a problem based on kinematic equations.

AIM 4 : To investigate whether students have the *minimum mathematical competencies* necessary for the manipulation of the kinematic equations.

AIM 5 : To investigate students' thought *processes when solving problems* based on kinematic equations.

AIM 6 : To comment on the *usage of problem-solving strategies*.

AIM 7 : To identify the *factors that impede a meaningful mastery* of problem-solving skills.

1.6. SCOPE OF THE STUDY

This study covers the following.

Chapter 2: The literature review

General theories concerning problem-solving and problem-solving strategies will be investigated more rigorously by referring to the literature. This will be undertaken with particular reference to specific prior studies on alternative conceptions and problem-solving in kinematics in a broader South African context. Various textbooks will also be critically evaluated with particular emphasis on any preferred ordering of topics, suggested problem-solving strategies, and definition of the knowledge baseline of students investigated in this study.

Chapter 3: The research questionnaire
This chapter will focus on the nature of the questions used.

Chapter 4: Study 1: Analysis of written responses
This chapter will focus on the analysis of the written responses.

Chapter 5: Study 2: The workshop intervention
This chapter will report on the workshop intervention which is basically used to ensure reliability, validity, and the richness of data collected in this study.

Chapter 6: Summary of findings, conclusions and recommendations
This concluding chapter summarises the findings, draws conclusions and suggests recommendations as far as problem-solving with specific focus on kinematics is concerned.

1.7. SAMPLES USED IN THE STUDY

The work will be conducted in 1998 mainly with 86 first year university physics students (PHYS100) at the University of the North (UNIN). This course is a component of the three-year B.Sc. curriculum which is offered at UNIN. Some of these students come from academically disadvantaged backgrounds. Unlike the PHYS110 course, a student who passes PHYS100 can proceed to PHYS200. MATH100 is a compulsory ancillary course that must be taken before, or simultaneously with, the PHYS100 course. In the PHYS100 course, students study mechanics, waves and optics, thermal physics, modern physics, electrostatics and direct current theory.

1.8. METHODOLOGY

This study is confined to first year university physics students. Tests will be conducted after instruction or tuition. Problems (questions) to be used will be based only on motion in a horizontal or vertical line. i.e. motion along an inclined plane is not to be considered in this study, since it involves the use of components.

1.8.1. Analysis of Written Responses (Study 1; Chapters Three & Four)

A Research Instrument consisting of twelve (12) short questions will be compiled and will be completed by all respondents in the sample. Details of this questionnaire (shown in Appendix 1) will be discussed in Chapter Three and the analysis of the responses will be discussed in Chapter Four. It is crucially important to note that the compilation of the research instrument is not trivial in this regard. Problems will have to be carefully selected so that they satisfy a particular objective. In other words, there has to be a coherent and mutual relationship between the selected problems (questions) and the aims in this study. Problems (questions) to be utilised will differ in nature to adequately cater for the key areas to be investigated. Some questions will serve as a critical evaluation of students' conceptual understanding of the various quantities associated with kinematic equations, while others will critically assess the conceptions students hold when solving problems based on kinematic equations.

1.8.2. The Workshop Intervention (Study 2; Chapter Five)

The following methods will be used as part of the workshop intervention to ensure reliability, validity, and richness of data collected:

(i) *Think-aloud sessions* as a means of recording the problem-solving behaviour of participants. The transcripts will be used to capture the train of thought of the solver, and the problem-solving knowledge and style used.

(ii) *Pen-and-paper sessions* to explore the information accessed and used to solve a problem, and to supplement the think-aloud data collected.

(iii) *Observations* to record knowledge that might not be verbalized (e.g., checking the text).

(iv) *Interviews* to seek clarification of data collected.

All participants in this regard will be volunteers. Prior to each session, the participants will be informed that the aim of the data collection is to determine how they go about solving the problem, and to obtain information used by them to solve the problem. The following instructions will be stressed:

- Please verbalize every thought of action.
- The exercise is not a test of your ability to solve the problem, but is for data collection on problem solving.
- Help not pertaining to the solution of the problem can be obtained.
- You may take as long as you wish.
- You may refer to the text provided or your notes at any time during the session.

The verbalizations will be audiotaped. The researcher will observe and take notes to document actions that are performed but not verbalized. Participants will be politely reminded by the researcher to keep verbalizing if they stop or if their voice seem to fade. The verbalizations will be transcribed to obtain the problem-solving transcripts. These will be analyzed and used to make choice of questions for further research and programme development.

1.8.3. Coding the Transcripts

To obtain insight into the individual problem-solving process, and to describe it in detail, each transcript will be coded to document an action, with the aim of being able to identify and label actions performed by the participants. Each action can be classified as a physical or a cognitive activity. These two activities capture the problem-solving process. The coding will be commenced by reading each transcript from the beginning. When the first cognitive or physical activity is encountered, it will be noted and reading of the transcript will be carried on until the next activity is identified or inferred. The beginning of the second activity is used to mark the end of the first. In this way, apart from the first and the last activities, each activity is deemed to end with the commencement of the next activity and to begin with the end of the previous activity. It should be clarified that the activities are not determined by the size of the statements used by the participants to describe their actions.

A paragraph, a sentence, or merely a couple of words can represent or constitute an activity. The labeling is commenced by identifying and naming the first activity encountered in the transcript. As the transcript is read more labels of activities will be created each time an action performed cannot be classified or included within the existing label. Before the creation of a new label, an attempt will be made to classify the action within the existing category of activities. Care will be taken to ensure that each activity is distinct and descriptive as well as representative of a different action. This will be done by contrasting each newly created activity with the existing set with the aim of identifying the minimum number of activities required to describe the problem-solving process of each participant. In this way, every portion of each transcript is labelled and coded with the activities identified.

1.8.4. Analysis of Data

The data collected provide insight into the problem-solving activities performed by the participants. Dhillon (1995) has categorised fourteen activities and labelled them as: checking, pictorial representation, quantitative representation, question reading, relating-quantities, reference, symbol usage, clarifying, comparison, declaring quantities, qualifying, qualitative analysis, recapitulating, and resolving difficulties. The first five activities involve the possible performance of physical actions by the participants, whereas the others are more cognitive in nature. It should not be assumed that the first five do not involve a degree of cognitive processing as well.

It should be noted that these activities are interrelated in the problem-solving process. For example, when resolving a difficulty, participants might recapitulate, perform quantitative representation, and qualify work being done. Furthermore, there is overlap between the activities. For example, in the process of recapitulating, the participants would also relate quantities. The activities highlight the actions that students perform or would wish to perform within the problem-solving strategies reported in the literature. Each of the activities will be discussed briefly with excerpts from the transcripts used to provide examples of their occurrence within the problem-solving process. The excerpts will be provided in two columns. The first column consists of the verbalizations transcribed, and the second the researcher's comments to place the excerpt in context.

1.8.4.1. *Checking*

Checking involves ascertaining the logic of the steps undertaken and the correctness of the mathematics used. An example of a check to be performed is by substituting numerical values and using practical experience and knowledge to determine the possibility of the answer being correct.

1.8.4.2. *Clarifying*

Clarifying involves attempting to make sense of the information under current consideration. Clarification will be done by referring to the text, by verbalizing the difficulties encountered, and by evaluating the current work being performed. e.g., the text will be used to obtain clarification of formulae and the information required.

1.8.4.3. *Comparison*

Comparison includes the use of examples and information of a nature similar to that under consideration in attempting to make sense of the situation. As an activity it merely involves the making of a comparison with other examples seen as similar to the problem under consideration.

1.8.4.4. *Declaring Quantities*

Declaring a quantity is the process whereby a participant mentions or uses a quantity. Declaring involves mentioning a principle or quantity, an equation, an expression using one or more quantities, or merely stating a value for a quantity.

1.8.4.5. *Pictorial Representation*

Pictorial representation refers to drawing a diagram and marking information on it.

1.8.4.6. *Resolving Difficulties*

Resolving difficulties involves trying to correct a mistake and finding means to perform the next step in the solution to the problem.

1.8.4.7. *Qualitative Analysis*

Qualitative analysis involves describing the motion of an object to make sense of the situation.

1.8.4.8. *Qualifying*

Qualifying involves using the content knowledge and principles to make deductions and to provide supportive information to connect the solution steps. This is done to stipulate and convince oneself of the conditions, or terms, under which the deduction or connection of the solution steps is in line with the underlying physical principles.

1.8.4.9. *Quantitative Representations*

Quantitative representations include using numbers or algebraic symbols to represent quantities, choosing and writing equations, and performing mathematical manipulations.

1.8.4.10. *Question Reading*

Question reading involves referring to the question.

1.8.4.11. *Recapitulating*

Recapitulating involves recalling prior work done by going back to previous steps to make corrections if necessary.

1.8.4.12. *Reference*

Reference refers to the process of accessing information from the text or from lecture notes.

1.8.4.13. *Relating Quantities*

Relating quantities involves using previous experience and knowledge to recall information needed to proceed in the solution of the problem.

1.8.4.14. *Symbol Usage*

Symbols are used to represent algebraically physical quantities used in the problem solution.

1.9. LIMITATIONS OF THE STUDY

This study will be confined to first year university physics students in the PHYS100 course at UNIN, some of whom come from academically disadvantaged backgrounds. Therefore the sample used represents only a subset of the population of physics students at UNIN and indeed at comparable South African tertiary institutions. There are obviously interesting issues like gender, age and language, but these will not be investigated in this study. Nevertheless the findings of the study may have important implications in a much broader South African context.

NOTE: We remind the reader of the distinction we are making between the terms <u>activity</u> and <u>strategy</u> (see p.2). Activity is a micro-skill while strategy is a macro-process. For easy reference in reading later chapters, the ten (10) strategies and fourteen (14) activities are listed in Table 1.1 (p.25).

TABLE 1.1: Strategies and Activities

Ten Strategies		*Fourteen Activities*	
1. Analogy	*(p.7)*	*1. Checking*	*(p.22)*
2. Brainstorming	*(p.7)*	*2. Clarifying*	*(p.22)*
3. Envisioning	*(p.7)*	*3. Comparison*	*(p.22)*
4. Forward strategy	*(p.7)*	*4. Declaring Quantities*	*(p.22)*
5. Generate and test	*(p.8)*	*5. Pictorial Representation*	*(p.23)*
6. Heuristic search	*(p.8)*	*6. Resolving Difficulties*	*(p.23)*
7. Means-end analysis	*(p.8)*	*7. Qualitative Analysis*	*(p.23)*
8. Problem abstraction	*(p.8)*	*8. Qualifying*	*(p.23)*
9. Problem decomposition	*(p.9)*	*9. Quantitative Representations*	*(p.23)*
10. Working backward	*(p.9)*	*10. Question Reading*	*(p.23)*
		11. Recapitulation	*(p.23)*
		12. Reference	*(p.24)*
		13. Relating Quantities	*(p.24)*
		14. Symbol Usage	*(p.24)*

CHAPTER TWO

THE LITERATURE REVIEW

2.1. INTRODUCTION

All the sciences, both pure and applied, are centrally concerned with developing and systematizing knowledge useful for solving various kinds of problems. Hence education in the sciences must address the crucially important task of teaching students to become proficient problem-solvers. This task is difficult because most students find it considerably easier to acquire a knowledge about science, than to acquire the abilities for applying this knowledge flexibly to diverse problems. Nor is this situation too surprising since problem-solving is a very sophisticated cognitive skill. Hence understanding and teaching scientific problem-solving is both practically important and intellectually challenging.

Problem-solving is considered basic for developing an understanding of the processes as well as the content of science. A better understanding of the role of problem-solving abilities in the learning process would enable one to more fully comprehend the nature of learning. This study is based on a large body of research on physics problem-solving.

This chapter reflects specifically on the following aspects: problem-solving, differences between expert and novice, problem-solving skills, alternative conceptions in mechanics, problem-solving strategies, conflicting trends in the literature, problem-solving and conceptual understanding, instructional strategy, the Ausubelian tradition, the Piagetian tradition and the cognitive science tradition.

2.2. PROBLEM-SOLVING

A problem exists when there is an imbalance between the concepts inherent in the problem situation and conceptual schema of the individual. Festinger (1962) referred to this imbalance as "cognitive dissonance", which motivates the individual to solve the problem. Gagne (1965) stated that problem-solving requires the combining of prior knowledge into a new higher-order that solves the problem. Novak (1977a) indicated that problem-solving requires a reorganization of information stored in memory to reach a special goal - the solved problem - and that if the problem requires new information, it requires a search process.

2.2.1. Differences Between Expert and Novice

Numerous studies have documented the problem-solving techniques of novices and have compared them to the techniques that experts use when they solve problems (Chi, Feltovich & Glaser, 1981; Larkin, McDermott, Simon & Simon, 1980; Larkin & Reif, 1979). These researches identified important differences between the ways experts and novices solve problems, which in turn have been used to help teach students how to solve problems. For example, experts tend to represent a problem qualitatively in terms of fundamental physics concepts before they translate the problem into mathematical equations, while novices often tend to plunge into mathematical manipulations of equations with little if any qualitative description of the problem (Larkin *et al.*, 1980). Experts also tend to engage in more planning than novice problem solvers. Experts tend to carefully consider alternatives and to develop plans of attack before manipulating equations, while novices tend to immediately work from first impressions without developing plans (Larkin, 1981; Larkin *et al.*, 1980; Reif & Heller, 1982). Experts also tend to carry out solutions to problems differently from novices.

Among other things, experts tend to solve problems in a more logical, organized manner than novices (Woods, 1989). When experts know the solution to a problem, they tend to work <u>forward</u> using the "givens" in the problem to select the appropriate equations and calculate the desired unknown variable (Larkin *et al.*, 1980). When experts are faced with a problem for which they do not immediately know the solution, they tend to solve equations algebraically by working backward, starting with the unknown variable to be found, substituting the "givens" into this equation, and then solving for the unknown variable (Larkin, 1983).

Research on the differences between experts and novices has led in turn to the development of explicit problem-solving strategies designed to teach students how to use more advanced techniques. Numerous studies have reported that explicit problem-solving instruction can help improve students' problem-solving performance more than traditional or textbook problem-solving instruction (Heller, Keith & Anderson, 1992; Heller & Reif, 1984; Larkin & Reif, 1979; Mestre, Dufresne, Gerace, Hardiman & Touger, 1993; Reif, Larkin & Brackett, 1976; Van Heuvelen, 1990; Wright & Williams, 1986). Each of these studies measured slightly different aspects of problem-solving performance but, in general, students who learned the explicit problem-solving strategies exhibited more advanced problem-solving performance, including better qualitative descriptions of problems, more extensive planning, and more complete solutions.

2.2.2. Problem-Solving Skills

Greeno (1978a) observed that when instruction emphasizes a discovery-problem-solving approach, students achieve greater problem-solving skill development than when problem solutions are simply illustrated to the students. Sternberg (1985) and Simon and Simon (1978) stressed that students meaningfully learn problem-solving skills through concrete experiences. Mayer (1975) noted that students given meaningful instruction showed greater skills in problem identification and problem-solving.

If a goal of science education is to develop problem-solving skills of students, instruction must be devoted to problem-solving. Unfortunately, many science students receive instruction where the only learning strategy is that of rote memorization and recall (Smith & Good, 1984). They concluded that rote memorization of information does not improve the problem-solving ability of students. Science teachers are frequently in a hurry to teach facts, rather than develop students' thinking (Osborn & Freyberg, 1985). This is further evidenced by findings that 95% of science teachers use a textbook 90% of the time (Stake & Easley, 1978). Newmann (1988) stated: "The addiction to coverage fosters the delusion that human beings are able to master everything that is worth knowing" [p. 346]. Even when a laboratory instructional strategy is used, it is often a means of verification of what the student was taught during lecture (Blum, 1979), not to solve problems in science. Brandwein (1981) found that most science students do not conduct one experiment where the solution is unknown throughout the academic year. Such instructional approaches fail to develop problem-solving skills of students, to relate the importance of problem-solving to science, and do not enhance the development of higher-order thinking skills. Educators who do not believe in teaching problem-solving find that their biggest challenge is to integrate problem-solving into their instruction (Woods, 1977).

The success of applying knowledge to a problem is related to the degree that existing knowledge in the long-term memory can be related to the problem in a meaningful manner (Greeno, 1978a). Meaningful acquisition is dependent on the problem solver's available and relevant concepts in memory. Thus, problems are formulated by concepts embedded within the conceptual schema of the student (Freundlich, 1978). The understanding of problems is then facilitated by the integration of the problem-solver's existing knowledge with the problem (Greeno, 1978a). Therefore, problem-solving is dependent on the information represented in memory and how the information is retrieved and applied to problem situations.

While problems are diverse, all problems have three basic components: given information, operations to be used to solve the problem, and a goal or description of the solved problem. In addition, there is a series of "states of knowledge" that the problem-solver passes through while solving the problem (Glass *et al.*, 1979). The states of knowledge that the problem-solver passes through are: the initial knowledge state, the current knowledge state and the goal state. The initial knowledge state consists of the information known about the problem. The current knowledge state is the outcome of the application of the operator.

There are several common steps for solving problems:

(1) accepting and understanding the problem

(2) planning a solution

(3) implementing the plan

(4) testing/checking the results that lead to a solution.

Through this process the problem solver creates a problem space, which is a mental representation of the problem that includes a description of objects, the initial problem situation, the necessary operator(s) to solve the problem, and an idea of the goal or final state - the solved problem (Newell & Simon, 1972).

The problem- solver's ability to transform a problem into a problem space requires a process for identifying concepts in the problem that are related to the problem solver's existing knowledge (Greeno, 1978). In other words, understanding the problem constructs the problem space and determines the problem-solving procedure used to explore and solve the problem (Simon, 1978). The problem can be represented in more than one problem space, depending on how the problem solver defines or re-defines the problem (Glass *et al.*, 1979).

To solve problems a repertoire of thinking skills are needed, which may be acquired through experiences in science courses (Butts, 1981). According to Presseisen (1985) thinking skills essential for problem-solving are: assembling of facts, determining if additional information is necessary, inferring or suggesting alternative solutions and testing them, reducing to simpler levels of explanation, eliminating discrepancies, and checking solutions for generalizations. Meta-components include recognizing a problem, defining the problem, deciding on a problem-solving procedure, allocating time and resources, monitoring the solution to the problem, and forming a mental representation.

Performance components are used to execute the meta-components and provide feedback, and vary by discipline. Typical performance components include inductive reasoning, deductive reasoning, spatial visualization, and reading. Knowledge acquisition processes are used to learn concepts or procedures. Selective encoding involves screening information, whereas selective combination involves assembling and organizing relevant information, and selective comparison involves relating existing knowledge to new information.

Freundlich (1978) indicated that students need to experience meaningful problems, that is, problems which have been formulated to the students' conceptual schema. Thus, the problem needs to be identified and defined by the student. Zoller (1987) differentiated problem-solving instruction from exercise-solving instruction. Exercise-solving instruction is that which requires students to solve problems by merely applying a known procedure to obtain the correct solution i.e. the solution required by the teacher. Problem instruction, on the other hand, can be defined as a strategy where students construct their own solution to a problem. The problems students solve should not contain "guaranteed" solutions, but require the application of science concepts (Freundlich, 1978). Teaching students how to solve physics problems is only one of the many goals of physics instruction. Another important goal is to help students develop an understanding of the concepts and principles of physics. It is clear that beginning physics students have great difficulty learning physics concepts.

The curricular document (Alberta Education, 1996) refers to problem-solving as a 'variety of processes used to obtain a desired result' and suggests that 'the skills of problem-solving include: identifying what is needed, proposing ways of solving the problem, trying out ideas and evaluating how things work' (p. A.3).

A series of stages (not necessarily sequential) are suggested: focus; explore and investigate; reflect and interpret.

2.2.3. Alternative Conceptions in Mechanics

A vast array of science education research into students' construction of scientific concepts concludes that most students exhibit creativity and intransigence in their quest to circumvent the construction of scientific concepts (Driver *et al.*, 1994; Loughran & Derry, 1997; Pfundt & Duit, 1994; West & Pines, 1985), that is, to circumvent assimilation and at the same time avoid expending unnecessary effort. When students learn science within a multicultural environment, they need to move between their everyday life-world of school science. For a small proportion of students, crossing these cultural borders does not present problems serious enough to affect their learning of science. But many do experience serious problems and must deal with cognitive conflicts between these two worlds. According to Aikenhead & Jegede (1999), this conflict is played out daily in science classrooms around the world where science students are expected to construct scientific concepts meaningfully.

Much existing research focuses on employer's requirements in general terms rather than in terms of science. For example, in a recent report, Harvey *et al.* (1997) used in-depth interview techniques to explore 'what employers think significant'. They conclude that what employers want for the twenty-first century is recruits who are adaptive (e.g. with good interpersonal skills), adaptable (e.g. able to respond well to change) and transformative (e.g. able to analyse and synthesise).

Many international studies (Trowbridge & McDermott, 1981; McDermott, 1984) have shown that the conceptual difficulties encountered by pupils and students in Newtonian mechanics have their origins in their understanding of kinematical concepts such as speed, velocity and acceleration. A literature study shows that extensive research has focussed on kinematical concepts and on dynamical concepts (McDermott, 1984; Halloun *et al.*, 1985) but there is scarcity of research concerning students' understanding of sign conventions in mechanics. Phenomenographic studies in specific domains have made a contribution to the characterization of students' differing understanding of concepts (Lybeck *et al.*, 1988; Linder, 1996).

Research indicates that a significant number of students do not master the basic kinematical ideas in the first year of introductory physics (Trowbridge & McDermott, 1980, 1981). Aquirre (1988) also suggests that teachers of introductory physics need to give explicit consideration to study of vectors. Inconsistencies that are abundant in textbook discussions of vector quantities especially the treatment of velocity and acceleration, not only fail to remove the inconsistent interpretations but often introduce needless additional inconsistencies.

University students' understanding of the concept of velocity in one dimension was also investigated (Trowbridge & McDermott, 1980). Students have difficulty in separating the concepts of velocity and position at a particular instant. Students' understanding of the concept of acceleration in one dimension was investigated (Trowbridge & McDermott, 1981). Even after instruction, some confused the concepts of velocity and acceleration.

In the graphical analysis of motion, there was also confusion about the meaning of velocity as shown in the velocity-time graph (Peters, 1982). One graph showed velocity being positive during the entire motion, despite the reversal of the glider. In examining the results, there was confusion between velocity and acceleration and between acceleration and the time rate of change of speed. Students who lacked mathematical skills often focussed on the mathematics and less on the scientific principles.

Results from an investigation of students' understanding of speed, velocity and acceleration indicated that the majority of the students did not realize that acceleration involved a change in speed (Champagne *et al.*, 1980). Research by Lawson (in McDermott, 1984), reflects that the difficulties that students had with the dynamical concepts were often confused with difficulties by kinematics. In addition, a lack of understanding of the concepts of a vector and an inability to apply rules of vector algebra to the situation at hand were significant problems for many students.

Over the past two decades, international research on students understanding of science concepts has produced a vast literature that has attempted to describe that understanding. Much of the research has catalogued the interpretations that students have of scientific concepts (e.g. Boeha, 1990) and many of the researchers have attempted to explain the origins and nature of these interpretations (e.g. Bliss & Ogborn, 1994). The terms *alternative frameworks* (e.g. Terry & Jones, 1986), *alternative conceptions* (e.g. Ramadas et al., 1996), *student prior conceptions* (e.g. Driver, 1988), *misconceptions* (Hestenes, 1992), *preconceptions* (e.g. Arons, 1990) and *conceptual profiles* (e.g. Mortimer, 1995) have been used to refer to the various interpretations of scientific concepts that are at odds with the well-defined meaning of these concepts held by the scientific community. The research on the various students' interpretations of scientific concepts has generated a constructivist perspective that seems to be a major influence in science education (Matthews, 1997; Mortimer, 1995).

2.2.3.1. Conflicting Trends in the Literature

Conflicting reports and suggestions have appeared in the literature. Compare and contrast the following two statements:

- Research should not only discover the form of the misconception, but also the factors which could cause or influence the construction of this view by an individual. This could provide the necessary basis for the constructive intervention by the educator. Physics is known as being an especially fertile soil for students' misconceptions. A huge edifice, which today we call physics, consists of various domains. **The importance of mechanics is more than just being one of these domains. It determines the 'rules of the game', defines the main tools in physics, presents the most universal laws in nature. It actually describes the method of the discipline of physics which is then applied in all other domains in this discipline. This is why mechanics always opens any physics curriculum** (Galili, 1995, p.371; emphasis added).

- What should be our goals? Is the central purpose of physics instruction to uncover the students' misconceptions, to confront them with counter-intuitive examples which many physics teachers themselves misinterpret the first time they see them (after that, they are logical) and then to hone the students' skills in recognizing and avoiding such snares? This sounds suspiciously like electro-shock treatment, in which the temporary disorientation opens the otherwise resistant patient to the guidance of the therapist in constructing a better version of reality. Physics is a spiral subject and significant misconceptions tend to get corrected with further exposure and experience.... **If content must be reduced, truncate mechanics. It may be that the subtleties of Newton's laws of motion should be reserved for professional physicists** (Geilker, 1997, p.107; emphasis added).

On the other hand, Galili emphasises the centrality of mechanics in the physics curriculum; yet on the other hand Geilker suggests that the mechanics content of the curriculum should either be reduced or removed. Galili and Geilker also make statements about misconceptions that are very contradictory. One suggests the constructive intervention of the educator, while the other seems to suggest that misconceptions will eventually wither through further experience.

How is the following statement:

- Our experience indicates that it is much easier to engage students intellectually in a learnin situation that is activity-centered than in a traditional laboratory/lecture format.... We recognize that if we want teachers to be able to provide this kind of instruction, we must give them the opportunity to learn in a hands-on manner (McDermott, 1991, p.306).

to be reconciled with the following two statements?

- One cannot discover what one cannot conceive. Likewise, students must become familiar with the Newtonian world before they can recognize reflections of the physical world within it and use it as a conceptual tool for understanding the physical world (Hestenes, 1992, p.733).

- As Hodson has commented, pupils need to spend more time interacting with ideas and less time interacting with apparatus (Osborne, 1996, p.272).

McDermott (1991), McDermott *et al.* (1994), together with Arons (1982, 1990) advocate a 'hands-on' *phenomenological* approach - a mixture of Piagetian constructivism and positivism [both speak of the need for students to have the ability to define concepts *operationally*, that is, to define the concepts in terms of the operations employed in applying them and the need for stu ;nts to *construct* their own concepts]. Operationalism and constructivism are cont radictory in that one is a passive affair, that knowledge is a summary of sense perception and the other is more of an active affair, that knowledge is constructed to make sense of experience. Hestenes (1992), on the other hand, discusses the teaching of mechanics as a *modelling game* whereby explicit models have to be constructed prior to any attempt to make sense of the physical world - so-much-so that experimental games are mode deployment games [this is consistent with Chalmers' (1978) argument that the... precedes experiment and that experiment and observation are theory laden; and Toulmin's (1967) point that a scientist does not perform an experiment without some theoretical idea in mind].

Concrete operational thinkers should be given the opportunity to interact with concrete objects and models. Von Glasersfeld (1995) offers what he calls a down-to-earth approach for teachers by outlining different types of conceptual change:

1. *Differentiation*, wherein new concepts emerge from existing, more general concepts - for example, velocity and acceleration emerging from generic ideas of motion.

2. *Class extension*, wherein existing concepts considered different are found to be cases of one subsuming concept - for example, rest and constant velocity coming to be viewed as equivalent from the Newtonian point of view.

3. *Re-conceptualization*, wherein a significant change occurs in the nature of and relationship between concepts - for example, the change from 'force implies motion' to 'force implies acceleration'....

Whereas, on the other hand, Champagne *et al.* (1982) stated a decade previously:

> The typical uninstructed student has the motion schema: 'A push produces motion'. As a result of appropriate instructional experiences, the student's motion schema could become: 'A force produces acceleration'. The fixed portion, 'push' in the initial schema has been replaced by a more general variable, 'force' which can take on several values in addition to 'push'. Similarly, the general variable 'acceleration', which can have different values, has replaced the initial schema's fixed portion, 'motion'. The modified schema is considerably more abstract and, hence, should have a much broader range of applicability.... *Empirical evidence on mechanics*

learning demonstrates that this instructional strategy is not generally effective and suggests that, while the gradual modification of schemata doubtlessly involves generalization and specialization, in highly integrated schemata more dramatic changes, amounting essentially to a shift to a new paradigm, must also take place (p.40; emphasis added).

2.2.4. Problem-Solving Strategies

Research indicates that alternative conceptions of mechanics are very prevalent among high school and college students, and that they are highly resistant to change (Clement, 1982; diSessa, 1982; Gunstone, 1987; McClosky, 1983; McDermott, 1984; Minstrell, 1982). One technique that has been used to address both problem-solving and conceptual understanding is explicit problem solving. Explicit problem solving tends to emphasize both the qualitative and quantitative aspects of problem solving, and it is this dual emphasis which may help students not only to improve their problem-solving performance, but also to understand concepts better. Textbook problem-solving, on the other hand, tends to emphasize primarily the quantitative aspects of problem solving, and some physics educators claim that an emphasis on the quantitative aspects of problem-solving may actually obscure students' understanding of physics (Hewitt, 1992).

In general, textbook problem-solving is characterized by a multi-step procedure used to solve one- or two-step physics problems. The strategy commonly used includes the following steps:

(1) Draw a sketch

(2) define known and unknown quantities

(3) select equations

(4) check the answer.

According to the textbook strategy, the first step in solving a physics problem is to draw a sketch of the problem situation. This sketch usually includes a simple drawing of all relevant objects and interactions. The second step is to define the variable by identifying both the known and unknown quantities in the problem.

The third step is to select the equations. Usually this involves selecting a mathematical relationship that contains the unknown quantity to be found and any other relationships that contain necessary unknown quantities. The fourth step is to solve equations by substituting the values that are given in the problem into the mathematical relationships and solving for the unknown. The final step is to check the answer; this is usually done by substituting the answer into a different equation to verify the accuracy of the answer.

Although on the surface the explicit strategy appears to be quite similar to the textbook strategy, the explicit strategy provides a much more detailed series of instructions for students to follow, including bridging steps that help students move from one step to the next. The explicit strategy can be viewed as a systematic series of translations, in which each step requires the student to translate the problem into increasingly more abstract and mathematical representations of the problem. By contrast, the textbook strategy merely provides a general framework for solving a problem and provides fewer specific instructions on how to perform each step and how to make the translation from one step to the next.

2.2.5. Problem-Solving and Conceptual Understanding

Classroom-based experimental studies that focus specifically on the effect of problem-solving instruction on students' conceptual understanding of physics are relatively rare in the problem-solving literature. The majority of research related to problem-solving and conceptual understanding focuses on the relationship between conceptual understanding and problem-solving performance, rather than *vice versa*. In one of the few studies on the effect of problem-solving on students' physics knowledge, Heller *et al.* (1992) reported that during the group problem-solving process of justifying statements, clarifying ideas, and elaborating on explanations, students appeared to be deepening their understanding of physics concepts and principles. However, this claim has never been formally tested.

There is a growing body of research studies which have investigated factors in relation to improving student learning of problem-solving skills. According to Fuller (1982), this research has proceeded in two directions: information processing, and constructing solutions. Information processing is concerned with the conscious (observable and measurable) steps of the problem-solver, while constructing solutions is concerned with the internal cognitive processes which result in these steps.

In information processing, researchers (e.g., Larkin & Reif, 1979; Champagne & Klopfer, 1981; Linn, 1982) have contrasted the problem-solving processes of the novice physics student and expert physicist. Their findings indicated that the novice student tends to look for an equation or a series of equations in which all the independent variables can be identified, thus leading to a solution for the dependent variable. By contrast, the expert physicist follows a process of successive refinements, starting from a general description (in words or pictures) to find the applicable concept, which ultimately leads to the appropriate equations and a solution.

In another aspect of the research in this area, Larkin and Rainard (1984) found that correct solutions were always accompanied by many spatial statements and incorrect solutions were accompanied by few spatial statements when analyzing student statements while they solved physics problems. In cognitive processes, Byron and Clement (1980) and Champagne and Klopfer (1981) found that the students' cognitive structure is filled with stable, alternative concepts of the physical world and was constructed from years of past experience. For example, they found that many students feel that more force means more speed and that the motion of an object implies the presence of a force. In addition, Reif (1986) suggested that the manner in which students organize knowledge in cognitive structure affects their performance of various tasks. He found that students who organized scientific information in a hierarchical manner performed better on recall, modification of an argument, and error diagnosis, as compared to those who or   ni..ed the same information in a linear manner.

In another aspect of research in this area, Pallrand and Seeber (1984) found that physics achievement was directly related to entering spatial-visual abilities. However, they found that student spatial-visual abilities increased as a result of taking a physics course. In addition, they stated that "Increases in spatial-visual abilities are manifest in those areas in which diagrammatic and graphical representation are found as well as in the laboratory phase of the progamme."

In summary, these findings indicate that the novice problem solver (as compared to the expert physicist) appears to lack the critical knowledge necessary to apply the appropriate equations or functions that ultimately result in the solution of a problem. In some cases, rather than a lack of knowledge, the novice has incorrect knowledge or cannot relate the knowledge to the task at hand. In addition, the visual-spatial cognitive skills, necessary for successful problem solving, are inadequately developed. Although traditional physics instruction improves these visual-spatial abilities, graphical representation or analysis enhances improvement of these abilities and hence problem-solving. Tobias (1976) reported that when graphic representation of algebraic functions was used in teaching algebra, performance improved significantly. Additional support for this position was given by Arons (1983):

> *A powerful way of helping students master a mode of reasoning is to allow them to view the same reasoning from more than one perspective. In the case of arithmetical reasoning a very useful alternate perspective is that of graphical representation. (p. 578)*

The authors of *An Application Guide to Open Use of APL in Teaching Science* (1975) stated that major concepts in science disciplines can be represented as functions.

Some are functions by which observations of nature are summarized and extrapolated, and others are conventions by which data is organized....The choice of functions by which data is treated determines the facts observed. Taken together, a collection of functions imposes a structure on the understanding of a topic. (pp.3-4)

Most concepts can be expressed as functions, especially in physics.

2.2.6. Instructional Strategy

A careful analysis of both end-of-chapter problem exercises and example solutions presented in popular physics textbooks (e.g., Sears, Zemansky, and Young, 1976; Miller, 1977; Serway, 1982) and of the 1974 Advanced Placement Physics Examination revealed two broad categories of physics problems: *Local problems* required discrete numeric solutions, while *global problems* required gener ations involving stating equations, plotting and interpreting graphs, describing relationships and models. In conventional physics instruction, student activities, laboratory activities and homework problems frequently emphasize the solution of *local* and *global* problems in a dichotomous manner.

Usually more emphasis is placed on *local* problems with discrete numeric solutions. Classroom instruction, laboratory activities, and homework problems frequently do not focus attention on functional relationships. By contrast, the teaching strategy used in this study emphasizes meaningful learning of concepts by treating both local and global problems in an inter-related manner. In class and laboratory investigations, students frequently explored concepts by examining functional data for patterns and relationships with calculators used to generate the functional data. To cite one specific example: class discussions in a unit on projectile motion frequently focus on determining the range and/or the maximum height of a projectile or other object given the initial velocity, height and the angle of inclination. The context of each problem is usually different (a projectile fired from a gun, a person diving from a diving board, etc.). From this experience and the solution of subsequent homework problems, the student develops important skills (local) in generating these numeric answers. However, he or she may not develop an understanding of important functional relationships.

Two traditions in science education have influenced research on learning and problem solving. Piagetian researchers such as Lawson (1975; 1979), Lawson and Blake (1976), Lawson and Nordland (1977), Renner and Stafford (1972), and Walker, Hendrix, and Mertens (1980) argue that the developmental stage of a student can be used to account for his or her success or failure with particular science content. Researchers utilizing the work of Ausubel (Novak, 1977) argue that relevant prior conceptual knowledge is the important factor in learning science content as well as in using that knowledge to solve problems. Research in each of these traditions has produced interesting results, yet it has not examined the relationship between students' conceptual knowledge and problem-solving strategies. A third research tradition, which more explicitly treats this relationship, is that of "cognitive science" (Greeno, 1978a; Larkin, 1980; Newell & Simon, 1972; Simon & Simon, 1979).

2.2.6.1. The Ausubelian Tradition

The focus of Ausubelian research has been on the influence of existing knowledge on learning. The means of assessing student knowledge acquisition has been to have them solve problems in paper-and-pencil and clinical interview situations (Atkin, 1977; Hibbard & Novak, 1976; Nussbaum, 1973; Pines, 1978; Thorsland, 1972). Atkin (1977) presents a strong case for isomorphy between learning and problem solving and this view is shared by Novak (1977): "... I see problem-solving as essentially a special case of meaningful learning..." (p. 108).

In a study of learning in a college physics course (Thorsland & Novak, 1974), students were rated on two dimensions: analytic ability and intuitive ability. In analytic problem solutions, the problem was attacked in a reasonably explicit fashion, a step at a time. Intuitive problem solutions were characterized by an implicit feel for the subject matter in which the problem-solver often arrived at an answer with little awareness of the steps taken. Thorsland concluded that students high on the intuitive dimension possessed a more differentiated cognitive structure, and were bringing higher level concepts to bear on the problem solution (than were students high in the analytic dimension). Although interesting, this study lacked an analysis of the problem-solving strategies employed by students in the analytic and intuitive categories; nor was any attempt made to correlate strategies with detailed analysis of individuals' cognitive structures.

Further research on college physics students by Naegele (1974) and Wesney (1978) provided evidence supporting Ausubel's dicta relating prior knowledge and achievement. Yet the lack of fine-grained tools for representing knowledge and problem-solving strategies precluded discussions of specific interrelations between knowledge and achievement.

2.2.6.2. The Piagetian Tradition

As with the Ausubelian tradition, problem-solving studies in a Piagetian tradition have not been common in science education. However, the theoretical positions taken by Piagetians, as well as the claims which they make about what should or should not be taught at particular grade levels, are intimately tied to problem-solving. This stems from their equation thinking with problem-solving (Lawson, 1979) and their use of problems (the Piagetian tasks) to assess an individual's level of schema development or success in various content domains (Cantu & Herron, 1978; Grant & Renner, 1975; Lawson, Karplus & Adi, 1978a; Walker, Hendrix, & Mertens, 1980).

In the context of teaching science for all, Aikenhead & Jegede (1999) described the act of cultural border crossing into school science and its cognitive explanation (collateral learning). They drew upon cultural anthropology which regards the learning of science as the acquisition of the culture of science. They opine that to acquire the culture of science, students must travel from their everyday life-world to the world of science found in their classroom.

2.2.6.3. The Cognitive Science Tradition

Newell and Simon (1972) and others have relied heavily on computer modelling to produce theoretical advances in the understanding of human problem-solving. These advances have included the categorization of problem types (Greeno, 1978b; Simon, 1978) and the analysis of strategies that individuals use when solving each type of problem (Greeno, 1978a). In addition, problem-solving has been studied in semantically rich domains such as engineering thermodynamics (Bhaskar & Simon, 1977), physics (Clement, 1979; Larkin, 1979; Simon & Simon, 1978), mathematics (Greeno, 1978a).

Greeno's (1978a) work emphasizes the interrelationships between the conceptual knowledge possessed by problem-solvers and their knowledge of the procedures their use to solve problems. He terms this m ningful problem-solving and, in many respects, it parallels Ausubel's discussion of the role that meaningfully learned concepts and generalizations play in problem-solving.

Greeno argues that all problem-solving is based upon two types of knowledge: knowledge of problem-solving strategies and conceptual knowledge. Knowledge of actions in a particular domain may be more useful than the acquisition of general strategies. Of course, knowledge of action, if it is action undertaken with understanding, will be intimately related to an individual's conceptual knowledge. The conceptual knowledge, as well as the procedural knowledge related to the problem, governs what "problem space" will be constructed by the problem solver. It is very likely that the nature of the initial problem space constructed greatly influences the rapidity and accuracy with which a problem is solved.

Effective cultural border crossing is indeed a complex event. The *cognitive* experience of border crossing is captured by the theory of collateral learning (Jegede, 1995). The phenomenon to which collateral learning refers is universal and well known worldwide and the theory was proposed to explain why many students experienced culturally related cognitive dissonance in their science classes (Jegede, 1995).

Collateral learning generally involves two or more conflicting schemata held simultaneously in long-term memory. Jegede (1995, 1996, 1997) recognized variations in the degree to which the conflicting ideas interact with each other and the degree to which conflicts are resolved. Collateral learning theory postulates a spectrum of cognitive experiences (parallel, simultaneous, dependent and secured collateral learning) to explain cultural border crossings. These four types of collateral learning are not separate categories but points along a spectrum depicting degrees of interaction/resolution.

At one extreme of collateral learning, the conflicting schemata do not interact at all. This is *parallel* collateral learning , the compartmentalization technique. Students will access one schema or the other depending upon the context. For example, students will use a scientific concept of energy only, never in their everyday world where commonsense concepts of energy prevail (Solomon, 1983). This segregation of school science content within the minds of students was called 'cognitive apartheid' by Cobern (1996).

At the opposite extreme of collateral learning, conflicting schemata consciously interact and the conflict is resolved in some manner. This is *secured* collateral learning. The person will have developed a satisfactory reason for holding on to both schemata even though the schemata may appear to conflict, or else the person will have achieved a convergence towards commonality by one schema reinforcing the other, resulting in a new conception in long-term memory. Between these two extremes of parallel and secured collateral learning there are varying degrees and types of interaction between conflicting schemata. In this context it is convenient to designate points in between the two extremes, one of which is called *dependent* collateral learning.

A great deal of descriptive research is needed to assess the knowledge and procedures used by students when solving problems in particular content domains.

CHAPTER THREE
THE RESEARCH QUESTIONNAIRE

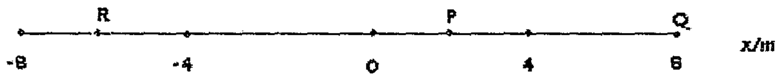
3.1. INTRODUCTION

Kinematics is a core foundation topic of physics. Importantly, it provides ample opportunity to teach and learn fundamental concepts and skills. To name a few: relationships between quantities, the use of words, graphs and functions in describing motions, the concept of change (velocity and acceleration), the role of mathematics in physics and the development of critical thinking in the remediation of misconceptions. This topic is also open to experimentation, allowing the development of theory based on experimental results.

This study was confined to first year university physics students. A questionnaire was developed and used as the basic research instrument in this regard. This questionnaire was administered to 86 university first year physics students after instruction or tuition. Problems (questions) used were based only on motion in a horizontal or vertical line. i.e. motion along an inclined plane was not considered in this study, since it involves the use of components. It is crucially important to note that the compilation of the research instrument was not trivial in this regard. Problems were carefully selected so that they satisfy a particular objective. In other words, a coherent and mutual relationship between the selected problems (questions) and the aims in this study was ensured. Problems (questions) utilised differed in nature in order to adequately cater for the key areas investigated. For example, some questions served as critical evaluation of students' conceptual understanding of the various quantities associated with kinematic equations while others critically assessed the conceptions students hold when solving problems based on kinematic equations. What follows is a discussion of the nature of the problems (questions) utilised.

3.2. QUESTION 1

Consider the figure below. Calculate the displacements and velocities and draw the velocity vectors.



(a) A moves from P to Q in 2,0 s.
Displacement of A.
Average velocity v_A.

(b) Now A moves from Q to P in 2,0 s.
Displacement of A.
Average velocity v_A.

(c) Say in words what difference you would see between cases (a) and (b).

3.2.1. Objectives

(i) *To differentiate between moment in time and time interval, and between distance and place (or position).*

(ii) *To develop an understanding that a vector quantity, i.e. displacement, is needed to describe where an object has gone to.*

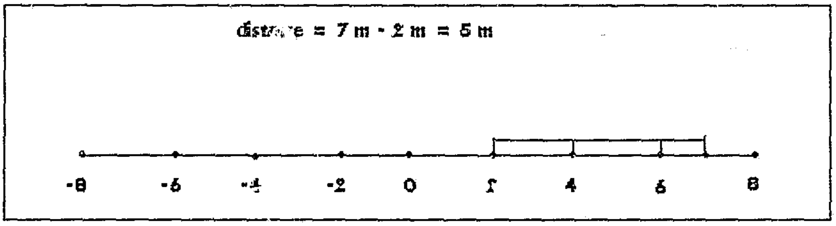
(iii) *To develop an understanding that a vector quantity, i.e. velocity, is needed to describe how an object moves.*

The focus of this question is to indeed establish whether students are able to distinguish between moment in time and duration. This becomes critical in developing an understanding about average and instantaneous velocity. If we allow an indiscriminate use by students of the terms 'moment in time' and 'duration' students do not develop the tools for analysing motions. The correct use of the terms by the students has to be ensured right from the start in teaching.

Moments are points on the time-line. One moment is chosen to be at $t = 0$ s. All other moments are then given by a number and a unit. **Periods** are segments on this line. A period (also called **time-interval**) is indicated by its start and end.

When we write: time-interval [-5,0 s ; 10,5 s], we mean: the period that starts at -5,0 s and ends at 10,5 s.
The duration of this period (its length of time) is calculated by:
duration = t_{end} - t_{begin}.
The duration of [-5,0 s; 10,5 s] is: 15.5 s. This is calculated by taking:
10,5 - (- 5,0) s.

The position for movements in a straight line can be represented on a number line. Consider the figure below:



The number line for position

Figure 3.1: The position for movements in a straight line.

Each position is a point on this line, indicated by a number. After choosing one point as the origin ($x = 0$ m), the coordinates of the other points can be given by a number.

Positions are points on the line. One position is chosen as the origin and given the coordinate $x = 0$ m. Each position is then given by a value and unit.

Again we could talk about position-intervals, indicated by start and end positions. We can talk about the length of that interval, i.e. distance.

Distance is the length of a position interval

See the figure above. If an object moves from place 2 m to 7 m, the distance moved is 5 m. If an object moves from place 2 m to 7 m, and then back to 2 m, the distance moved is : 5 + 5 = 10 m (the total length of the trip).

In order to define displacement properly, as a vector (change in position), it is necessary to define the position as a vector. However, to keep matters simple the displacement vector is defined as the vector pointing from the old position to the new position. To show the direction of movements we need to draw **vectors**. To do that, another definition is needed.

The **displacement vector** is the vector from starting position to end position of the movement. It points in the direction of the movement.

It is important to note that the question aims at developing the correct concept about 'negative' velocity. This serves to make students aware that a negative velocity does not mean that the object decelerates. A good understanding of the vector characteristics of the velocity is, therefore, crucial. Without this the change in velocity cannot be found, which is a crucial concept in developing the concept acceleration.

3.3. QUESTION 2

Explain in your own words the meaning of the following important definition:
"Uniformly accelerated motion is motion with a constant acceleration."

3.3.1. Objective

To establish whether students are able to differentiate between the words 'acceleration' and 'accelerating.'

The words 'acceleration' and 'accelerating' used in physics can be confusing. For example, consider the following statement: *The car is decelerating. The acceleration of the car is 5 m/s²*. This seems impossible; how can the car accelerate and decelerate at the same time? But we are actually using two words with two different meanings:

(a) The words *'accelerating'* and *'decelerating'* describe the type of motion of an object. For example, *if the speed increases*, the object is *accelerating (accelerated motion)*, *if the speed decreases*, the object is *decelerating (decelerated motion)* and if the *speed is constant*, the object moves *uniformly (uniform motion).*

(b) An object experiences *"acceleration"* when its *velocity changes.*

3.3.2. Example

Let the velocity of a car be -20 m/s at t = 3 s. Let the velocity be -5 m/s at t = 6 s. *"North"* represents a positive direction and *"south"* represents a negative direction in this case.

The speed of the car is: 20 m/s at t = 3 s, and it is: 5 m/s at t = 6 s.

The speed decreases, so the car is decelerating; it has a decelerated movement.

The **acceleration** of the car is: $a = \{v_{end} - v_{begin}\}/\{\text{time taken}\}$

$= \{(-5) - (-20)\}/\{6 - 3\}$

$= 5 \text{ m/s}^2$

Conclusion: The car is decelerating means the speed decreases while the acceleration of 5 m/s² means that the change in velocity is 5 m/s in every second.

The velocities in this problem are negative (i.e. southerly), while the acceleration is positive, i.e. in a northerly direction. In other words, a positive acceleration yet a decelerated motion. This is done on purpose to tackle the following incorrect understanding: It is commonly believed that a negative value for the acceleration simply means decelerated motion. This is incorrect. What the example has shown is that the acceleration was positive despite the fact that the body was slowing down (deceleration). In the correct approach the signs of both velocities (initial and final) and the acceleration have to be considered to determine the type of motion. The incorrect approach leads to serious misconceptions for problems in which objects are thrown upwards. In the school approach the acceleration is considered negative when the ball goes up and changes to a positive value when the ball goes down. This reinforces two serious misconceptions.

1. Changing from positive to negative value implies that the value must have been zero in between, in other words, the acceleration is 0 m/s^2 at the top (logical thinking but the conclusion is wrong).
2. Different signs imply that on the way up there must have been different forces compared to on the way down. This is also wrong; the only force on the way up and down is the force of gravity (if friction is ignored).

3.4. QUESTION 3

When does an object have velocity?

3.4.1. Objective

To establish whether students have an operational understanding of the concept velocity.

3.5. QUESTION 4

When does an object have acceleration?

3.5.1. Objective

To establish whether students have an operational understanding of the concept acceleration.

3.6. QUESTION 5

Aeroplanes flying long distances, for example from the U.S. to South Africa, generally fly at the same average air speed. Nevertheless it happens often that planes arrive at Johannesburg International Airport half an hour earlier or also, on other days, half an hour late. How is this possible?

3.6.1. Objective

To probe and establish the level of understanding of the fact that velocity can only be defined with respect to a frame of reference.

Velocity is often considered to be a property of a moving object. This question aims at establishing whether the students understand the fact that velocity describes the motion of one object in relation to another (e.g. the ground).

Consider the following conflict created to show the need for a frame of reference to define velocity, which is another interesting approach to make students mentally alert:

The class is asked: What is the velocity of a person sitting still on a chair? Then, what is the velocity of the chair the person sits on, the velocity of the ground underneath, the velocity of the building and finally the velocity of the Earth?

3.7. QUESTION 6

A boy runs a course of 100 m. Do you think this movement will be uniform throughout? Describe in words what you think will happen to the velocity from the start up to the moment he stops.

3.7.1. Objective

To probe and establish the level of understanding of the relationship between position and time.

3.8. QUESTION 7

What would you say about the direction of the velocity and acceleration for a decelerating object?

3.8.1. Objective

To establish whether students have a meaningful understanding of both the acceleration and velocity vector.

Accelerated and decelerated motions are characterized by *rate of change in velocity.* Often the *rate* of change in velocity is constant, for instance, in the case of acceleration due to gravity near the Earth's surface. The description of accelerated motions is more complicated than the description of uniform motion.

Change in the quantity = final value of the quantity - initial value of the quantity **or** **final value of the quantity = the initial value of the quantity + change in the quantity**

Students can do simple exercises on acceleration. E.g., Given the velocity at two different times students can apply the algorithm: $a = (v_{final} - v_{initial})$/time required and find the acceleration. Despite this students often completely lack a conceptual understanding of acceleration. An example showing this lack of understanding is given below:

A ball is thrown upwards. The ball goes up and comes down again.

1. Consider the *acceleration* of the ball at the highest point.

   What is its magnitude?

   Answer: *The magnitude of the acceleration decreases.*

   What is its direction?

   Answer: *The direction of the acceleration is upwards.*

3.8.2. Acceleration is a vector quantity

The definition of acceleration is given below:

$$\text{Rate of ch-ge in velocity} = \text{acceleration} = \frac{\text{velocity}_{change}}{\text{time}_{required}}$$

Velocity is a vector so the change in velocity is also a vector. The acceleration is the quotient of the change in velocity (a vector) and time (a scalar) and, therefore, a vector itself. The fact that acceleration is a vector must be used in the analysis of movements.

3.8.3. Change in velocity

Acceleration is based on the change in velocity so the change in velocity should be discussed first.

Change in velocity = final velocity - initial velocity

or

$$\Delta v = v_{final} - v_{initial}$$

or

$$v_{final} = v_{initial} + \Delta v$$

In words: the final value is the initial value plus the change.

3.8.4. Example

A person walks to the right with a velocity $v = 2,0$ m/s. The person starts walking faster and 3,0 s later $v = 5,0$ m/s. What is the magnitude of a? What is the direction of a?

So:	$v_{initial} = 2,0$ m/s and $v_{final} = 5,0$ m/s
Thus:	$\Delta v = v_f - v_i = 5,0 - 2,0 = 3,0$ m/s
hence:	$a = \Delta v / t = 3,0/3,0 = 1,0$ m/ s^2

The change in the velocity vector is to the right, therefore, the acceleration vector is also to the right.

3.8.5. Method for drawing the vectors

$\Delta v = v_f - v_i$ which is a subtraction of two vectors. It is easier to draw a vector addition. For that we rewrite the equation: $v_{final} = v_{initial} + \Delta v$.

1. Draw $v_{initial}$. Draw v_{final}. The tails of both vectors must start at the same place (dotted line P).
2. Draw Δv: - The tail of Δv is at the head of $v_{initial}$ (dotted line Q).
   - the head of Δv is at the head of v_{final} (dotted line R).

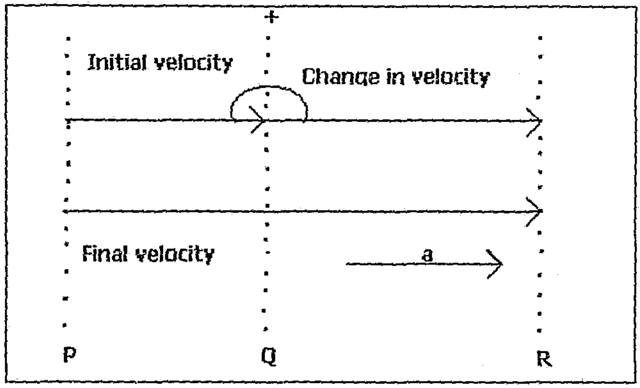


Figure 3.2: Method for drawing vectors.

It is clear from the diagram above that: $v_{final} = v_{initial} + \Delta v.$

Note that all vectors are in the same direction and should therefore be drawn on one line.

3.9. QUESTION 8

Which type of velocity, instantaneous or average, is being discussed in the statements below? Explain your answer.

(a) "My car is faster than yours, occasionally it goes at 130 km/h."

(b) "No, my car is faster, it can keep going at 125 km/h."

(c) "The maximum speed of an athlete is 10 m/s because running a distance of 100 m takes 10 s."

3.9.1. Objectives

(i) *To probe and establish the level of understanding of the average and the instantaneous velocity.*

(ii) *To probe and establish the level of understanding of the fact that formulas* *have limited application ranges.*

3.9.2. Uniform motion

The following definition for uniform motion is used in this instance.

If the instantaneous velocity does not change, the motion is UNIFORM.

For all movements the **average velocity** in a time interval is:

$$velocity_{average} = \frac{displacement}{time}$$

If the movement is uniform, **the instantaneous velocity** at any moment :

$$velocity_{instantaneous} = velocity_{average} = \frac{displacement}{time}$$

It is crucially important to note that the average and instantaneous speeds are measured in different ways and have different values. They are not the same quantities. Average speed is distance over time taken and for the instantaneous speed, v is not equal to x /t.

3.10. QUESTION 9

A trolley accelerates uniformly from rest and reaches a velocity of 5,0 m/s after 7,0 s. A student is asked to calculate the distance covered during these 7,0 s. He answers as follows: distance = velocity x time = 5,0 m/s x 7,0 s = 35 m

What are the mistakes made by the student? Explain how the student has reasoned and his/her confusion about certain quantities.

3.10.1. Objectives

(i) *To establish whether students are aware of the notion that formulas have certain application ranges.*

(ii) *To investigate students' thought processes when solving problems based on kinematic equations.*

3.11. QUESTION 10

A raindrop falls from a cloud downwards. The cloud is at a height of 500 m above the ground.

(a) If there were no air resistance, how long would it take to reach the ground, and what is the velocity when it hits the ground?

(b) Is this realistic? Why/Why not?

3.12. QUESTION 11

An object is thrown vertically upwards with an initial velocity of 10 m/s.

(a) How long will it take to come back to the initial position?

(b) How high will it go?

(c) How long will it take to reach the maximum height?

(d) How long will it take to reach the thrower's hand?

(e) With what velocity will it reach the thrower's hand?

(f) When will it be 1 m above the thrower's hand?

(g) If the object misses the thrower's hand, with what velocity will it move 1 m below the thrower's hand?

3.13. QUESTION 12

An object starts from rest and attains a final speed of 10 m/s, after increasing its speed uniformly for 5 seconds.

(a) How far has it moved?

(b) With what acceleration is it moving?

The following are the objectives of **Questions 10, 11, and 12.**

3.13.1. Objectives

(i) *To probe and establish the level of understanding of the functions and the interplay between mathematics and physics.*

(ii) *To probe and establish the level of understanding of the role of signs in algebraic manipulations in kinematics.*

(iii) *To raise an awareness that pictorial representation is essential and helpful in solving problems in kinematics.*

(iv) *To promote the application of theoretical knowledge to a practical problem thereby reinforcing the understanding.*

(v) *To investigate whether students are able to differentiate between kinematic equations.*

(vi) *To investigate whether students are able to interpret and analyse the given data before attempting to solve a problem based on kinematic equations.*

(vii) *To critically expose some of the problem-solving strategies, if any, used by the students.*

(viii) *To identify factors that might impede a meaningful mastery of problem-solving skills in kinematics.*

CHAPTER FOUR

STUDY 1 : ANALYSIS OF WRITTEN RESPONSES TO THE QUESTIONNAIRE

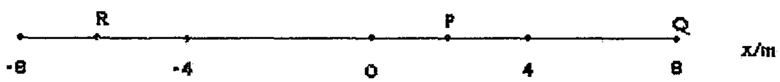
4.1. INTRODUCTION

The analysis of responses is carried out using a coding system and also in terms of percentages. Each code corresponds to a particular response. The correct response for each question is provided. The percentage of students answering each question is calculated in order to identify common errors committed and the general line of thinking followed [see Appendix 2].

4.2. QUESTION -BY-QUESTION ANALYSIS AND DISCUSSION

4.2.1. QUESTION 1

Consider the figure below. Calculate the displacements and velocities and draw the velocity vectors.



(a) A moves from P to Q in 2,0 s.
Displacement of A.
Average velocity v_A.

(b) Now A moves from Q to P in 2,0 s.
Displacement of A.
Average velocity v_A.

(c) Say in words what difference you would see between cases (a) and (b).

4.2.1.1. *Question 1(a) - Analysis and discussion*

A considerable number of students (58,1%) obtained the correct solution to the problem. 5,8% of the students obtained the solution as "displacement = 12 m; average velocity $v_A = 6$ m/s", which is incorrect. A further 5,8% of the students obtained the solution as "displacement = 8 m and $v_A = 4$ m/s", which is also incorrect. There were other variations of incorrect solutions which were obtained by 1,2% of the students. This is a clear indication that at least 58% of the students understood the concepts "displacement" and "average velocity". Their understanding is limited, though. Other students lacked a meaningful understanding of these concepts.

4.2.1.2. *Question 1(b) - Analysis and discussion*

34,9% of the students obtained the correct response. 15,1% obtained the solution as "displacement = 6 m; average velocity $v_A = 3$ m/s", which is incorrect. While most of the students were able to work out the solution for **Question 1(a)**, it is interesting to note that they could not work out the solution for **Question 1(b)** which involved a change in direction. In fact, they did not seem to be aware that displacement and velocity are both vector quantities. 5,8% of the students, for instance, obtained the response which was different from the correct one with the sign. There were also other variations of responses given which confirm that the students indeed lacked a meaningful understanding of the concepts under consideration.

4.2.1.3. *Question 1(c) - Analysis and discussion*

80,2% of the students obtained the correct solution but cannot relate the signs "+" and "-" with "right" and "left" directions. They were able to visualize that the motion is to the "right" and "left" respectively but could not assign the necessary signs. 2,3% of the students thought that an object accelerates when moving to the right and decelerates when moving to the left, which is incorrect. A further 2,3% of the students thought an object moved with a positive acceleration to the right and a negative acceleration to the left, which is also incorrect. The choice of direction proved problematic to the students.

4.2.2. <u>QUESTION 2</u>

Explain in your own words the meaning of the following important definition: "Uniformly accelerated motion is motion with a constant acceleration."

4.2.2.1. <u>*Question 2 - Analysis and discussion*</u>

11,6% of the students answered this question correctly. 31,4% thought the motion is characterised by constant acceleration. This clearly indicates that the students do not actually understand that constant acceleration implies that the rate at which the velocity changes is the same in every second and this can be attributed to their poor understanding of uniformly-accelerated motion. 19,8% of the students thought that the motion is characterised by constant velocity and constant acceleration which is grossly incorrect. A constant velocity does not imply constant acceleration. In fact, when the velocity of an object is constant, then its acceleration is zero, i.e. an object accelerates only when its velocity changes. There were also other variations of responses given which serve to confirm that the students indeed had been taught inadequately in the past.

4.2.3. <u>QUESTION 3</u>

When does an object have velocity?

4.2.3.1. <u>*Question 3 - Analysis and discussion*</u>

10,5% of the students obtained the correct answer to this question. Incidentally, 34,9% of the students thought that an object has velocity when it is moving and no mention of the direction was made. The students obviously had a problem with the operational definition of the concept "velocity". Velocity is actually a measure of how fast an object moves in a given direction. 16,3% thought that an object has velocity when it moves a certain distance per unit time. This is merely a mathematical relationship between these quantities. 14,0% of the students maintained that an object has velocity when it moves a certain displacement per unit time. This clearly shows that the students could not differentiate between "distance" and "displacement".

4.2.4. QUESTION 4

When does an object have acceleration?

4.2.4.1. *Question 4 - Analysis and discussion*

31,4% of the students obtained the correct answer. However, 23,3% of the students indicated that an object has acceleration when it moves a certain velocity per unit time. Clearly, the students used relationships to explain and define a concept such as acceleration in this case. Conceptual understanding cannot be enhanced in this way because these relationships are merely mathematical formulations. A further 15,1% of the students indicated that an object accelerates when its velocity increases. While this might be true, this is not the only condition for an object to accelerate. When the velocity of an object decreases, it implies that the object is slowing down and it is actually accelerating since its velocity is changing.

4.2.5. QUESTION 5

Aeroplanes flying long distances, for example from the U.S. to South Africa, generally fly at the same average air speed. Nevertheless it happens often that planes arrive at Johannesburg International Airport half an hour earlier or also, on other days, half an hour late. How is this possible?

4.2.5.1. *Question 5 - Analysis and discussion*

30,2% of the students got the correct answer. 22,1% gave the correct answer as "air resistance". 5,8% indicated that the correct answer is " air resistance and the wind". The implication here is that air resistance and the wind are two different things. 2,3% thought that the frictional force plays a role as far as the motion of the aeroplane is concerned. There was a great variety of answers which indicate that students did not realize that the motion of an object is described in terms of a frame of reference.

4.2.6. <u>QUESTION 6</u>

A boy runs a course of 100 m. Do you think this movement will be uniform throughout? Describe in words what you think will happen to the velocity from the start up to the moment he stops.

4.2.6.1. *Question 6 - Analysis and discussion*

11,6% of the students answered this question correctly. 5,8% did not answer this question at all. A further 11,6% indicated that the velocity of the athlete will increase, decrease and the athlete will finally stop. 10,5% indicated that the velocity of the athlete will increase, become constant, decrease and the athlete will finally stop. 8,1% claimed the velocity of the athlete will only increase and decrease and the implication here is that the athlete will never stop. Qualitative description of the motion of an object seems to be a major problem in this case.

4.2.7. <u>QUESTION 7</u>

What would you say about the direction of the velocity and acceleration for a decelerating object?

4.2.7.1. *Question 7 - Analysis and discussion*

45,4% of the students answered this question correctly. 2,5% indicated that the direction of acceleration and velocity will be the same. The great variety of responses given in this regard clearly show that the students could not differentiate between the acceleration vector and velocity vector.

4.2.8. <u>QUESTION 8</u>

Which type of velocity, instantaneous or average, is being discussed in the statements below? Explain your answer.

(a) "My car is faster than yours, occasionally it goes at 130 km/h."

(b) "No, my car is faster, it can keep going at 125 km/h."

(c) "The maximum speed of an athlete is 10 m/s because running a distance of 100 m takes 10 s."

4.2.8.1. *Question 8(a) - Analysis and discussion*

14,0% of the students answered this question correctly. 10,5% indicated that the instantaneous velocity is the speed that occurs occasionally. 8,1% gave the answer as "instantaneous velocity", but no explanation was given. 5,8% did not answer this question at all. A great variety of responses given in this regard show that the students could not differentiate between the average and the instantaneous velocity.

4.2.8.2. *Question 8(b) - Analysis and discussion*

Only 2,3% of the students got the correct answer to this question. 23,3% gave the answer as "average velocity" because it is the velocity that does not change. 14,0% on the contrary gave the answer as " instantaneous velocity" because it is the velocity that does not change. 11,6% gave the answer as "average velocity", but no explanation was given. 4,7% indicated that the answer is "instantaneous velocity" because it is the velocity at a particular moment in time. Considering the responses given, it becomes clear that the students could not apply these concepts to practical situations because of their poor conceptual understanding.

4.2.8.3. *Question 8(c) - Analysis and discussion*

Only 2,3% of the students got the correct answer to this question. Incidentally, 23,3% of the students gave the answer as "average velocity", but no explanation was given. A great variety of responses given in this regard confirm that the students could not differentiate between the instantaneous and the average velocity.

4.2.9. QUESTION 9

A trolley accelerates uniformly from rest and reaches a velocity of 5,0 m/s after 7,0 s. A student is asked to calculate the distance covered during these 7,0 s.

He answers as follows: distance = velocity x time = 5,0 m/s x 7,0 s = 35 m
What are the mistakes made by the student? Explain how the student has reasoned and his/her confusion about certain quantities.

4.2.9.1. ***Question 9 - Analysis and discussion***

7,0% of the students did not answer this question at all. 9,3% obtained the correct answer. 11,6% indicated that the correct equation should have been used. 9,3% of the students felt the mistake was that the student in question did not consider the fact that the object started from rest. 10,5% thought the student should have indicated that the initial velocity is zero. 12,8% thought the units were not indicated. 7,0% thought the mistake was that the acceleration was not calculated. These responses indicate that the students found it difficult to solve problems involving concepts they did not understand. Thus, conceptual understanding plays a considerably important role as far as problem-solving is concerned. These students had difficulties caused by the poor quality of their prior knowledge. They were not only in the habit of rote learning, studying for reproduction of facts and formulae, but also acquired a number of alternative conceptions on fundamental physics concepts.

4.2.10. QUESTION 10

A raindrop falls from a cloud downwards. The cloud is at a height of 500 m above the ground.

(a) If there were no air resistance, how long would it take to reach the ground, and what is the velocity when it hits the ground?

(b) Is this realistic? Why/Why not?

4.2.10.1. ***Question 10(a) - Analysis and discussion***

25,6% of the students got the correct solution to this question. 16,3% of the students solved only one part of the problem. 17,4% got the correct answer by using more than one kinematic equation. 9,3% felt that the given information was insufficient. Considering this variety of given responses, it becomes evident that some of the students could not interpret the problem and consequently were unable to use the given information to solve the problem. This is attributed to limited knowledge and lack of understanding, or to the wording of the diagnostic test item itself.

4.2.10.2. *Question 10(b) - Analysis and discussion*

Only 1,2% of the students got the correct answer to this question. 15,1% did not answer this question at all. 5,8% indicated that the situation is not realistic because the force of friction will disturb the motion of the raindrop. 15,1% indicated that the situation is realistic because the gravitational force will make it possible for the raindrop to reach the ground. 9,3% felt that the situation under consideration is not realistic because air resistance will disturb the motion of the raindrop. 8,1% indicated that the cloud cannot be at a height of 500 m above the ground and as a result the situation is not realistic. A further 8,1% indicated that the situation is realistic but no explanation was given. Clearly, the students had little or no understanding of the concept "terminal velocity".

4.2.11. QUESTION 11

An object is thrown vertically upwards with an initial velocity of 10 m/s.

(a) How long will it take to come back to the initial position?
(b) How high will it go?
(c) How long will it take to reach the maximum height?
(d) How long will it take to reach the thrower's hand?
(e) With what velocity will it reach the thrower's hand?
(f) When will it be 1 m above the thrower's hand?
(g) If the object misses the thrower's hand, with what velocity will it move 1 m below the thrower's hand?

4.2.11.1. *Question 11(a) - Analysis and discussion*

4,7% of the students obtained the correct solution to this question. 34,9% solved only one part of the problem unaware. This implies that the students had difficulty with the choice of the appropriate kinematic equation to use. 22,1% solved one part of the problem and used deductive logic to obtain the ultimate solution. 8,1% got an incorrect solution because they used an incorrect kinematic equation coupled with their inability to manipulate the chosen equation. A great variety of responses given in this regard indicate that the students could not interpret the given information. This is attributed to the fact that they were not using problem-solving strategies.

4.2.11.2. *Question 11(b) - Analysis and discussion*

22,1% of the students got the correct solution to this question. 18,6% used an incorrect kinematic equation resulting in an incorrect solution. 7,0% put down an answer without showing the steps followed. 9,3% used a totally different equation which is not even a kinematic equation. This clearly shows that some of the students could not differentiate between kinematic equations hence they were not able to apply them appropriately.

4.2.11.3. *Question 11(c) - Analysis and discussion*

14,0% obtained the correct solution to this question. A further 20,9% put down an answer without showing the steps followed. 18,6% used more than one kinematic equation to solve the problem. 3,5% used an incorrect kinematic equation and the substitution made was also completely incorrect. The major difficulty here was that the students determined quantities which were not required by the question.

4.2.11.4. *Question 11(d) - Analysis and discussion*

Only 2,3% of the students got the correct response. Incidentally, 29,1% put down an answer without showing the necessary steps followed. In fact, the students became highly confused as they were not using problem-solving strategies to guide them in the process. A further 19,8% put down a different answer again without showing the necessary details. 12,8% used an incorrect kinematic equation and the substitution made was completely unacceptable. Clearly, the importance of problem-solving strategies and conceptual understanding cannot be over-emphasized during the problem-solving process. However, it has to be emphasized that problem-solving strategies are not an end in themselves.

4.2.11.5. ***Question 11(e) - Analysis and discussion***

Only 1,2% of the students obtained the correct solution to this question. 14.0% did not answer this question at all. 12,8% used an incorrect kinematic equation and the substitution made was completely incorrect. A further 16,3% also used an incorrect kinematic equation and the substitution was incorrect as well. 19,8% gave an answer without showing the necessary details. 7,0% used more than one kinematic equation to solve the problem. The choice of an appropriate kinematic equation has once again been a major difficulty for the students.

4.2.11.6. ***Question 11(f) - Analysis and discussion***

14,0% of the students got the correct response. 25,6% did not answer this question at all. 8,1% gave an answer without showing the necessary details. 7,0% used a correct kinematic equation but the substitution was incorrect.

4.2.8.1. ***Question 11(g) - Analysis and discussion***

Only 3,5% of the students got the correct response. 22,1% gave an answer without showing the necessary details. 37,2% did not answer this question at all. 8,1% used a correct kinematic equation but the substitution was incorrect. A deeper analysis of the responses given in this regard shows that the students had serious problems with kinematic equations.

4.2.12. **QUESTION 12**

An object starts from rest and moves uniformly with a velocity of 10 m/s for 5 s.

(a) How far has it moved?

(b) With what acceleration is it moving?

4.2.12.1. *Question 12(a) - Analysis and discussion*

Only 4,7% of the students obtained the correct response. 40,7% used an incorrect kinematic equation and the substitution was completely incorrect as well. This was also a problem for a further 16,3% of the students.

4.2.12.2. *Question 12(b) - Analysis and discussion*

30,2% of the students obtained the correct solution to this question. 44,2% got the correct solution without showing much detail. Generally, the students had difficulty in expressing what they had in mind and this is attributed to their poor interpretation of the problem at hand.

4.3. OVERALL ANALYSIS OF THE WRITTEN RESPONSES TO THE QUESTIONNAIRE

The students' concept of displacement is based upon the definition found in textbooks and it is learnt by rote without understanding. Scalar subtraction rather than vector addition to determine the displacement is commonly used by the students. They do not seem to understand that calculations with scalar quantities use the operations of ordinary arithmetic but vector addition requires a different set of operations. In particular, subtraction of vectors means to add the vector of the same magnitude but opposite direction.

Velocity is not seen as an instantaneous quantity. The interpretation of instantaneous velocity as a number referring to a single instant is a real conceptual hurdle for many students (Trowbridge, 1980). Students' conceptions are that if *velocity is positive*, motion occurs *"faster"* and if *velocity is negative*, then motion occurs *"slower"*. Velocity is not correctly interpreted as how fast an object is moving but rather as *"faster"* or *"slower"* and is confused with acceleration.

Deciding what the problem is, and what kind of action is required, is considered by many students to be the most difficult part of problem-solving. Because the problematic features may not be obvious when first encountered, students need to '*set*' the problem in such a way that it comes to be known. This complex activity can be labelled as '*identifying*' or '*defining*' the problem and is accomplished at two levels: the '*big*' picture and the focused '*piece*' of the picture. Assembly of the '*big*' picture is needed to contextualize the problem which, as a specific component in that context, contributes to and is shaped by the broader context. The way forward requires the making of choices through an iterative movement among impinging factors. The endeavour of fitting a solution into the problem space requires choosing between alternative possibilities.

Students realized that every problem is new by virtue of its particular context and that the complexity of problems varies, depending on the interactions between the context and the nature of the problem space. Their responses indicated that they adopt procedures according to the complexity of a particular problem. It has been deduced from some of the responses that the students sort the *'knowns'* from the '*unknowns*'. Others opted for a process of '*compartmentalizing*' or '*sectionalizing*' a problem into a collection of smaller subproblems which can be worked on in parallel. Clearly, although the participants did not lay out a single set of steps for choosing a '*critical*' path, ways of thinking involved analysis of the situation interwoven with knowledge of prior experiences. Design was framed by the problem as a whole and was a recursive activity.

Solving problems meant using specific analytic strategies, such as compartmentalizing a problem. In this way students learn 'the aspects of establishing your boundaries, identifying your knowns and finding the unknowns and applying solutions to realize a solution'. Learning to solve problems involves extensive practice-experience-in the process. Opportunities for such practice in problem-solving are not generally presented or taken up regularly. Time is needed to accumulate experience which scaffolds the construction of possible solutions. Students benefit from mentorship of their supervisors to help them struggle along to solve problems by developing problem-solving strategies.

Many students used a combination of the problem-solving strategies mentioned in Chapter One. The strategies used depend on the amount of factual and procedural information available and the experience of the problem-solver. Many of these students used strategies without realizing the style adopted and this can be attributed to the fact that their understanding is both shallow and fragmented.

Of the problem-solving strategies detailed earlier, *brainstorming* and *backward strategy* were used to a lesser extent because problem-solving was individually performed and the answer was not known. *Forward strategy* involved using the information given in the question to infer the steps required to solve the problem. Some students undertook this strategy. This is a good strategy to use for representing the problem-solving knowledge required.

Generate and test was used by some students. Some used this because they were not sure of any meaningful pattern of relationships between the initial state and the information supplied to reach the goal state. This was also used when an incorrect path was taken. Some wrote different equations or relations in their attempts to connect the given information to unknown quantities. When an equation did not provide the needed connection, they went on to use another and so on until they made a connection or ceased performing the solution.

Means-end analysis was used to determine the difference between the current solution state and the goal state. Attempts were then made to reduce the difference. This strategy was used when one was unsure of the steps leading to the solution, attempting to simplify expressions and eliminating unknown quantities through substitutions. Some students used this strategy.

Problem decomposition involved breaking the problem into smaller subproblems. Each subproblem was then solved and combined to form the solution to the original problem. Some students used this strategy. *Analogy* was used to a lesser extent as the transference of knowledge from related problem-solving situations was not prevalent.

Some students used *envisioning* to provide the qualitative knowledge to roughly predict what will happen at various points in a given problem situation or state. Principles and rules were then applied to obtain a qualitative causal description of the problem situation. Those who envisioned in detail then went on to solve the problem using the forward strategy. *Heuristic search* was used by some students to determine possibilities and constraints necessary to generate trial solutions and to guide the search for the solution. *Problem abstraction* was used to a limited extent as only few students were able to construct a simplified representation of the problem.

Cognitive aspects of problem-solving include the analysis of the problem by recognizing its boundaries and its parts and the relationships between these. But the affective dimensions of being a problem-solver are also of great importance. Certainly, confidence in one's ability to eventually put the pieces together in the construction of a viable solution is a significant attribute. Doing problem-solving could build the required confidence: '*By doing, the more you try, the easier it is not be scared by it which is probably a big problem too. To encounter new situations and not be totally terrified if you do not know what to do, just go ahead and try different things'*. However this '*doing*' of problem-solving is unlikely to build confidence unless some success is achieved and so it is important '*to give challenges that students have a reasonable chance of succeeding at'*. Students cannot succeed all the time, they lose interest and they become discouraged. The reward should be in the actual solving of the problem itself.

Only a few of the students drew on their everyday experiences of contextualizing and characterizing the problem, or on successful strategies for making choices and achieving solutions. From the perceptions of the students in this study, it is clear that learning to solve problems entails embarking on an extended practice of problem-solving in order to acquire both the cognitive skills needed for taking a problem apart and constructing a solution and the personal confidence to deal with uncertainties faced during that cognitive activity.

Learning to solve problems in the context of the school curriculum, particularly as a component of a science curriculum, has the potential to accentuate distinctions between acquiring knowledge and applying knowledge. In this study, some students described their work in terms of using the building blocks of science to solve 'real world' problems and they emphasized the practical nature of their work. But when students described how they went about the activity of problem-solving, it was not primarily as an application of previously acquired knowledge, but rather as a construction of possible ways forward dependent on interacting with the problem and its situation and actively searching for information related to the problem.

For the students in this study, understanding emerges from participating in interaction with a problem situation. Problem-solving takes place at the interface of knowing and doing and, for many of these students, is learned by participating in the activities of getting to '*know*' problems and constructing possible resolutions. Hiebert *et al.* (1996) have contrasted this perspective (referred to as a functional view of understanding) with what they call a structural perspective, in which the focus is not so much on the nature of the activity, but rather on the structure of the understandings which remain after the activity is over. When students have been engaged in problem-solving situations in mathematics, these researchers claim that 'what gets left behind are the conceptual underpinnings and methods for actually working out new procedures when they are needed' (p.17).

Learners need practice in engagement with problems which are challenging but not so difficult that failure to resolve them will lead to discouragement. Learners need support in the form of pieces of information to which they may not have ready access, to techniques which they could see modelled and to strategies which can be adopted. Such suggestions bear an affinity with a pedagogical approach advocated by Woods (1994), in which half of the time allocated for solving a problem is devoted to '*getting to know*' the problem in small groups. Developing a pedagogy for problem-solving is itself one of the major challenges. Generic problem-solving strategies have been introduced in mathematics programmes, often in tandem with the use of materials for manipulation moves by students. There is considerable discussion in the literature about the value and/or transferability of such skills.

Instructors generally have considerable expertise in generic pedagogical strategies; but most are willing to acknowledge a lack of confidence in their understandings of concepts and skills. In order to build a pedagogy for problem-solving, instructors need access to key concepts in content domains and to ways of dealing with problems. Without conceptual understanding and procedural knowledge, instructors will be hampered in their ability to transform problem-solving situations into authentic learning engagement.

CHAPTER FIVE

STUDY 2: THE WORKSHOP INTERVENTION

5.1. INTRODUCTION

[Note: Before commencing to read this chapter, the reader should refer to the note on p.24 and Table 1.1 (p.25)].

Most problem-solvers use a combination of the problem-solving strategies mentioned in Chapter One. The strategies used depend on the amount of factual and procedural information available and the experience of the problem-solver; many use strategies without realizing the style adopted. In general, search processes dominate much of the problem-solving behaviour of novices (Chi, Feltovich & Glaser, 1981) as their understanding is both shallow and fragmented. As experience is gained and knowledge accumulated the search becomes more selective.

The aim of exposing students to the various strategies and knowledge is to move them from the inexperienced problem-solver (novice) state to the experienced (expert) mode. Davis (1989) suggests five stages of performance from novice to expert.

- Stage 1 (novice) uses context-free facts and rules to produce actions based on these facts.
- Stage 2 (advanced beginner) learns to recognize elements not defined in terms of context-free facts.
- Stage 3 (competent) learns to organize thoughts in terms of plans and goals. This involves choices and decisions.
- Stage 4 (proficient) intuitively recognizes a familiar situation and the goal.
- Stage 5 (expert) has the ability to intuitively know the sense of the situation,

and from prior experience knows what to do.

This review provides the theoretical background for addressing and discussing the aims of the study. Ten common problem-solving strategies have been outlined (see **Table 1.1** on p.25) and these will be used to provide the framework for relating the problem-solving behaviour of the participants to the activities identified.

5.2. THE WORKSHOP INTERVENTION

A total of 25 students participated in this workshop. All were volunteers. At each session the participants drew lots to determine the problem they would attempt. Each session was individually conducted with a participant and one problem was attempted each time. The prescribed physics text (Tipler, 1991) was available for reference. Prior to solving the question, each candidate first attempted a different and simple warm-up question. This was done to get them used to thinking aloud and verbalizing every thought and action during the problem-solving session.

As mentioned in the Introduction (see p.2), an activity is distinct from a problem-solving strategy. A strategy cannot be inferred from a minute portion of the problem solution; individual activities can be so inferred. The activities may be considered to constitute the infrastructure of the strategy. A sequence of activities constitutes a strategy or signifies the application of a strategy.

Fourteen activities (see **Table 1.1** on p.25) generally performed by the participants and representative of their problem-solving performance were identified from the transcripts. Each activity is a representative description of a distinct and fundamental action performed by the participants. These fourteen activities are deemed to comprehensively and exhaustively capture the detailed behaviour of the participants throughout the problem-solving process. The finalized set of fourteen activities was used by the researcher to individually code each transcript. This was done to ensure that the coding was not a random or subjective assignment.

5.2.1. Analysis of Activities

The data collected provided insight into the problem-solving activities performed by the participants. These fourteen (14) activities have been labelled as: checking, pictorial representation, quantitative representation, question reading, relating quantities, reference, symbol usage, clarifying, comparison, declaring quantities, qualifying, qualitative analysis, recapitulating, and resolving difficulties. The first five activities involve the possible performance of physical actions by the participants, whereas the others are more cognitive in nature. It should, however, not be assumed that the first five do not involve some degree of cognitive processing as well.

In the discussion that follows, each of the activities is exemplified by a quotation or quotations made during the workshop.

5.2.1.1. Checking

"Displacement and velocity in case (a) are greater than those in case (b)".

Checking involved asc rtaining the logic of the steps undertaken and the correctness of the mathematics used. An example of a check performed was by substituting numerical values and using practical experience and knowledge to determine the possibility of the answer being correct. The participants performed checking to determine the logic of the solution steps as an inherent part of their problem solving. They used their practical knowledge and experiences in their checks. Some participants used dimensions to check the correctness of expressions, while others generally performed checking when they encountered difficulties, or when the expressions obtained failed to make sense. They also used their intuitive knowledge as a check.

5.2.1.2. Clarifying

> *"It is the average velocity; however, the word maximum is wrong since we know quite well that the maximum speed of the athlete is greater than 10 m/s".*

Clarifying involves attempting to make sense of the information under current consideration. Clarification was done by the students by referring to the text (Tipler, 1991), by verbalizing the difficulties encountered, and by evaluating the problem being solved. e.g. the text was used to obtain clarification of formulae and information required. Clarification was done to explain, simplify, and refine the problem.

5.2.1.3. Comparison

> *"Displacement and velocity are the same in both cases".*

Comparison included the use of examples [e.g. from Tipler (1991)] and information similar to the problem being solved. As an activity it merely involves making a comparison with other examples similar to the present problem. Comparison was used to make sense of the quantities involved, and to try to understand the motion of the object. Some participants did refer to the text, while others did not make any comparisons with other examples.

5.2.1.4. Declaring Quantities

> *"The equation to employ in this instance is:* $v = u + at$
> *The value for the calculated time is* $t = 2$ *s."*

Declaring a quantity is the process whereby a participant mentioned or used a quantity. Declaring involved mentioning a principle or quantity, an equation, an expression using one or more quantities, or merely stating a value for a quantity. This activity was performed by all participants.

5.2.1.5. Pictorial Representation

> *"The following situation is represented by means of a diagram. An object is thrown vertically upwards and I have to determine the time it takes to come back to the initial position".*

Pictorial representation refers to drawing a diagram and marking information on it. This activity was performed by some participants. Some diagrams contained precise information of the quantities involved, but others were incomplete. Some participants failed to successfully perform the problem solution because they had incorrect or incomplete representations of the information pertaining to problem solution. This is in agreement with the research findings on novices as reported by Larkin (1981).

5.2.1.6. Resolving Difficulties

> *"Since the object takes 1 second to go upwards and 1 second to go downwards, then* $t = 1\ s + 1\ s = 2\ s$*."*

Resolving difficulties involved trying to correct a mistake and finding means to perform the next step in the solution to the problem. Resolving difficulties often occurred when participants reached an expression or answer that did not make sense or which they had difficulty in attempting to simplify. The difficulties usually arose due to an unknown quantity appearing in the final expression, a misconception or perception mistake, a mathematical error, or wrongly relating quantities.

5.2.1.7. Qualitative Analysis

"Aeroplanes flying long distances generally fly at the same average air speed but sometimes reach their destinations earlier or later than expected. This is usually due to the strong wind blowing in the same or opposite direction to the motion of the aeroplane".

Qualitative analysis involved describing the motion of an object to make sense of the situation. The process of qualitatively describing a situation involved using surface features mentioned in the question, or physical entities, to describe the motion of the object. Some participants used physical entities to describe the motion while others used surface features or superficial references to physical entities. Some did not qualitatively describe the motion of the object at all. This is similar to the findings of Chi, Feltovich, and Glaser (1981), who reported that novices used surface features whereas experts used physical entities to categorize physics problems.

5.2.1.8. Qualifying

"It is the instantaneous velocity since it is the velocity at a particular instance".

Qualifying involved using the content knowledge and principles to make deductions and to provide supportive information to connect the solution steps. This is done to stipulate and convince oneself of the conditions, or terms, under which the deduction or connection of the solution steps is in line with the underlying physical principles. Some participants performed this activity to some extent. Some performed this activity excessively, taking the wrong solution path several times and experiencing difficulties in making sense of the steps undertaken.

5.2.1.9. Quantitative Representations

$$velocity_{average} = \frac{displacement}{time}$$

Quantitative representations included using numbers or algebraic symbols to represent quantities, choosing and writing equations, and performing mathematical manipulations. This was an activity that all the participants performed to a large extent.

5.2.1.10. Question Reading

"A raindrop falls from a cloud downwards. The cloud is at a height of 500 m above the ground. We know the height and so we must use the relation involving displacement".

Question reading involves referring to the question. Styles of reading the questions used included:

(i) reading the question verbatim before beginning the next problem-solving step.

(ii) reading the question in parts and noting information directly provided by the question wording.

(iii) processing the information provided when reading the question.

5.2.1.11. Recapitulating

> *"Okay, I know the height of the cloud and so I am going back to identify the correct equation from the kinematic equations".*

Recapitulating involved recalling prior work done by going back to previous steps to make corrections if necessary. Some participants recapitulated when relating solution steps and when considering the plausibility of the answer while others recapitulated mainly when they found an error in their calculations or logic or, primarily, when they were at a loss on how to proceed.

5.2.1.12. Reference

> *"So, we need a numerical value for the gravitational acceleration which is one of the fundamental physical constants given in the text".*

Reference refers to the process of accessing information from the text or from lecture notes. Information in the text was accessed using keywords. Some participants did not make any reference at all.

5.2.1.13. Relating Quantities

> "
>
> $S = ut + \frac{1}{2}at^2$ *and solving for* t *we can then determine the*
>
> *value of* v *using the equation* $v = u + at$
>
> "

Relating quantities involved using previous experience and knowledge to recall information needed to proceed in the solution of the problem. The knowledge recalled was usually in the form of equations and algebraic relations or in terms of concepts.

5.2.1.14. Symbol Usage

> *"A raindrop falls from a cloud downwards. The cloud is at a height of 500 m above the ground. Now, let the height be denoted by h".*

Symbols were used to represent algebraically physical quantities used in the problem solution.

5.2.1.15. General Comments about the Activities and Strategies

As mentioned earlier, an activity is a specific physical or cognitive action. A strategy, on the other hand, is a plan of action. It is the representation of a block of knowledge, procedural and declarative, used to move from the initial state to the goal state. The block can be seen as consisting of a series of sequenced application of activities. The strategy starts and ends with an activity. It does not have to begin and end with the same activity. A strategy cannot be inferred from a minute portion of the problem solution performed; a sufficient block of the transcript is required to observe any problem-solving pattern. Activities, representing fundamental actions, can be inferred each time they are performed.

Therefore, the activities may be considered as forming the internal structure of the strategy. Within a strategy the problem solver performs a range of some or all of the fourteen activities identified. The activities inform us of the various individual actions used within the strategy and the problem-solving process. The strategy informs us of how the activities are used and sequenced in blocks of the problem solution. The use and sequence of the activities within each strategy is dependent on the problem solver's application of knowledge in the solution of the problem. The general methods and problem-solving strategies used by the participants are now separately discussed in relation to the fourteen activities identified.

5.3. GENERAL METHODS

Five general methods were used by the participants: assessing information; transforming information; generalizing application of information; attempting one-step solution; and assessing the solution (**Table 5. 1** on p.88). Each of these general methods is linked to some or all of the fourteen activities identified.

5.3.1. Assessing Information

Assessing information involved use of some or all of the activities: clarifying; pictorial representation; resolving difficulties; qualifying; question reading; symbol usage; and recapitulating. Some participants explicitly demonstrated this general strategy to assess the information given or implied in the question and later to determine the next step in the problem solution.

Assessing information given	*Activities*
So, the boy accelerates from start, then moves uniformly, slows down and finally stops. If the boy starts from rest, his initial velocity is zero.	Qualifying Declaring quantity Clarifying

TABLE 5. 1: Number of Participants Using the General Methods

General Methods	*Participants*
1. Assessing information	*7*
2. Transformation of information	*10*
3. Attempting one-step solution	*9*
4. Generalizing information application	*8*
5. Solution assessment	*5*

Assessing information to determine the next step	*Activities*
The student assumed that the velocity remained constant at 5 m/s. Instead of multiplying by the *average velocity*, he/she multiplied by the *instantaneous velocity*.	Declaring quantities Clarifying Qualitative analysis Resolving difficulty Relating quantities

5.3.2. Transformation of Information

Transformation of information involved the use of some or all of the three activities: pictorial representation; quantitative representation; and symbol usage. The information was transferred to diagrams or mathematical symbols. Some participants transformed information to aid them in solving the problem.

5.3.3. Attempting One-Step Solution

Attempt at one-step solution was used only by some participants who expected to obtain an answer by applying an algorithm and substituting values to obtain an answer. Activities performed were quantitative representation (to represent the algorithm), relating quantities (to make the substitutions) and resolving difficulties (when answer was not obtained).

One-step solution expectation	*Activities*
We have, $s = ut + \frac{1}{2}at^2$ and we want to calculate t. Making t the subject of the equation, we get $t = 2$ s.	Declaring quantities Relating quantities Resolving difficulty Quantitative representation.

5.3.4. Generalizing Information Application

This method was applied when participants encountered difficulties or when they recalled solving a similar problem. They referred to the text for similar examples or for familiar relations between physical quantities. These were then applied to the solution of the problem with little discrimination. In some cases, similarity of symbols was used to relate quantities.

Generally applying information without discrimination	***Activities***
It means the motion is characterized by a change in velocity and a constant acceleration. But, what about the displacement covered?	Declaring quantities Qualitative analysis

Generally applying information by using a relation with similar quantities	***Activities***
So, $s = ut + \frac{1}{2}at^2$ But, since we do not have *a*, we can first use $v = u + at$ to determine *a*.	Declaring quantities Relating quantities Symbol usage Qualifying Resolving difficulty

5.3.5. Solution Assessment

Solution assessment involved use of some or all of the activities: checking, clarifying, qualifying, and recapitulating, during problem solving or at the completion of the task. Some participants checked and clarified the information and solution steps throughout the process while others left this until the end.

Some performed periodic or final assessment of the solution, whereas others did not do so.

Assessing solution at the end	*Activities*
This is realistic because the gravitational force will make it possible for the raindrop to reach the ground.	Clarifying Qualifying Declaring quantity Checking

Assessment while performing the solution	*Activities*
Instead of multiplying by the average velocity, the student multiplied by the instantaneous velocity, which is wrong. It is the average velocity; However, the word maximum is wrong since we know quite well that the maximum speed of the athlete is greater than 10 m/s.	Declaring quantities Clarifying Checking Recapitulating

5.4. STRATEGIES

Each of the activities was discussed briefly with excerpts from the transcripts used to provide examples of their occurrence within the problem-solving process. The excerpts were provided in two columns. The first column consists of the verbalizations transcribed, and the second the researcher's comments to place the excerpt in context.

Of the problem-solving strategies detailed earlier, *brainstorming* (a group activity) and *backward strategy* requiring knowledge of the goal state were not used because problem solving was individually performed and the answer was not known. *Heuristic search* and *problem abstraction* are other strategies which were not used. Use of the other strategies is given in **Table 5.2** on p.93. Excerpts are quoted:

- To provide evidence for the use of the strategy.
- To highlight the content knowledge and activities used by the participants in the application of each strategy.
- To provide examples of ways in which knowledge is accessed during the use of each strategy.

The knowledge required to solve the problems and that used by the participants is itemized in **Table 5.3** on p.94. The table and the excerpts combine to give an indication of the richness as well as deficiencies in content knowledge of the participants for each strategy.

Analogy involved comparing the problem to another example. Analogy commences with the activity of comparing and leads to the employment of some or all of the other thirteen activities. To be successful it requires recognition of the differences and similarities between the example and the problem. The participants who used this strategy concentrated mainly on the similarities and ignored the differences.

Envisioning involved visualizing what will happen when the object moves to predict how the motion will take place or change at different positions. Some participants performed envisioning. An understanding can only be fully obtained when envisioning uses physical entities. Some participants envisioned using physical entities. Those who envisioned in detail then went on to solve the problem using the forward strategy. Others envisioned using surface features. An example of surface feature use is provided in the discussion of qualitative analysis activity. This activity heralds the commencement of envisioning, which can also

TABLE 5.2: Number of Participants Using the Strategies

Strategies	*Participants*
1. Analogy	*7*
2. Envisioning	*6*
3. Forward strategy	*2*
4. Generate and test	*4*
5. Means-end analysis	*8*
6. Problem decomposition	*4*

TABLE 5. 3: Summary of Information Used by the Participants

THE KINEMATIC CONSIDERATIONS

CONCEPTS:

Displacement

Velocity

Acceleration

Time

KINEMATIC EQUATIONS:

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

$$s = [\frac{v+u}{2}]t$$

OTHER EQUATIONS:

$$velocity_{average} = \frac{displacement}{time}$$

$$acceleration = \frac{velocity_{change}}{time}$$

involve clarifying, declaring quantities, qualifying, quantitative representation, relating quantities, and symbol usage. Clarifying, declaring quantities, qualitative analysis, and relating quantities were largely used due to the descriptive nature of the strategy.

Forward strategy involved using the information given in the question to infer the steps required to solve the problem. Some participants undertook this strategy. This is a good strategy to use for representing the problem-solving knowledge required. A variety of sequential paths for the solution of the problem can be obtained from the concept map. All fourteen activities can be related to the variety of general steps or components in the concept map.

Generate and test was used by some participants. Some used this because they were not sure of any meaningful pattern of relationships between the initial state and the information supplied to reach the goal state. This was also used when a wrong path was taken. Some wrote different equations or relations in their attempts to connect the given information to unknown quantities. When an equation did not provide the needed connection, they went on to use another and so on until they made a connection or ceased performing the solution. Relating quantities, declaring quantities, quantitative representation, clarifying, reference, and recapitulating were the commonly used activities.

Activities	*Excerpt*	*Comments*
Comparing Clarifying Qualifying Declaring quantities	*"No difference because displacement is the same in both cases. Motion is characterized by constant velocity and constant acceleration".*	The distance is the same in both cases and not displacement. The rate at which the velocity changes is the same in every second. Constant velocity does not imply constant acceleration. In fact, constant velocity implies the acceleration is actually zero.

Activities	*Excerpt*	*Comments*
Declaring quantity Qualitative analysis	*"So, the boy's velocity increases, decreases and finally stops".*	The boy accelerates from start, moves uniformly, slows down and finally stops.

Activities	*Excerpt*	*Comments*
Relating quantities Declaring quantities Quantitative representation	*"So, I can use the expression that contains v, u, a and t".*	$v = u + at$

Means-end analysis was used to determine the difference between the current solution state and the goal state. Attempts were then made to reduce the difference. This strategy was used when one was unsure of the steps leading to the solution, attempting to simplify expressions, and eliminating unknown quantities through substitutions. Some participants used this strategy. Relating quantities, declaring quantities, reference; and quantitative representation were the commonly used activities.

Activities	*Excerpt*	*Comments*
Declaring quantities	*So, displacement and velocity in case (a) are greater that those in case (b).*	The direction of displacement and velocity are different in the two cases.

Problem decomposition involved breaking the problem into smaller subproblems. Each su[illegible]oblem was then solved and combined to form the solution to the original problem. Some participants decomposed the problem into sub-parts. Initially, qualitative analysis, clarifying, and qualifying were performed and only subsequently were the quantitative aspects used.

Activities	*Excerpt*	*Comments*
Qualitative analysis Declaring quantities Symbol usage	*"The first thing to do is to determine the time t taken by the object when going up".*	Creates a subproblem.

5.5. COMMENTS

Knowledge accessed and the way it was used were governed by the prior knowledge of the problem solver. Some participants used a forward strategy and problem decomposition using principles and laws. These imply large well-organized schemata of knowledge. The generate and test, means-end analysis, and problem decomposition at the minute level used by some participants suggest fragments of independent schemata that have fewer connections. Some participants were using prior knowledge and experience to solve the problem, whereas others were using prior knowledge and building on it in trying to make sense while applying the knowledge.

The use of the fourteen activities within each of the specific strategies was very diverse. Even when vaguely the same activities were used the frequency and order in which they were used was vastly different. This does not imply that the activities are not representative of the strategies. Through the activities used by the students, weakness of content and procedural knowledge can be understood at the fundamental level.

The most frequent activities were: declaring quantities; resolving difficulties; qualifying; quantitative representation; and relating quantities [see **Table 5.4** on p.99]. All of these, except qualifying, involve mathematical representation. Qualifying was used to justify the mathematical representation and the problem-solving steps being used. The excessive use of mathematical representation is expected because it is emphasized in physics instruction and textbook problem-solving. A large part of physics training requires becoming familiar with mathematical representations. This explains the low use of qualitative analysis, comparison, pictorial representation, and reading the question.

The least-used activity was comparison. Reference, which involved obtaining mathematical relations from the text, was infrequent, because once such information had been accessed it was applied to perform quantitative manipulations. Two other less frequent activities were pictorial representation and symbol usage. Participants generally drew a single or no diagram and summarized information on it. Some participants drew more than one diagram

TABLE 5.4: Frequency of Activities Performed by the Participants

Activity	*Participants*	
1. Checking	*2*	
2. Clarifying	*6*	
3. Comparison	*2*	*"Physical" Activities*
4. Declaring Quantities	*25*	
5. Pictorial Representation	*5*	
6. Resolving Difficulties	*13*	
7. Qualitative Analysis	*3*	
8. Qualifying	*10*	
9. Quantitative Representations	*20*	
10. Question Reading	*4*	*"Cognitive" Activities*
11. Recapitulation	*4*	
12. Reference	*2*	
13. Relating Quantities	*19*	
14. Symbol Usage	*7*	

when they encountered a difficulty and wished to add more symbolic information. Related symbols were generally represented on the diagram at the same time because these needed to be assigned beyond those given in the question.

Another less frequent activity was reading the question. This could be because, once the problem had been read and initially understood, the need to reference it again did not arise. Re-interpreting information in the question was also not frequently done. This can again be attributed to the speed with which the students moved to mathematical representation of symbols. Also, participants tended to use diagrams and symbols to represent the information provided by the question, which reduced the need to consult the question. Participants tended to refer to the question a second time when they completed the first part of the question and wished to confirm what else th question entailed.

While solving problems, the participants used a variety of general methods and strategies while performing all or some of the fourteen activities identified earlier. The participants were not always aware of the strategies they were using. These were inferred from the think-aloud data collected. Before relating the activities to the strategies, their distinction needs to be explicated.

The general methods and strategies just tell us that the student, for example, used means-end analysis or generate and test, and is at the level of using that strategy. If the student uses an analogy incorrectly, the strategy identifies it as a weakness of the student's capability in using it. Other aspects of students' knowledge, such as lack of making comparisons or lack of understanding of the applicability conditions of the analogy, might be identified. Through activities, the specific aspects of not being able to apply the analogy can be pinpointed.

The student weaknesses and strengths in relation to some or all of the fourteen activities can be identified. The activities provide insight into the problem-solving skills at the minute level. They can be used to infer the strengths and weaknesses in relation to content as well as procedural knowledge. However, the use of activities within physics and other disciplines requires further research to determine any general patterns on the use of activities across subjects.

5.6. INSTRUCTIONAL IMPLICATIONS

Problem solvers move across strategies. Hence, the strategies do not provide flexibility of accessing information. On the other hand, the fourteen activities can be used to access the information represented within each of the strategies. They can also be used to represent the information within each strategy. The forward strategy, used by some participants who correctly performed the solution of the problem, encompasses the use of all the fourteen activities providing a possibility for structurally representing the knowledge. Its component parts encompass the knowledge accessed and the activities used when the other strategies were employed. Within this structure the fourteen activities can be used to provide the access and use of the content and procedures required for problem solving in a random and idiosyncratic way.

The general methods and problem-solving strategies highlight how the participants explore and access information, and use the activities for the solution of the problem. The application of these strategies shows how the participants focus on different information while solving the problem. Most of the participants used a combination of strategies in attempting the solution of the problem.

Knowledge of the strategies helps to inform the representation of knowledge. The knowledge representation must cater for the strategies used by the participants. These findings suggest that knowledge needs to be represented:

- In descriptive form to cater for envisioning.
- As basic relations to enable means-end analysis to be employed.
- In diagrammatic form to enable transformation of information and to help obtain a total picture.

- To provide explanations on the applicability of knowledge.
- Separately, in fundamental blocks, to enable problem decomposition.
- To enable choice of variable values, to allow envisioning as well as information and solution assessment.
- With reference to other similar examples to enable the use of analogy.
- Structurally, using the forward strategy.

The analysis of the problem-solving strategies was used to inform the representation of knowledge for a problem-solving program. The random and idiosyncratic way in which the fourteen activities were performed (even within each strategy) points to a constructivist learning environment as suitable for problem-solving. When problem solvers sought information to make progress, checked out understanding of parts of their procedure, and referred to previous knowledge in an idiosyncratic manner, they revealed the need for a flexible constructivity learning environment. Transmission of knowledge has to be incorporated in this environment so that knowledge required may be provided and accessed. The information can be supplied in small doses using the fourteen activities rather than in large sequential block. How this can be accomplished requires further research. The requirement for information to be available when needed means that the knowledge within a program has to be structured such that it can be accessed at different stages of the problem-solving process. This implies that the use of the fourteen activities to structure and access knowledge is viable and efficacious.

These findings suggest that the understanding of problem-solving, in terms of activities and in relation to strategies, provides insight into knowledge structuring, representation, and access. The forward strategy can be used to represent the knowledge within the fourteen activities being used to randomly access it.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1. INTRODUCTION

Research on problem-solving performance in science has made and will continue to make contributions to the improvement of instruction. In order for the full potential of this to be realized, however, problem-solving research must reflect the range of problem-solving activities that scientists engage in and that philosophers of science have begun to analyse. Thus, research should emphasize questions about what students learn from solving problems (model elaboration) and how they revise models in response to anomalies in data, in addition to questions relating to model-using situations. Research of philosophers of science on models and problem-solving include insights to guide both problem-solving research and instructional development. A systematic study of problem-solving skills has been described in basic physics, a domain of practical significance for instruction, but not of prohibitive complexity.

6.2. SUMMARY OF FINDINGS

This study shows that an inexperienced student tends to solve a problem by assembling individual equations. By contrast, an experienced student solves a problem by a process of successive refinements, first describing the main problem features by seemingly vague words or pictures, and only later considering the problem in greater detail in more mathematical language.

Thus, this investigation yields some basic insights into thinking processes effective for problem-solving. Furthermore, it offers the prospect that these insights can be used to teach students improved problem-solving skills and to modify common teaching practices which inhibit the development and a meaningful mastery of such skills.

It has also been established that students appear to lack the critical knowledge necessary to apply the appropriate kinematic equations that ultimately result in the solution of a problem. This can be attributed to the fact that most students confused kinematic equations with other equations. In some cases, rather than a lack of knowledge, the students have incorrect knowledge or cannot relate the knowledge to the task at hand. In addition, the cognitive skills necessary for successful problem-solving are inadequately developed and some of the students lacked the minimum mathematical competencies necessary for the manipulation of the kinematic equations. When solving problems, students used a variety of general methods and strategies. These students were not always aware of the strategies they were using.

This investigation illustrates the large gap that exists between the *"protoconcepts"* with which most students come to the study of kinematics and their grasp of the physical constructs put forth in text and lecture presentations. Deficiencies in assimilation and understanding of the concepts remain concealed from physics teachers partly because of their own wishful thinking regarding the lucidity of their presentations and partly because conventional homework problems and test questions do not reveal the true state of student thinking and comprehension. It is tempting to believe that adequate performance on conventional end-of-chapter problems indicates understanding, but, in fact, it does not.

The sample used in this research study represents only a subset of the population of physics students, yet the findings in the study may have important implications for a much broader set of students in introductory physics.

The results of this study suggest:

- An instructional method emphasizing the nature of good problem-solving techniques is of great practical importance.
- Interrelated emphasis on global and local problem-solving skills enhances student learning of both types of problem-solving skills.
- Effective tools facilitate the understanding of concepts and problem-solving skills when used properly by students and instructors.
- The use of coherent methods should include a number of principles (e.g., Newton's laws and kinematic relations).
- Low-detail qualitative descriptions should be used to explore the potential difficulties and to plan the execution of a method.
- It is advantageous to teach students how to integrate separate principles into some coherent methods useful in the solutions of many diverse problems. By contrast, ordinary teaching practices, which tend to discuss individual principles successively, often fail to provide adequate review and instruction to coalesce such principles into more encompassing methods.
- It is particularly important to teach students to approach problem-solving hierarchically by a process of successive refinements, from more global to more detailed aspects of a problem, instead of proceeding sequentially by combining individual equations. Correspondingly, students should then also be taught how to describe their knowledge at various levels of detail. By contrast, teaching practices presently common in many science or engineering courses often place such an undue emphasis on precise mathematical formulations that may harm the development of students' problem-solving skills. Indeed, many students thus come to believe that the use of seemingly vague verbal or pictorial descriptions is inappropriate or illegitimate in scientific contexts. Such verbal or pictorial descriptions are commonly used by experts and are powerful tools for making the crucial early decisions needed to plan the

solution of a problem. Thus, instruction designed to enhance students' problem-solving skills should not suppress students' natural verbal inclinations. Instead, students should be taught how to use verbal or pictorial arguments effectively and how then to translate them into more precise mathematical form when appropriate.

This study has provided some evidence suggesting that instructors who place interrelated emphasis on *local* and *global* problems by emphasizing the nature of functions as well as their specific application, can help to enhance the understanding of concepts and the development of certain problem-solving skills. This claim is consistent with the findings of Tobias (1976), Arons (1983), and Pallrand & Seeber (1984).

One plausible explanation is that graphical representation of function promotes visual-spatial abilities in the learner's cognitive structure, as suggested by Pallrand and Seeber (1984). Visual-spatial abilities, according to Larkin & Rainard (1984), are apparent requisites to successful problem-solving. However, other changes may have occurred in the cognitive structure.

The factors that impede a meaningful mastery of problem-solving skills in kinematics are:

- student's confusion of kinematic equations with other equations as this is a cause of problem-solving failure.
- the presence of a large gap between the *"protoconcepts"* with which most students come to the study of kinematics.
- the use of conventional ho work problems and test questions by instructors as these do not reveal the actual states of student thinking and comprehension.
- ordinary teaching practices which often fail to coalesce fundamental principles into more encompassing methods.
- students' lack of knowledge of appropriate problem-solving strategies.

An interrelated emphasis on global and local problem-solving skills enhances student learning of both types of problem-solving skills and this will serve to increase the percentage of students who become proficient at solving problems.

6.3. CONCLUSION

Students bring to the formal study of physics an intuitive understanding of the meaning of common concepts associated with motion. The concept of position, displacement, speed, velocity and acceleration are not distinguished clearly and often exist as memorized definitions used mainly for tests and examinations and soon forgotten. A holistic understanding of basic physical concepts should not be limited to mechanics alone, but should be the case with the physics course as a whole. Qualitative questions that probe for conceptual understanding must be seen as an essential aspect of the proposed outcomes-based education.

The following general conclusions can be drawn from this study.

- It is possible to identify consistent and reliable individual differences in problem-solving approach and to categorize an individual's preferred mode of attack.
- One of the crucial variables relating to the approach an individual uses in problem-solving is the degree of differentiation of his cognitive structure and the concomitant availability of subsuming concepts. The individual who possesses the global, superordinate concepts in a discipline, and also has the ability to construct lower level concepts when and if needed, is at a significant advantage in terms of the achievement and learning efficiency.
- The individual who possesses the ability to regenerate subordinate concepts but lacks the overall subsuming concepts finds it necessary to spend large amounts of low-efficiency learning time.

6.4. RECOMMENDATIONS ARISING FROM THE RESEARCH PROJECT

Warren (1997) advises teachers to start with motion in two dimensions and to treat vectors as essentially positive quantities with magnitude and direction. This would obviate incorrect interpretations of signs and one-dimensional motion can then be treated as a specialised case. Although this is common practice with some lecturers, the treatment of kinematics in most physics textbooks starts with the one-dimensional approach.

Concepts like those of kinematics which are central to students' scientific understanding in a wide range of topics should be given an appropriate amount of teaching time. Students beginning a physics course need explicit instruction in, and practice, with the use of vectors. Kinematics is often treated in textbooks as a sequence of definitions and operations, with little reference to actual motions of bodies. If instruction is to be more effective, the concepts must be introduced first and equations and problem-solving later, otherwise students are forced to deal simultaneously with the difficulties of concept interpretation as well as with other complexities, a situation which leads to frequent mistakes (Reif & Allens, 1987; Arons, 1997).

Helm (1980) suggests possible reasons for the prevalence of these misconceptions. Some of these are due to errors in textbooks and a mismatch between the demands of the syllabus and students' intellectual development. He also suggests that a strong case can be made for improving the training of science teachers. If the instructor is aware of the type of conceptions or the categories of conceptions held by students, he/she can make use of those conceptions during instruction; this approach may facilitate student understanding. Results from this and other phenomenographic studies (Bowden *et al.*, 1992) have shown that it is inadequate to say that a student understands a concept and success in quantitative problem-solving can mask inadequate understanding of basic concepts that may hinder learning in advanced courses of the subject.

Hewitt (1989) is convinced that the ideas of physics should first be understood conceptually and that a conceptually based physics course should be accessible to all students. Linder (1996) argues that an undergraduate physics course should include an introductory phase that deals with conceptual dynamics of elementary physics, i.e. a qualitative study of the central concepts of physics with emphasis on mental imagery that relates to things and events that are familiar in the everyday environment. Students will not value conceptual understanding unless they realize that in tests and examinations they will be asked to explain very basic physical concepts, or in other cases be asked to discuss the meanings and general implications of various physical laws. Qualitative questions that probe conceptual understanding must be seen as an essential aspect of the proposed outcomes-based education and can be included in continuous assessment programmes, viz. homework assignments, in laboratory reports, tests and examinations. It also vital to adopt such an approach in the training of teachers, if they are to acquire the competence necessary to foster conceptual development in their students.

Science educators know very little about what students learn from science instruction. One way to fill this void would be for researchers to do detailed analyses of the conceptual and procedural knowledge that students are expected to learn in science courses. With these descriptions, it would be possible to detail the knowledge (especially misconceptions) that students take away from instruction, thus providing a rational basis for changing science instruction.

Presentations can be refined and improved to some degree, and this is always worth doing, but is illusory to expect that vividness and lucidity of exposition are sufficient in themselves. To help the learner assimilate abstract concepts, it is essential to engage the learner's mind in active use of the concepts in concrete situations. The concepts must be explicitly connected with immediate, visible, or kinesthetic experience. Furthermore, the learner should be led to confront and resolve the contradictions that result from his own misconceptions.

The gaps in understanding cannot be fully resolved for all students on the first passage through kinematics, even with better exercises and tests. Genuine learning of abstract ideas is a slow process and requires both time and repetition. Repetition without intervening time yields meagre results. The most efficient approach is to move on through the subject matter but to keep returning and re-invoking the kinematic concepts in concrete, intuitive ways at every opportunity. As the ideas are re-encountered in increasingly rich contexts, they are gradually assimilated - but at different rates by different individuals.

Problem-solving environments have a major role to play in physics education by increasing the percentage of students who become proficient at solving problems. It will certainly help weaker students by giving them some security so that they can focus on some of the higher-level skills that make problem-solving easier. More able students will also gain because the problem-solving environment allows access to a wider range of problems and emphasizes high-level organizational and interpretive skills.

It is worth pointing out some general implications of the approach to studying the performance and teaching of a complex cognitive skill (such as problem-solving). Such research need not be restricted either to philosophical speculation or to gross statistical investigations in classroom settings. Instead, it is both possible and promising to formulate explicit information-processing models of a complex skill, and then to substantiate and improve these models by detailed observations of individual persons. The resulting understanding of underlying thought processes can then be used to design more effective instruction which can be cumulatively improved by repeated experimental testing and revisions.

Such a systematic approach to educational tasks, if pursued with serious attention to underlying theoretical models, can utilize and contribute to the cognitive or information sciences (such as modern cognitive psychology or artificial intelligence) where progress has been very rapid in recent years. In this way there is hope that education itself might be developed into a more effective science which is both intellectually challenging and socially significant.

6.5. RECOMMENDATIONS FOR FURTHER STUDY

It is suggested that the role played by the following factors during the problem-solving process can be rigorously investigated for purposes of further research.

- Language
- Gender
- Age
- Attitude

It is hoped that this research will serve to suggest further investigations of a similar nature. After all, this is an area we have yet to explore.

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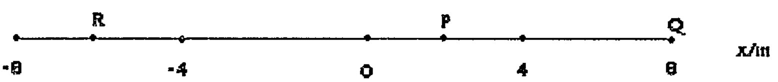
APPENDIX 1

RESEARCH QUESTIONNAIRE

QUESTION 1

Consider the figure below. Calculate the displacements and velocities and draw the velocity vectors.



(a) A moves from P to Q in 2,0 s.
Displacement of A.
Average velocity v_A.

(b) Now A moves from Q to P in 2,0 s.
Displacement of A.
Average velocity v_A.

(c) Say in words what difference you would see between cases (a) and (b).

QUESTION 2

Explain in your own words the meaning of the following important definition:
"Uniformly accelerated motion is motion with a constant acceleration."

QUESTION 3

When does an object have velocity?

QUESTION 4

When does an object have acceleration?

QUESTION 5

Aeroplanes flying long distances, for example from the U.S. to South Africa, generally fly at the same average air speed. Nevertheless it happens often that planes arrive at Johannesburg International Airport half an hour earlier or also, on other days, half an hour late. How is this possible?

QUESTION 6

A boy runs a course of 100 m. Do you think this movement will be uniform throughout? Describe in words what you think will happen to the velocity from the start up to the moment he stops.

QUESTION 7

What would you say about the direction of the velocity and acceleration for a decelerating object?

QUESTION 8

Which type of velocity, instantaneous or average, is being discussed in the statements below? Explain your answer.

(a) "My car is faster than yours, occasionally it goes at 130 km/h."

(b) "No, my car is faster, it can keep going at 125 km/h."

(c) "The maximum speed of an athlete is 10 m/s because running a distance of 100 m takes 10 s."

QUESTION 9

A trolley accelerates uniformly from rest and reaches a velocity of 5,0 m/s after 7,0 s. A student is asked to calculate the distance covered during these 7,0 s. He answers as follows: distance = velocity x time = 5,0 m/s x 7,0 s = 35 m
What are the mistakes made by the student? Explain how the student has reasoned and his/her confusion about certain quantities.

QUESTION 10

A raindrop falls from a cloud downwards. The cloud is at a height of 500 m above the ground.

(a) If there were no air resistance, how long would it take to reach the ground, and what is the velocity when it hits the ground?

(b) Is this realistic? Why/Why not?

QUESTION 11

An object is thrown vertically upwards with an initial velocity of 10 m/s.

(a) How long will it take to come back to the initial position?

(b) How high will it go?

(c) How long will it take to reach the maximum height?

(d) How long will it take to reach the thrower's hand?

(e) With what velocity will it reach the thrower's hand?

(f) When will it be 1 m above the thrower's hand?

(g) If the object misses the thrower's hand, with what velocity will it move 1 m below the thrower's hand?

QUESTION 12

An object starts from rest and attains a final speed of 10 m/s, after increasing its speed uniformly for 5 seconds.

(a) How far has it moved?

(b) With what acceleration is it moving?

APPENDIX 2

ANALYSIS OF WRITTEN RESPONSES TO THE QUESTIONNAIRE

INTRODUCTION

The analysis of responses is carried out using a coding system and also in terms of percentages. Each code corresponds to a particular response. The correct response for each question is provided. The percentage of students answering each question is calculated.

QUESTION 1(a) - *Coding of responses*

A00	-	No response
A01	-	Uncodable
A02*	-	Displacement of A = 6 m; average velocity v_A = 3 m/s.
A03	-	Displacement of A = 10 m; average velocity v_A = 5 m/s.
A04	-	Displacement of A = 2 m; average velocity v_A = 1 m/s.
A05	-	Displacement of A = 6 m; average velocity v_A = 0,3 m/s.
A06	-	Displacement of A = 6 m; average velocity v_A = 4 m/s.
A07	-	Displacement of A = 3 m; average velocity v_A = 3 m/s.
A08	-	Displacement of A = 3 m; average velocity v_A = 1,5 m/s.
A09	-	Displacement of A = 12 m; average velocity v_A = 6 m/s.
A10	-	Displacement of A = 4 m; average velocity v_A = 2 m/s.
A11	-	Displacement of A = 0,6 m; average velocity v_A = 0,3 m/s.
A12	-	Displacement of A = 8 m; average velocity v_A = 4 m/s.
A13	-	Displacement of A = 0 m; average velocity v_A = 6 m/s.
A14	-	Displacement of A = 6 m; average velocity v_A = -3 m/s.
A15	-	Displacement of A = 6 m; average velocity v_A = 6 m/*t*.
A16	-	Displacement of A = v_A/2,0 s; average velocity v_A = 3 m/s.
A17	-	Displacement of A = -1,0 m; average velocity v_A = -2,0 m/s.
A18	-	Displacement of A = 3 m; average velocity v_A = 0,15 m/s.
A19	-	Displacement of A = 6 m; average velocity v_A = 2 m/s.
A20	-	Displacement of A = 20 m; average velocity v_A = 20 m/s.

A21 - Displacement of A = 16 m; average velocity $v_A = 4$ m/s.
A22 - Displacement of A = 6 m; average velocity $v_A = 5$ m/s.

** Correct response*

<u>QUESTION 1 (a)</u> - ***Responses of students (1 -86)***

1. A02
2. A02
3. A03
4. A04
5. A02
6. A02
7. A02
8. A05
9. A06
10. A02
11. A07
12. A08
13. A02
14. A09
15. A02
16. A09
17. A02
18. A10
19. A09
20. A05
21. A02
22. A02
23. A02
24. A04
25. A02
26. A02
27. A02
28. A02
29. A02
30. A02
31. A11
32. A02
33. A12
34. A03
35. A12
36. A15
37. A02
38. A16
39. A13
40. A02
41. A02
42. A08
43. A02
44. A09
45. A02
46. A02
47. A02
48. A02
49. A02
50. A14
51. A02
52. A17
53 A00
54. A02
55. A12.
56. A02
57. A02
58. A12
59. A00
60. A02
61. A18
62. A02
63. A02
64. A10
65. A02
66. A02
67. A02
68. A19
69. A20
70. A21
71. A09
72. A02
73. A02
74. A02
75. A22
76. A02
77. A02
78. A02
79 A02
80. A02
81. A02
82. A02
83. A02
84. A12
85. A02
86. A02

QUESTION 1(a) - *Summary percentages*

	Number of students	Percentage
A00	2	2.3%
A01	0	0%
A02*	50	58.1%
A03	2	2.3%
A04	2	2.3%
A05	2	2.3%
A06	1	1.2%
A07	1	1.2%
A08	2	2.3%
A09	5	5.8%
A10	2	2.3%
A11	1	1.2%
A12	5	5.8%
A13	1	1.2%
A14	1	1.2%
A15	1	1.2%
A16	1	1.2%
A17	1	1.2%
A18	1	1.2%
A19	1	1.2%
A20	1	1.2%
A21	1	1.2%
A22	1	1.2%

***Correct response**

QUESTION 1 (b) - ***Coding of responses***

B00	-	No response
B01	-	Uncodable
B02*	-	Displacement of A = -6 m; average velocity v_A = -3 m/s.
B03	-	Displacement of A = 6 m; average velocity v_A = 3 m/s.
B04	-	Displacement of A = -12 m; average velocity v_A = -6 m/s.
B05	-	Displacement of A = 6 m; average velocity v_A = -3 m/s.
B06	-	Displacement of A = 2 m; average velocity v_A = 1 m/s.
B07	-	Displacement of A = -6 m; average velocity v_A = 0,3 m/s.
B08	-	Displacement of A = -6 m; average velocity v_A = 4 m/s.
B09	-	Displacement of A = -6 m; average velocity v_A = 3 m/s.
B10	-	Displacement of A = -3 m; average velocity v_A = -3 m/s.
B11	-	Displacement of A = -3 m; average velocity v_A = -1,5 m/s.
B12	-	Displacement of A = 0 m; average velocity v_A = 0 m/s.
B13	-	Displacement of A = 4 m; average velocity v_A = 2 m/s.
B14	-	Displacement of A = 12 m; average velocity v_A = 6 m/s.
B15	-	Displacement of A = -12 m; average velocity v_A = 6 m/s.
B16	-	Displacement of A = 0,6 m; average velocity v_A = 0,3 m/s.
B17	-	Displacement of A = -8 m; average velocity v_A = -4 m/s.
B18	-	Displacement of A = 10 m; average velocity v_A = 5 m/s.
B19	-	Displacement of A = v_A/2,0 s; average velocity v_A = -3 m/s.
B20	-	Displacement of A = 0 m; average velocity v_A = 6 m/s.
B21	-	Displacement of A = -3 m; average velocity v_A = 1,5 m/s.
B22	-	Displacement of A = 8 m; average velocity v_A = 4 m/s.
B23	-	Displacement of A = 3 m; average velocity v_A = -0,15m/s.
B24	-	Displacement of A = 6 m; average velocity v_A = 5 m/s.
B25	-	Displacement of A = -6 m; average velocity v_A = -6 m/s.
B26	-	Displacement of A = 1,0 m; average velocity v_A = 2,0 m/s.

***Correct response**

<u>QUESTION 1(b)</u>- ***Responses of students (1-86)***

1. B02	21. B02	41. B02	61. B23	81. B03
2. B05	22. B02	42. B21	62. B02	82. B03
3. B03	23. B02	43. B02	63. B05	83. B05
4. B06	24. B06	44. B04	64. B13	84. B17
5. B02	25. B09	45. B02	65. B02	85. B02
6. B03	26. B02	46. B02	66. B02	86. B03
7. B02	27. B02	47. B09	67. B02	
8. B07	28. B02	48. B02	68. B24	
9. B08	29. B02	49. B02	69. B03	
10. B09	30. B03	50. B03	70. B14	
11. B10	31. B16	51. B05	71. B14	
12. B11	32. B02	52. B26	72. B02	
13. B02	33. B17	53. B00	73. B02	
14. B04	34. B18	54. B05	74. B25	
15. B03	35. B14	55. B06	75. B24	
16. B04	36. B09	56. B02	76. B05	
17. B12	37. B03	57. B02	77. B02	
18. B13	38. B19	58. B22	78. B02	
19. B15	39. B20	59. B00	79. B03	
20. B11	40. B03	60. B02	80. B03	

QUESTION 1 (b)- *Summary percentages*

	Number of students	Percentage
B00	2	2.3%
B01	0	0%
B02*	30	34.9%
B03	13	15.1%
B04	3	3.5%
B05	5	5.8%
B06	3	3.5%
B07	1	1.2%
B08	1	1.2%
B09	4	4.7%
B10	1	1.2%
B11	2	2.3%
B12	1	1.2%
B13	2	2.3%
B14	3	3.5%
B15	1	1.2%
B16	1	1.2%
B17	2	2.3%
B18	1	1.2%
B19	1	1.2%
B20	1	1.2%
B21	1	1.2%
B22	1	1.2%
B23	1	1.2%
B24	2	2.3%
B25	1	1.2%
B26	1	1.2%

***Correct response**

QUESTION 1 (c)- ***Coding of responses***

C00	-	No response
C01	-	Uncodable
C02*	-	(a) motion is to the right; (b) motion is to left.
C03	-	(a) motion is to the right; (b) motion is to the right.
C04	-	(a) object A accelerates; (b) object A decelerates.
C05	-	(a) object A moves with positive acceleration; (b) object A moves with negative acceleration.
C06	-	Displacement and velocity are the same in both cases.
C07	-	(a) object A increases distance; (b) object A decreases distance.
C08	-	Displacement is a vector quantity.
C09	-	No difference because displacement is the same in both cases.
C10	-	(a) object A was decelerating; (b) object A was moving with constant velocity.
C11	-	Displacement and velocity in case (a) are greater than those in case (b).
C12	-	No difference because the distance and the time are the same.
C13.	-	No difference, but no reason is given.

****Correct response***

QUESTION 1 (c)- *Responses of students (1-86)*

1. C04	21. C02	41. C02	61. C02	81. C02
2. C02	22. C02	42. C02	62. C02	82. C02
3. C05	23. C02	43. C02	63. C02	83. C02
4. C02	24. C07	44. C02	64. C02	84. C02
5. C02	25. C02	45. C02	65. C02	85. C02
6. C06	26. C02	46. C02	66. C02	86. C02
7. C05	27. C02	47. C09	67. C02	
8. C02	28. C02	48. C02	68. C02	
9. C02	29. C02	49. C02	69. C02	
10. C02	30. C02	50. C02	70. C12	
11. C02	31. C02	51. C02	71. C06	
12. C02	32. C02	52. C10	72. C02	
13. C02	33. C02	53. C00	73. C02	
14. C02	34. C02	54. C02	74. C02	
15. C02	35. C02	55. C11	75. C02	
16. C02	36. C08	56. C02	76. C02	
17. C11	37. C02	57. C02	77. C02	
18. C02	38. C02	58. C02	78. C02	
19. C02	39. C02	59. C00	79. C02	
20. C04	40. C09	60. C02	80. C02	

QUESTION 1 (c)- *Summary percentages*

	Number of students	Percentage
C00	2	2.3%
C01	0	0%
*C02**	*69*	80.2%
C03	0	0%
C04	2	2.3%
C05	2	2.3%
C06	2	2.3%
C07	1	1.2%
C08	1	1.2%
C09	2	2.3%
C10	1	1.2%
C11	2	2.3%
C12	1	1.2%
C13	1	1.2%

***Correct response**

QUESTION 2 - *Coding of responses*

D00 - No response
D01 - Uncodable
D02* - The rate at which the velocity changes is the same in every second.
D03 - Motion is characterised by constant acceleration.
D04 - Motion is characterised by constant velocity.
D05 - Motion is characterised by changing velocity
D06 - Motion is characterised by increasing velocity.
D07 - Motion is characterised by constant velocity and constant acceleration.
D08 - Motion is characterised by a change in velocity and a constant acceleration.
D09 - Motion is characterised by a constant increase in velocity.
D10 - Motion is characterised by uniform force and a constant acceleration.
D11 - Motion in which the acceleration of an object is due to a constant applied force.
D12 - Motion characterised by a constant velocity and zero acceleration.
D13 - Motion characterised by constant acceleration and zero velocity.

***Correct response**

__QUESTION 2__ - *Responses of students (1-86)*

1. D07
2. D03
3. D03
4. D07
5. D03
6. D04
7. D02
8. D03
9. D08
10. D04
11. D03
12. D03
13. D06
14. D03
15. D04
16. D04
17. D07
18. D07
19. D0[illegible]
20. [illegible]
21. D03
22. D02
23. D02
24. D07
25. D09
26. D02
27. D00
28. D03
29. D03
30. D09
31. D10
32. D03
33. D02
34. D00
35. D07
36. D03
37. D03
38. D03
39. D07
40. D03/D06
41. D02
42. D07
43. D03
44 D11
45. D09
46. D07
47. D03
48. D07
49. D06
50. D03
51. D09
52. D07
53. D00
54. D01
55. D07
56. D06
57. D03
58. D04
59. D00
60. D07
61. D01
62. D02
63. D02
64. D07
65. D09
66. D09
67. D03
68. D03
69. D07
70 D04
71. D12
72. D02
73. D11
74. D00
75. D07
76. D03
77. D01
78. D02
79. D03
80. D13
81. D09
82. D03
83. D03
84. D09
85. D03
86. D03

QUESTION 2 - *Summary percentages*

	Number of students	Percentage
D00	5	5.8%
D01	3	3.5%
D02*	10	11.6%
D03	27	31.4%
D04	7	8.1%
D05	0	0%
D06	4	4.7%
D07	17	19.8%
D08	1	1.2%
D09	8	9.3%
D10	1	1.2%
D11	2	2.3%
D12	1	1.2%

Correct response

<u>QUESTION 3</u> - *Coding of responses*

E00	-	No response
E01	-	Uncodable
E02*	-	When an object moves in a given direction.
E03	-	When an object is moving.
E04	-	When an object starts to move.
E05	-	When an object moves a certain distance per unit time.
E06	-	When an object travels along a straight line.
E07	-	When an object is moving in a straight line.
E08	-	When an object moves a certain displacement per unit time.
E09	-	When an object is moving at a certain acceleration per unit time.
E10	-	When an object exists.
E11	-	When acceleration is not constant.
E12.	-	When its speed changes.
E13	-	If there is a force applied on an object.
E14.	-	When the acceleration of an object is zero.
E15	-	An object has velocity all the time.

Correct response

QUESTION 3 - *Responses of students (1-86)*

1. E03	21. E03	41. E02	61. E14	81. E08
2. E04	22. E10	42. E05	62. E02	82. E05
3. E07	23. E02	43. E03	63. E03	83. E05
4. E03	24. E03	44. E03	64. E03	84. E05
5. E05	25. E03	45. E05	65. E15	85. E03
6. E04	26. E08	46. E07	66. E04/E08	86. E03
7. E03	27. E08	47. E03	67. E03	
8. E08	28. E05	48. E02	68. E03	
9. E05	29. E08	49. E08	69. E05	
10. E03	30. E06/E08	50. E09	70. E13	
11. E07	31. E02	51. E02	71. E03	
12. E05	32. E03	52. E09	72. E03	
13. E03	33. E03	53. E00	73. E03	
14. E09	34. E11	54. E08	74. E03	
15. E03	35. E02	55. E03	75. E03	
16. E03	36. E03	56. E13	76. E04	
17. E03	37. E08	57. E08	77. E05	
18. E04	38. E03	58. E02	78. E03	
19. E04	39. E02	59. E00	79. E13	
20. E05	40. E12	60. E08	80. E05	

QUESTION 3 - *Summary percentages*

	Number of students	Percentage
E00	2	2.3%
E01	0	0%
E02*	9	10.5%
E03	30	34.9%
E04	6	7.0%
E05	14	16.3%
E06	1	1.2%
E07	3	3.5%
E08	12	14.0%
E09	3	3.5%
E10	1	1.2%
E11	1	1.2%
E12	1	1.2%
E13	3	3.5%
E14	1	1.2%
E15	1	1.2%

***Correct response**

QUESTION 4 - *Coding of responses*

F00	-	No response.
F01	-	Uncodable.
F02*	-	When its velocity changes.
F03	-	When its velocity increases.
F04	-	When its velocity decreases.
F05	-	When an object is moving.
F06	-	When an object starts to move.
F07	-	When displacement changes with time.
F08	-	When an object moves with certain velocity per unit time.
F09	-	Whenever an object exists.
F10	-	When an object changes its direction.
F11	-	When it has velocity and covers a certain distance.
F12	-	When a force is applied on an object.
F13	-	When an object is moving with constant velocity.
F14	-	When an object changes its acceleration.
F15	-	When an object moves with constant acceleration.

Correct response

QUESTION 4 - *Responses of students (1-86)*

1. F11	21. F03	41. F02	61. F05	81. F02
2. F05/F02	22. F09	42. F13	62. F02	82. F08
3. F08	23. F02	43. F05	63. F02	83. F08
4. F02	24. F12	44. F05	64. F05	84. F08
5. F02	25. F15	45. F02	65. F06	85. F03
6. F02	26. F08	46. F08	66. F02	86. F02
7. F08	27. F08	47. F05	67. F05	
8. F03	28. F08	48. F02	68. F05	
9. F08	29. F03/F04	49. F00	69. F03/F12	
10. F03	30. F08	50. F08	70. F02	
11. F08	31. F08	51. F03	71. F05	
12. F14	32. F02	52. F02	72. F02	
13. F02	33. F02	53. F00	73. F02	
14. F08	34. F08	54. F02	74. F02	
15. F11	35. F02	55. F13	75. F03	
16. F05	36. F05	56. F03/F12	76. F02	
17. F08	37. F03	57. F08	77. F05	
18. F06	38. F03	58. F03	78. F02	
19. F03	39. F10	59. F00	79. F03	
20. F08	40. F02	60. F02	80. F08	

<u>QUESTION 4</u> - *Summary percentages*

	Number of students	Percentage
F00	3	3.5%
F01	0	0%
F02*	27	31.4%
F03	13	15.1%
F04	1	1.2%
F05	12	14.0%
F06	2	2.3%
F07	0	0%
F08	20	23.3%
F09	1	1.2%
F10	1	1.2%
F11	2	2.3%
F12	3	3.5%
F13	2	2.3%
F14	1	1.2%
F15	1	1.2%

***Correct response**

QUESTION 5 - *Coding of responses*

G00 - No response.

G01 - Uncodable.

G02* - Because of the wind.

G03 - Because of air resistance.

G04 - Because of air resistance and the wind.

G05 - Because of air friction.

G06 - Because of the gravitational force.

G07 - Because of the way in which the aeroplane took off.

G08 - Because of air friction and the wind.

G09 - Because of the more mass of the plane.

G10 - Because of weather and air friction.

G11 - Because of weather and air resistance.

G12 - Because of the frictional force.

G13 - Because of air resistance and frictional force.

G14 - Because of the frictional force and the wind.

G15 - Depends on the direction of the aeroplane.

G16 - Because the average speed will be the same but the instantaneous speed will differ.

G17 - When the displacement of one aeroplane is greater than the other.

G18 - The speed of the aeroplane depends on the force exerted on the engine.

G19 - Because the instantaneous velocity is not always the same whereas the average velocity is the same.

G20 - It is determined by the initial velocity.

G21 - Because velocity is proportional to time.

G22 - Depends on the atmospheric layer.

G23 - Because of the atmospheric air and the angle at which the aeroplane moves.

G24 - Because the aeroplane does not move with uniform velocity.

G25 - Because of forces acting on the aeroplane.

G26 - Because of the change of time.

G27 - Because the velocity of the aeroplane does not change.

G28 - Because of the frame of reference.

**Correct response*

<u>QUESTION 5</u> - ***Responses of students (1-86)***

1. G02
2. G03
3. G06
4. G02
5. G05
6. G07
7. G08
8. G03
9. G03
10. G09
11. G15
12. G02
13. G02
14. G10
15. G16
16. G11
17. G03
18. G17
19. G02
20. G03
21. G03
22. G03
23. G02
24. G18
25. G02
26. G19
27. G03
28. G02
29. G02
30. G03
31. G12
32. G04
33. G14
34. G20
35. G00
36. G21
37. G02
38. G02
39. G03
40. G22
41. G04
42. G05
43. G14
44. G03
45. G04
46. G23
47. G03
48. G08
49. G02
50. G00
51. G19
52. G02
53. G00
54. G03
55. G24
56. G04
57. G03/G12
58. G03
59. G00
60. G03
61. G02
62. G02
63. G02
64. G05
65. G03
66. G02
67. G02
68. G02
69. G25
70. G26
71. G27
72. G02
73. G02
74. G02
75. G25
76. G02
77. G03
78. G02
79. G24
80. G02
81. G08
82. G05
83. G04
84. G28
85. G02
86. G03

QUESTION 5 - *Summary percentages*

	Number of students	Percentage
G00	4	4.7%
G01	0	0%
G02*	26	30.2%
G03	19	22.1%
G04	5	5.8%
G05	4	4.7%
G06	1	1.2%
G07	1	1.2%
G08	3	3.5%
G09	1	1.2%
G10	1	1.2%
G11	1	1.2%
G12	2	2.3%
G13	0	0%
G14	2	2.3%
G15	1	1.2%
G16	1	1.2%
G17	1	1.2%
G18	1	1.2%
G19	2	2.3%
G20	1	1.2%
G21	1	1.2%
G22	1	1.2%
G23	1	1.2%
G24	2	2.3%
G25	2	2.3%
G26	1	1.2%
G27	1	1.2%
G28	1	1.2%

***Correct response**

QUESTION 6 - *Coding of responses*

H00 -	No response
H01 -	Uncodable
H02* -	Accelerates from start, uniform motion, slows down, stop.
H03 -	Initial velocity is small, velocity increases, stop.
H04 -	Velocity is zero at the starting point, velocity changes to other form.
H05 -	Velocity at the starting point, velocity and acceleration changes, decelerates, stop.
H06 -	Velocity increases and decreases.
H07 -	Velocity increases, velocity decreases, stop.
H08 -	Initial velocity increases, velocity remains constant.
H09 -	Initial velocity is zero at the starting point, velocity increases, velocity decreases, stop.
H10 -	Initial velocity becomes higher than the final velocity, stop.
H11 -	There is change in velocity from the starting point to the final point.
H12 -	The velocity decreases.
H13 -	Initial velocity is smaller than the final velocity.
H14 -	Velocity is zero, velocity increases, velocity becomes constant, velocity decreases.
H15 -	Initial velocity is small, velocity increases, velocity decreases, stop.
H16 -	Initial velocity is small, velocity increases, constant velocity, velocity decreases, stop.
H17 -	Velocity increases, uniform velocity.
H18 -	Velocity increases, constant velocity, velocity decreases, stop.
H19 -	Initial velocity is zero, final velocity is zero when he stops.
H20 -	Velocity increases, stop.
H21 -	Initial velocity is zero, velocity increases, constant acceleration, velocity decreases, stop.
H22 -	Initial velocity is zero, velocity increases, stop.
H23 -	Accelerates, decelerates, stop.
H24 -	Initial velocity is zero, velocity increases, slows down, stop.
H25 -	Accelerates from rest until reaching terminal velocity.

H26 - Velocity will be the same and the motion will no longer be uniform.

H27 - Initial velocity is small, velocity increases.

**Correct response*

QUESTION 6 - *Responses of students (1-86)*

1. H03	21. H02	41. H07	61. H06	81. H18
2. H02	22. H14	42. H02	62. H16	82. H15
3. H04	23. H02	43. H20	63. H18	83. H20
4. H05	24. H06	44. H07	64. H16	84. H02
5. H06	25. H15	45. H18	65. H18	85. H16
6. H07	26. H07	46. H10	66. H02	86. H22
7. H07	27. H00	47. H15	67. H07	
8. H06	28. H16	48. H09	68. H06	
9. H08	29. H17	49. H02	69. H07	
10. H09	30. H09	50. H15	70. H24	
11. H10	31. H17	51. H18	71. H01	
12. H07	32. H02	52. H21	72. H23	
13. H06	33. H18	53. H00	73. H06	
14. H09	34. H00	54. H02	74. H25	
15. H07	35. H15	55. H22	75. H15	
16. H11	36. H19	56. H23	76. H07	
17. H06	37. H02	57. H24	77. H26	
18. H10	38. H18	58. H16	78. H18	
19. H12	39. H01	59. H00	79. H20	
20. H13	40. H18	60. H00	80. H27	

QUESTION 6 - *Summary percentages*

	Number of students	Percentage
H00	5	5.8%
H01	2	2.3%
H02*	10	11.6%
H03	1	1.2%
H04	1	1.2%
H05	1	1.2%
H06	7	8.1%
H07	10	11.6%
H08	1	1.2%
H09	4	4.7%
H10	3	3.5%
H11	1	1.2%
H12	1	1.2%
H13	1	1.2%
H14	1	1.2%
H15	5	5.8%
H16	5	5.8%
H17	2	2.3%
H18	9	10.5%
H19	1	1.2%
H20	3	3.5%
H21	1	1.2%
H22	2	2.3%
H23	2	2.3%
H24	2	2.3%
H25	1	1.2%
H26	1	1.2%
H27	1	1.2%

***Correct response**

QUESTION 7 - *Coding of responses*

I00	-	No response.
I01	-	Uncodable.
I02*	-	Acceleration and velocity are in opposite direction.
I03	-	Direction of acceleration and velocity will be the same.
I04	-	Direction will be towards the left.
I05	-	Velocity decreases and acceleration becomes negative.
I06	-	They are directly proportional to each other.
I07	-	Direction of velocity and acceleration will depend on the direction of an object.
I08	-	Velocity of the object is negative and therefore acceleration would be negative and is called deceleration.
I09	-	Direction of acceleration will be negative and velocity will be increasing backward.
I10	-	Direction of velocity and acceleration will be changing.
I11	-	Velocity will be negative.
I12	-	Direction of acceleration will be negative and velocity will have no direction since velocity is a scalar quantity.
I13	-	Direction of acceleration will be opposite to that of motion but velocity will have the same direction.
I14	-	Acceleration and deceleration are opposite in direction.
I15	-	Acceleration will be negative.
I16	-	Direction of the velocity is towards the decelerating object.
I17	-	Acceleration and velocity have no direction since they are scalar quantities.
I18	-	Acceleration opposes gravity.

***Correct response**

QUESTION 7 - *Responses of students (1-86)*

1. I03
2. I02
3. I03
4. I02
5. I04
6. I05
7. I06
8. I02
9. I07
10. I02
11. I08
12. I09
13. I02
14. I02
15. I10
16. I11
17. I12
18. I02
19. I02
20. I02
21. I13
22. I14
23. I02
24. I07
25. I03
26. I02
27. I02
28. I03
29. I03
30. I06
31. I02
32. I02
33. I02
34. I15
35. I16
36. I03
37. I03
38. I02
39. I02
40. I02
41. I02
42. I02
43. I02
44. I02
45. I03
46. I05
47. I00
48. I02
49. I02
50. I03
51. I02
52. I17
53. I00
54. I02
55. I02
56. I02
57. I03
58. I13
59. I00
60. I01
61. I02
62. I02
63. I02
64. I03
65. I03
66. I03
67. I03
68. I02
69. I02
70. I11
71. I03
72. I02
73. I02
74. I02
75. I03
76. I02
77. I03
78. I02
79. I02
80. I03
81. I03
82. I18
83. I03
84. I03
85. I03
86. I13.

QUESTION 7 - *Summary percentages*

	Number of students	Percentage
I00	2	2.3%
I01	1	1.2%
I02*	39	45.4%
I03	22	25.6%
I04	1	1.2%
I05	2	2.3%
I06	2	2.3%
I07	2	2.3%
I08	1	1.2%
I09	1	1.2%
I10	1	1.2%
I11	2	2.3%
I12	1	1.2%
I13	3	3.5%
I14	1	1.2%
I15	1	1.2%
I16	1	1.2%
I17	1	1.2%
I18	1	1.2%

***Correct response**

<u>QUESTION 8 (a)</u> - ***Coding of responses***

J00	-	No response
J01	-	Uncodable
J02*	-	Instantaneous velocity; it is velocity at a particular instant.
J03	-	Instantaneous velocity; no explanation.
J04	-	Average velocity; it is given by $velocity = \frac{displacement}{time}$
J05	-	Average velocity; no explanation.
J06	-	Average velocity; it changes with time.
J07	-	Instantaneous velocity; it is the velocity the car can move at an hour.
J08	-	Instantaneous velocity; the velocity increases as the car accelerates.
J09	-	Instantaneous velocity; the speed of the car occurs occasionally, i.e. not all the time.
J10	-	Instantaneous velocity; it is the small velocity of the car.
J11	-	Average velocity; the velocity changes.
J12	-	Instantaneous velocity; it is the velocity of the car during time intervals.
J13	-	Instantaneous velocity; it is the high velocity of the car.
J14	-	Average velocity; the car moves at 130 km/h.
J15	-	Instantaneous velocity; it is the velocity at a specific distance.
J16	-	Average velocity; it is the velocity for whole motion.
J17	-	Average velocity; 130 km/h is the total speed of the car.
J18	-	Instantaneous velocity; the velocity does not change.
J19	-	Instantaneous velocity; the velocity changes.
J20	-	Average velocity; the velocity does not change.
J21	-	Average velocity; it is maximum velocity of the car.
J22	-	Average velocity; it is the least velocity of the car.
J23	-	Instantaneous velocity; it happens at short space of time.
J24	-	Average velocity; it is the velocity calculated over a certain distance.
J25	-	Average velocity; it is the general velocity of the car.
J26	-	Average velocity; it is the last velocity of the car.
J27	-	Average velocity; it is the velocity of the car at a particular instant.

J28 - Average velocity; the velocity of the car occurs occasionally, i.e. not all the time.

**Correct response*

QUESTION 8 (a)- *Responses of students (1-86)*

1. J05	21. J09	41. J02	61. J26	81. J09
2. J02	22. J18	42. J22	62. J11	82. J21
3. J06	23. J11	43. J19	63. J02	83. J25
4. J07	24. J19	44. J23	64. J03	84. J02
5. J05	25. J20	45. J02	65. J09	85. J02
6. J08	26. J02	46. J05	66. J20	86. J28
7. J05	27. J05	47. J00	67. J27	
8. J09	28. J11	48. J24	68. J05	
9. J02	29. J11	49. J02	69. J28	
10. J04	30. J21	50. J03	70. J03	
11. J07	31. J00	51. J09	71. J09	
12. J10	32. J02	52. J08	72. J03	
13. J11	33. J19	53. J00	73. J02	
14. J12	34. J00	54. J19	74. J03	
15. J13	35. J05	55. J17	75. J01	
16. J14	36. J03	56. J25	76. J21	
17. J17	37. J03	57. J02	77. J06	
18. J09	38. J03	58. J05	78. J09	
19. J16	39. J01	59. J00	79. J09	
20. J17	40. J11	60. J02	80. J04	

QUESTION 8 (a)- *Summary percentages*

	Number of students	Percentage
J00	5	5.8%
J01	2	2.3%
J02*	12	14.0%
J03	7	8.1%
J04	2	2.3%
J05	8	9.3%
J06	2	2.3%
J07	2	2.3%
J08	2	2.3%
J09	9	10.5%
J10	1	1.2%
J11	6	7.0%
J12	1	1.2%
J13	1	1.2%
J14	1	1.2%
J15	0	0%
J16	1	1.2%
J17	3	3.5%
J18	1	1.2%
J19	3	3.5%
J20	1	1.2%
J21	3	3.5%
J22	1	1.2%
J23	1	1.2%
J24	1	1.2%
J25	2	2.3%
J26	1	1.2%
J27	1	1.2%
J28	2	2.3%

***Correct response**

<u>QUESTION 8 (b)</u>- *Coding of responses*

K00	-	No response
K01	-	Uncodable
K02*	-	Average velocity; it is given by $velocity = \frac{displacement}{time}$
K03	-	Average velocity; no explanation.
K04	-	Instantaneous velocity; it is the velocity at a particular instant.
K05	-	Instantaneous velocity; no explanation.
K06	-	Instantaneous velocity; the velocity does not change.
K07	-	Average velocity; the velocity does not change.
K08	-	Instantaneous velocity; the acceleration is uniform.
K09	-	Average velocity; the velocity is different.
K10	-	Average velocity; it is the average of all the velocities the car can cover.
K11	-	Instantaneous velocity; the velocity of the car increases up to 125 km/h.
K12	-	Average velocity; the velocity changes.
K13	-	Average velocity; the velocity cannot be more than 125 km/h.
K14	-	Instantaneous velocity; it is the maximum velocity of the car.
K15	-	Average velocity; it is the velocity at various points.
K17	-	Instantaneous velocity; it is the velocity between 0 and 130 km/h.
K18	-	Instantaneous velocity; because of the change of displacement.
K19	-	Average velocity; it is the velocity of the car for the whole motion.
K20	-	Average velocity; the car often moves at 125 km/h.
K21	-	Both average and instantaneous velocity since it is a uniform motion where the average velocity is equal to the instantaneous velocity.
K22	-	Instantaneous velocity; the car can sometimes keep going at that speed.
K23	-	Average velocity; we are speaking of two velocities.
K24	-	Instantaneous velocity; it is the velocity of the car for the whole motion.
K25	-	Instantaneous velocity; the velocity can be more than 125 km/h.
K26	-	Average velocity; it is the maximum velocity of the car.

Correct response

QUESTION 8 (b)- *Responses of students (1-86)*

1. K06	21. K04	41. K19	61. K06	81. K07
2. K07	22.K01	42. K06	62. K18	82. K25
3. K08	23. K06	43. K07	63. K07	83. K04
4. K09	24. K07	44. K20	64. K23	84. K07
5. K05	25. K01	45. K03	65. K05	85. K26
6. K07	26. K07/K02	46. K03	66. K24	86. K01
7. K03	27. K05	47. K00	67. K07	
8. K07	28. K06	48. K21	68. K05	
9. K10	29. K06	49. K07	69. K06	
10. K11	30. K06	50. K05	70. K03	
11. K12	31. K18	51. K03	71. K07	
12. K13	32. K07	52. K08	72. K03	
13. K06	33. K07	53. K00	73. K07	
14. K07	34. K03	54. K07	74. K03	
15. K14	35. K00.	55. K22	75. K01	
16. K06	36. K05	56. K06	76. K04	
17. K15	37. K03	57. K07	77. K13	
18. K07	38. K03	58. K05	78. K21	
19. K17	39. K06	59. K00	79. K07	
20. K09	40. K04	60. K19	80. K02	

QUESTION 8 (b) -*Summary percentages*

	Number of students	Percentage
K00	3	3.5%
K01	3	3.5%
K02*	2	2.3%
K03	10	11.6%
K04	4	4.7%
K05	7	8.1%
K06	12	14.0%
K07	20	23.3%
K08	2	2.3%
K09	2	2.3%
K10	1	1.2%
K11	1	1.2%
K12	1	1.2%
K13	2	2.3%
K14	1	1.2%
K15	1	1.2%
K16	0	0%
K17	1	1.2%
K18	2	2.3%
K19	2	2.3%
K20	1	1.2%
K21	2	2.3%
K22	1	1.2%
K23	1	1.2%
K24	1	1.2%
K25	1	1.2%
K26	1	1.2%

Correct response

QUESTION 8 (c) - ***Coding of responses***

L00	-	No response
L01	-	Uncodable
L02*	-	Average velocity; However, the word maximum is wrong since we know quite well that the maximum speed of the athlete is greater than 10 m/s.
L03	-	Average velocity; no explanation.
L04	-	Instantaneous velocity; no explanation.
L05	-	Average velocity; he runs 100 m every 10 s.
L06	-	Average velocity; there is change in time due to velocity.
L07	-	Average velocity; it is given by $velocity = \frac{displacement}{time}$
L08	-	Average velocity; the distance travelled in 10 s equals the velocity travelled.
L09	-	Average velocity; it is the total velocity of the athlete for whole motion.
L10	-	Instantaneous velocity; we know that the maximum velocity is 10 m/s.
L11	-	Average velocity; the athlete started his speed from 0 m/s until he reached a certain point.
L12	-	Average velocity; the velocity changes.
L13	-	Average velocity; it is the maximum velocity of the athlete.
L14	-	Instantaneous velocity; it is the velocity at a particular instant.
L15	-	Average velocity; the velocity is constant.
L16	-	Instantaneous velocity; it is the velocity at a particular distance.
L17	-	Instantaneous velocity; the velocity changes.
L18	-	Instantaneous velocity; it is given by $velocity = \frac{displacement}{time}$

****Correct response***

QUESTION 8 (c) - ***Responses of students (1-86)***

1. L05
2. L05
3. L06
4. L07
5. L03
6. L08
7. L04
8. L09
9. L02
10. L10
11. L00
12. L03
13. L11
14. L10
15. L09
16. L12
17. L12
18. L13
19. L07
20. L09
21. L12
22. L12
23. L12
24. L13
25. L09
26. L09
27. L03
28. L12
29. L09
30. L13
31. L09
32. L07
33. L07
34. L03
35. L00
36. L03
37. L03
38. L04
39. L09
40. L12
41. L14
42. L07
43. L02
44. L07
45. L09
46. L04
47. L00
48. L07
49. L09
50. L03
51. L12
52. L01
53. L00
54. L12
55. L03
56. L10
57. L07
58. L04
59. L00
60. L15
61. L03
62. L07
63. L12
64. L16
65. L07
66. L03
67. L03
68. L03
69. L13
70. L03
71. L03
72. L03
73. L09
74. L03
75. L01
76. L17
77. L16
78. L07
79. L01
80. L18
81. L03
82. L03
83. L01
84. L03
85. L03
86. L09

QUESTION 8 (c) - *Summary percentages*

	Number of students	Percentage
L00	4	4.7%
L01	4	4.7%
L02*	2	2.3%
L03	20	23.3%
L04	4	4.7%
L05	2	2.3%
L06	1	1.2%
L07	11	12.8%
L08	1	1.2%
L09	12	14.0%
L10	3	3.5%
L11	1	1.2%
L12	10	11.6%
L13	3	3.5%
L14	1	1.2%
L15	1	1.2%
L16	2	2.3%
L17	1	1.2%
L18	1	1.2%

***Correct response**

QUESTION 9 - *Coding of responses*

M00 -	No response
M01 -	Uncodable
M02* -	The student assumed that the velocity remained constant at 5m/s. Instead of multiplying by the average velocity, he/she multiplied by the instantaneous velocity.
M03 -	No mistake.
M04 -	Should have used the correct equation of motion.
M05 -	Mistake is that he/she did not consider the object started from rest.
M06 -	Should have first calculated the average velocity.
M07 -	Should have used $v^2 = u^2 + 2as$.
M08 -	The student thought what is calculated is the distance whereas it is displacement.
M09 -	Mistake is that she/he did not get the average velocity.
M10 -	The student did not calculate the initial and the final velocity.
M11 -	The student should have indicated that the initial velocity is zero and indicated the units.
M12 -	Did not consider the initial time and the initial velocity.
M13 -	Should have indicated that the initial velocity is zero.
M14 -	Did not indicate the units.
M15 -	Did not calculate the acceleration of the trolley.
M16 -	Calculated the average distance instead of the total distance covered within that time.
M17 -	Did not include direction in the calculations.
M18 -	Did not realise that the velocity was changing uniformly. Thought that 5,0 m/s is the average velocity whereas it is the instantaneous velocity.
M19 -	Confuses the average and the final velocity.
M20 -	Calculated displacement instead of distance.
M21 -	Did not consider initial velocity and displacement.
M22 -	Thought the velocity was constant.
M23 -	Confuses uniform motion and uniformly accelerated motion. Used 5 m/s as constant speed i.e. instantaneous velocity.

M24 - Multiplied velocity by time instead of dividing velocity by time.

M25 - Confused change in velocity and the final velocity.

M26 - Calculates distance covered instead of change in velocity first.

M27 - Confused speed with velocity.

**Correct response*

<u>QUESTION 9</u> - ***Responses of students (1-86)***

1. M03	21. M14	41. M19	61. M05/M13	81. M19
2. M02	22. M02	42. M13	62. M23	82. M14
3. M04	23. M15	43. M15	63. M08	83. M14
4. M05	24. M04/M13	44. M08	64. M05/M04	84. M19
5. M06	25. M02	45. M00	65. M00	85. M05
6. M01	26. M16	46. M14	66. M02	86. M14
7. M07	27. M08	47. M14	67. M24	
8. M08	28. M01	48. M02	68. M25	
9. M09	29. M02	49. M13	69. M26	
10. M10	30. M17	50. M05	70. M13/M05	
11. M11	31. M08	51. M20	71. M14	
12. M12	32. M14/M15	52. M04	72. M23	
13. M02	33. M18	53. M00	73. M02	
14. M13	34. M00	54. M21	74. M18	
15. M02	35. M15	55. M05/M13	75. M04	
16. M13	36. M01	56. M14	76. M27	
17. M04	37. M00	57. M22	77. M14	
18. M14	38. M18	58. M13/M04	78. M05	
19. M15	39. M04	59. M00	79. M07	
20. M04	40. M15	60. M05	80. M04	

QUESTION 9 - *Summary percentages*

	Number of students	Percentage
M00	6	7.0%
M01	3	3.5%
M02*	8	9.3%
M03	1	1.2%
M04	10	11.6%
M05	8	9.3%
M06	1	1.2%
M07	2	2.3%
M08	5	5.8%
M09	1	1.2%
M10	1	1.2%
M11	1	1.2%
M12	1	1.2%
M13	9	10.5%
M14	11	12.8%
M15	6	7.0%
M16	1	1.2%
M17	1	1.2%
M18	2	2.3%
M19	2	2.3%
M20	1	1.2%
M21	1	1.2%
M22	1	1.2%
M23	2	2.3%
M24	1	1.2%
M25	1	1.2%
M26	1	1.2%
M27	1	1.2%

***Correct response**

<u>QUESTION 10 (a)</u> - ***Coding of responses***

N00 - No response

N01 - Uncodable

N02* -

$s = ut + \frac{1}{2} at^2$; $v = u + at$

$500 \text{ m} = ut + \frac{1}{2} at^2$; $v = 0 + 10(10)$

$500 = 0 + \frac{1}{2}(10)t^2$; $v = 100 \text{ m/s}$

$5t^2 = 500$

$t = 10 \text{ s}$

N03 -

$s = ut + \frac{1}{2} at^2$

$= (10)(5) + \frac{1}{2}(10)(5)^2$

$= 50 + 125$

$= 175 \text{ m}$

N04 -

$s = ut + \frac{1}{2} at^2$; $v = \frac{d}{t}$

$500 = 0 + \frac{1}{2}(10)t^2$

$t = 10 \text{ s}$; $= \frac{500m}{10s}$

N05 -

$s = ut + \frac{1}{2} at^2$

$500 = 0 + \frac{1}{2}(10)t^2$

$5t^2 = 500$

$t = 10 \text{ s}$

N06 -

$s = ut + \frac{1}{2} at^2$; $v^2 = u^2 + 2as$

$500 = 0 + \frac{1}{2}(10)t^2$; $= 0^2 + 2(10)(500)$

$5t^2 = 500$; $= 10000$

$t = 10 \text{ s}$; $= 100 \text{ m/s}$

N07 -

$v^2 = u^2 + 2as$; $v = u + at$

$= 0^2 + 2(10)(500)$; $t = \frac{v}{g}$

$= 10000$

$v = 100 \text{ m/s}$; $= \frac{100m/s}{10m/s^2}$

N08 - $s = 500$ m ; $v = 500$ m/s

N09 - $t = 0{,}05$ s ; $v = 10000$ m/s

N10 - Insufficient information given.

N11 - The following equation used: $v = \frac{s}{t}$

N12 - $v = 0$ m/s

N13 - $t = 10$ s ; $v = 0$ m/s

***Correct response**

QUESTION 10 (a) - ***Responses of students (1-86)***

1. N02	21. N10	41. N07	61. N08	81. N01
2. N02	22. N06	42. N01	62. N02	82. N01
3. N06	23. N05	43. N05	63. N10	83. N05
4. N04	24. N07	44. N02	64. N02	84. N00
5. N02	25. N02	45. N01	65. N13	85. N10
6. N05	26. N06	46. N05	66. N02	86. N01
7. N06	27. N02	47. N02	67. N02	
8. N05	28. N09	48. N06	68. N10	
9. N02	29. N02	49. N06	69. N02	
10. N08	30. N05	50. N06	70. N10	
11. N02	31. N07	51. N06	71. N05	
12. N05	32. N10	52. N02	72. N02	
13. N09	33. N04	53. N00	73. N07	
14. N02	34. N00	54. N02	74. N10	
15. N02	35. N05	55. N12	75. N05	
16. N06	36. N04	56. N01	76. N05	
17. N10	37. N06	57. N02	77. N01	
18. N11	38. N05	58. N06	78. N02	
19. N06	39. N05	59. N00	79. N00	
20. N02	40. N06	60. N06	80. N06	

<u>QUESTION 10 (a)</u> - *Summary percentages*

	Number of students	Percentage
N00	4	4.7%
N01	7	8.1%
N02*	22	25.6%
N03	0	0%
N04	3	3.5%
N05	14	16.3%
N06	15	17.4%
N07	4	4.7%
N08	2	2.3%
N09	2	2.3%
N10	8	9.3%
N11	1	1.2%
N12	1	1.2%
N13	1	1.2%

***Correct response**

QUESTION 10 (b) - ***Coding of responses***

O00 -	No response
O01 -	Uncodable
O02* -	No, the raindrop will reach a terminal velocity.
O03 -	No, because force of friction will disturb the raindrop.
O04 -	Yes, the drop is very small and it can penetrate through air.
O05 -	No, raindrop can't take so much time to fall.
O06 -	No, because raindrop can't travel at that speed from the cloud.
O07 -	Yes, gravitational force will make it possible for the raindrop to reach the ground.
O08 -	Yes, because the time taken by the raindrop to reach the ground is unknown.
O09 -	No, because air resistance will disturb the raindrop.
O10 -	No, because the initial and final time are not known.
O11 -	Yes, because of the effect of air resistance on the drop.
O12 -	No, the cloud cannot be at a height of 500 m above the ground.
O13 -	No, because the raindrop will accelerate uniformly and decelerate when hitting the ground.
O14 -	Yes, because the displacement is large and it will need much time to complete that journey.
O15 -	Yes, no reason given.
O16 -	No, because the raindrop cannot take the same time and same velocity to cover same displacement.
O17 -	No, because the velocity is very small.
O18 -	No, because the velocity large.
O19 -	Yes, because the velocity is large.
O20 -	No, no reason given.
O21 -	Yes, because the initial velocity is zero and final velocity is the one after the initial velocity.
O22 -	No, because the velocity is unknown.
O23 -	No, because wind affects the velocity of the raindrop.

***Correct response**

QUESTION 10 (b) - *Responses of students (1-86)*

1. O03	21. O12	41. O09	61. O18	81. O00
2. O04	22. O09	42. O07	62. O09	82. O07
3. O05	23. O08	43. O15	63. O08	83. O15
4. O06	24. O01	44. O15	64. O00	84. O08
5. O03	25. O04	45. O17	65. O07	85. O20
6. O07	26. O12	46. O12	66. O09	86. O00
7. O07	27. O12	47. O18	67. O18	
8. O07	28. O07	48. O09	68. O20	
9. O06	29. O01	49. O03	69. O00	
10. O08	30. O09	50. O15	70. O22	
11. O07	31. O00	51. O19	71. O00	
12. O07	32. O12	52. O07	72. O03	
13. O09	33. O13	53. O00	73. O03	
14. O07	34. O00	54. O18	74. O02	
15. O07	35. O00	55. O20	75. O12	
16. O00	36. O14	56. O20	76. O23	
17. O01	37. O12	57. O07	77. O15	
18. O10	38. O09	58. O00	78. O13	
19. O00	39. O15	59. O00	79. O00	
20. O11	40. O16	60. O21	80. O15	

QUESTION 10 (b) - *Summary percentages*

	Number of students	Percentage
O00	13	15.1%
O01	3	3.5%
O02*	1	1.2%
O03	5	5.8%
O04	2	2.3%
O05	1	1.2%
O06	2	2.3%
O07	13	15.1%
O08	4	4.7%
O09	8	9.3%
O10	1	1.2%
O11	1	1.2%
O12	7	8.1%
O13	2	2.3%
O14	1	1.2%
O15	7	8.1%
O16	1	1.2%
O17	1	1.7%
O18	3	3.5%
O19	1	1.2%
O20	4	4.7%
O21	1	1.2%
O22	1	1.2%
O23	1	1.2%

***Correct response**

QUESTION 11 (a) - *Coding of responses*

P00 - No response

P01 - Uncodable

P02* -
$s = ut + \frac{1}{2} at^2$
$0 = 10t + \frac{1}{2}(-10)t^2$
$0 = 10t - 5t^2$
$5t(t - 2) = 0$
$t = 2$ s

P03 -
$v = u + gt$
$0 = 10 - 10t$
$t = 1$ s

P04 -
$s = ut + \frac{1}{2} at^2$
$0 = 10t + \frac{1}{2}(10)t^2$
$0 = 10t + 5t^2$
$5t(t + 2) = 0$
$t = -2$ s

P05 -
$v = u + gt$
$0 = 10 + 10t$
$t = -1$ s

P06 -
$v = u + gt$
$0 = 10 - 10t$
$t = 1$ s
Since the object takes 1 s to go upwards and 1 s to go downward, then t = 1 s + 1 s = 2 s

P07 - The solution is as follows: $t = \frac{v_0}{g} = \frac{10m/s}{10m/s^2} = 1s$

P08 - It will take -10 m/s.

P09 -
$s = ut + \frac{1}{2} gt^2$
$5\text{ m} = 10t + \frac{1}{2}(-10)t^2$
$5t^2 - 10t + 5 = 0$
$t^2 - 2t + 1 = 0$
$t = 1$s

P10 - It will take 2 seconds.

P11 - The solution is as follows: $t = \frac{2\sin 90^0}{9{,}8m/s^2}$

P12 - After 1 second.

P13 - The solution is as follows: $t = \frac{2u}{g} = \frac{2x10m/s}{9{,}8m/s^2} = 2{,}03s$

P14 - The solution is as follows: $t = \frac{d}{v} = \frac{10m}{10m/s^2} = 1s$

P15 - Insufficient information given.

P16 - If friction is ignored the time at which it goes up will be more than the time it comes back because of the force of gravity is more than that of friction.

P17 - $t = 10$ m/s / 10 m = 1 s

Correct response

QUESTION 11 (a) - ***Responses of students (1-86)***

1. P03	21. P12	41. P06	61. P03	81. P16
2. P06	22. P02	42. P03	62. P06	82. P16
3. P04	23. P06	43. P03	63. P15	83. P05
4. P07	24. P03	44. P03	64. P15	84. P17
5. P06	25. P03	45. P14	65. P10	85. P01
6. P06	26. P03	46. P03	66. P03	86. P01
7. P06	27. P06	47. P05	67. P02	
8. P06	28. P13	48. P06	68. P01	
9. P03	29. P06	49. P06	69. P03	
10. P08	30. P06	50. P03	70. P15	
11. P03	31. P03	51. P06	71. P03	
12. P03	32. P03	52. P03	72. P03	
13. P01	33. P06	53. P00	73. P05	
14. P05	34. P03	54. P05	74. P06	
15. P03	35. P03	55. P03	75. P04	
16. P09	36. P01	56. P11	76. P03	
17. P10	37. P03	57. P03	77. P01	
18. P11	38. P05	58. P02	78. P05	
19. P06	39. P06	59. P00	79. P03	
20. P03	40. P02	60. P06	80. P03	

QUESTION 11 (a) - *Summary percentages*

	Number of students	Percentage
P00	2	2.3%
P01	6	7.0%
P02*	4	4.7%
P03	30	34.9%
P04	2	2.3%
P05	7	8.1%
P06	19	22.1%
P07	1	1.2%
P08	1	1.2%
P09	1	1.2%
P10	2	2.3%
P11	2	2.3%
P12	1	1.2%
P13	1	1.2%
P14	1	1.2%
P15	3	3.5%
P16	2	2.3%
P17	1	1.2%

***Correct response**

QUESTION 11 (b) - *Coding of responses*

Q00 - No response.
Q01 - Uncodable

Q02* - $v^2 = u^2 + 2as$
$0 = 10^2 + 2(-10)s$
$0 = 10^2 - 20s$
$20s = 100$
$s = 5$ m

Q03 - $s = ut + \frac{1}{2} at^2$
$= 10(1) + \frac{1}{2} (9.8)t^2$
$= 15$ m

Q04 - The solution is as follows: $h = \frac{v^2}{2g} = \frac{(10)^2}{2(10)} = 5m$

Q05 - $s = ut + \frac{1}{2} at^2$
$= 10(1) + \frac{1}{2} (-9.8)(1)^2$
$= 10 - 5$
$= 5$ m

Q06 - distance = velocity x time = 10 m/s x 1 s = 10 m

Q07 - $s = ut + \frac{1}{2} at^2$ (equation only)

Q08 - $s = \frac{1}{2} at^2 = \frac{1}{2} (10)(1)^2 = 5$ m

Q09 - Insufficient information given.
Q10 - It will be 10 m.
Q11 - It will depend on time.

Q12 - Solution: $h_{max} = \frac{u^2 \sin(2x90^0)}{2g} = \frac{(10m/s)^2 \sin(2x90^0)}{2(10m/s^2)}$

**Correct response*

QUESTION 11 (b) - ***Responses of students (1-86)***

1. Q03	21. Q10	41. Q05	61. Q02	81. Q10
2. Q05	22. Q05	42. Q03	62. Q05	82. Q11
3. Q02	23. Q03	43. Q03	63. Q09	83. Q10
4. Q04	24. Q02	44. Q05	64. Q00	84. Q03
5. Q02	25. Q08	45. Q10	65. Q10	85. Q06
6. Q02	26. Q02	46. Q06	66. Q05	86. Q06
7. Q05	27. Q02	47. Q03	67. Q00	
8. Q03	28. Q03	48. Q05	68. Q06	
9. Q05	29. Q05	49. Q02	69. Q06	
10. Q10	30. Q02	50. Q02	70. Q09	
11. Q05	31. Q05	51. Q03	71. Q03	
12. Q05	32. Q02	52. Q05	72. Q08	
13. Q02	33. Q05	53. Q00	73. Q05	
14. Q05	34. Q02	54. Q04	74. Q02	
15. Q03	35. Q08	55. Q06	75. Q06	
16. Q02	36. Q03	56. Q12	76. Q08	
17. Q06	37. Q03	57. Q05	77. Q00	
18. Q07	38. Q03	58. Q02	78. Q03	
19. Q02	39. Q03	59. Q00	79. Q02	
20. Q06	40. Q05	60. Q02	80. Q03	

QUESTION 11 (b) - *Summary percentages*

	Number of students	Percentage
Q00	5	5.8%
Q01	0	0%
Q02*	19	22.1%
Q03	16	18.6%
Q04	2	2.3%
Q05	19	22.1%
Q06	8	9.3%
Q07	1	1.2%
Q08	4	4.7%
Q09	2	2.3%
Q10	6	7.0%
Q11	1	1.2%
Q12	1	1.2%

***Correct response**

QUESTION 11 (c) - *Coding of responses*

R00 - No response

R01 - Uncodable

R02* - $v = u + at$
$0 = 10 - 10t$
$10t = 10$
$t = 1$ s

R03 - $s = ut + \frac{1}{2} at^2$
$5 \text{ m} = 10t + \frac{1}{2}(-10)t^2$
$5 = 10t - 5t^2$
$t^2 - 2t + 1 = 0$
$t = 1$ s

R04 - $t = 1$ s

R05 - $t = 2$ s

R06 - $v^2 = u^2 + 2gs$
$(10)^2 = (0)^2 + 2(10)s$
$s = 5$ m

R07 $s = \frac{1}{2} at^2 = \frac{1}{2}(10) \times (1)^2 = 5$ m

R08 - $s = \frac{1}{2} at^2$
$5\text{m} = \frac{1}{2}(10)t^2$
$t = 1$ s

R09 - Solution:

R10 - $s = 10$ m $t_{max} = \frac{v_0}{2g} = \frac{10}{20} = 0{,}5s$

R11 - $t = 3$ s

R12 - $s = \frac{1}{2} at^2$ (equation only)

R13 - $x = vt$

$$40 = 10t$$
$$t = 4 \text{ s}$$

R14 - $t = 0{,}5$ s

R15 - Solution: $s = \frac{(v+u)}{2}t = \frac{5(10+0)}{2}t$

$t = 1s$

R16 - Solution: $t = \frac{\sin 90^0}{g} = \frac{\sin 90^0}{10}$

R17 - Insufficient information given.

****Correct response***

<u>QUESTION 11 (c)</u> - ***Responses of students (1-86)***

1. R04	21. R10	41. R02	61. R04	81. R04
2. R02	22. R04	42. R03	62. R02	82. R01
3. R05	23. R02	43. R14.	63. R00	83. R11
4. R09	24. R04	44. R14	64. R00	84. R03
5. R03	25. R08	45. R04	65. R04	85. R04
6. R03	26. R03	46. R03	66. R03	86. R04
7. R06	27. R03	47. R00	67. R06	
8. R02	28. R08	48. R04	68. R05	
9. R02	29. R03	49. R04	69. R03	
10. R10	30. R02	50. R03	70. R17	
11. R02	31. R03	51. R08	71. R00	
12. R02	32. R02	52. R04	72. R14	
13. R11	33. R04	53. R00	73. R14	
14. R04	34. R08	54. R00	74. R04	
15. R06	35. R08	55. R00	75. R02	
16. R03	36. R13	56. R16	76. R00	
17. R07	37. R14	57. R03	77. R04	
18. R12	38. R13	58. R15	78. R00	
19. R04	39. R03	59. R00	79. R00	
20. R03	40. R15	60. R04	80. R02	

QUESTION 11 (c) - *Summary percentages*

	Number of students	Percentage
R00	11	12.8%
R01	1	1.2%
R02*	12	14.0%
R03	16	18.6%
R04	18	20.9%
R05	2	2.3%
R06	3	3.5%
R07	1	1.2%
R08	5	5.8%
R09	1	1.2%
R10	2	2.3%
R11	2	2.3%
R12	1	1.2%
R13	2	2.3%
R14	5	5.8%
R15	2	2.3%
R16	1	1.2%
R17	1	1.2%

***Correct response**

QUESTION 11 (d) - *Coding of responses*

S00 - No response.
S01 - Uncodable

S02* - $s = ut + \frac{1}{2}at^2$
$0 = 10t + \frac{1}{2}(-10)t^2$
$0 = 10t - 5t^2$
$5t(t - 2) = 0$
$t = 2$ s

S03 - $t = 2$ s

S04 - $t = 1$ s

S05 - $v = u + at$
$0 = 10 - 10t$
$t = 1$ s

S06 - $s = 10$ m

S07 - $s = ut + \frac{1}{2}at^2$
$5\text{m} = 10t + \frac{1}{2}(-10)t^2$
$t = 1$ s

S08 - $x = vt$
$= (10)(4)$
$= 40$ m

S09 - Solution: $s = \frac{(v+u)}{2}t = \frac{(10+0)(1)}{2} = 75m$

S10 - $t = 5$ s

S11 - Solution:

$$v = \frac{d}{t}$$

$$t = \frac{10m}{10m/s} = 1s$$

Then it becomes, 1 s + 1s = 2 s

S12 - Solution: $t = \frac{2\sin 2A}{g}$

S13 - It will depend on the distance between the thrower and the ground

S14 - Insufficient information given.

****Correct response***

<u>QUESTION 11 (d)</u> - ***Responses of students (1-86)***

1. S03	21. S04	41. S03	61. S04	81. S03
2. S03	22. S03	42. S03	62. S03	82. S12
3. S03	23. S03	43. S04	63. S00	83. S10
4. S04	24. S05	44. S04	64. S00	84. S07
5. S05	25. S04	45. S04	65. S03	85. S03
6. S05	26. S05	46. S00	66. S04	86. S00
7. S02	27. S03	47. S00	67. S07	
8. S05	28. S03	48. S03	68. S03	
9. S03	29. S03	49. S03	69. S04	
10. S06	30. S03	50. S05	70. S14	
11. S07	31. S03	51. S03	71. S00	
12. S05	32. S01	52. S05	72. S04	
13. S10	33. S03	53. S00	73. S04	
14. S04	34. S07	54. S03	74. S03	
15. S07	35. S00	55. S00	75. S05	
16. S05	36. S08	56. S12	76. S04	
17. S11	37. S05	57. S04	77. S04	
18. S12	38. S13	58. S01	78. S00	
19. S03	39. S04	59. S00	79. S00	
20. S11	40. S02	60. S04	80. S09	

QUESTION 11 (d) - *Summary percentages*

	Number of students	Percentage
S00	12	14.0%
S01	2	2.3%
S02*	2	2.3%
S03	25	29.1%
S04	17	19.8%
S05	11	12.8%
S06	1	1.2%
S07	5	5.8%
S08	1	1.2%
S09	1	1.2%
S10	2	2.3%
S11	2	2.3%
S12	3	3.5%
S13	1	1.2%
S14	1	1.2%

***Correct response**

QUESTION 11 (e) - ***Coding of responses***

T00 - No response

T01 - Uncodable

T02* - $v^2 = u^2 + 2as$
$v^2 = 10^2 + 2(-10)(0)$
$v^2 = 10^2$
$v = 10$ m/s

T03 - $v^2 = u^2 + 2as$
$= 10^2 + 2(10)15$
$= 100 + 300$
$= 400$ m/s

T04 - $v = u + gt$
$= 10 - 10(2)$
$= -10$ m/s

T05 - $v = u + gt$
$= 0 + 10(2)$
$= 20$ m/s

T06 - $v = u + gt$
$= 10 + 10(1)$
$= 20$ m/s

T07 - $v^2 = u^2 + 2as$
$v^2 = 0^2 + 2(10)(5)$
$v^2 = 100$
$v = 10$ m/s

T08 - $v = 10$ m/s

T09 - Solution: $t = \frac{s}{t} = \frac{5m}{2s} = 2{,}5 m/s$

T10 - $v^2 = u^2 + 2as$ (Equation only)

T11 - Insufficient information given.

****Correct response***

QUESTION 11 (e) - ***Responses of students (1-86)***

1. T03	21. T08	41. T05	61. T09	81. T08
2. T04	22. T07	42. T06	62. T04	82. T01
3. T01	23. T08	43. T05	63. T00	83. T01
4. T08	24. T06	44. T03	64. T00	84. T09
5. T04	25. T05	45. T08	65. T04	85. T08
6. T04	26. T03	46. T00	66. T06	86. T00
7. T05	27. T06	47. T00	67. T05	
8. T06	28. T09	48. T03	68. T08	
9. T01	29. T06	49. T03	69. T07	
10. T08	30. T07	50. T05	70. T11	
11. T06	31. T05	51. T06	71. T00	
12. T06	32. T10	52. T06	72. T08	
13. T09	33. T09	53. T00	73. T05	
14. T06	34. T07	54. T08	74. T08	
15. T05	35. T06	55. T00	75. T01	
16. T07	36. T05	56. T00	76. T08	
17. T08	37. T10	57. T08	77. T08	
18. T10	38. T08	58. T10	78. T00	
19. T07	39. T05	59. T00	79. T00	
20. T06	40. T02	60. T08	80. T06	

QUESTION 11 (e) - *Summary percentages*

	Number of students	Percentage
T00	12	14.0%
T01	5	5.8%
T02*	1	1.2%
T03	5	5.8%
T04	5	5.8%
T05	11	12.8%
T06	14	16.3%
T07	6	7.0%
T08	17	19.8%
T09	4	4.7%
T10	4	4.7%
T11	1	1.2%

***Correct response**

<u>QUESTION 11 (f)</u> - ***Coding of responses***

U00 - No response

U01 - Uncodable

U02* - $s = ut + \frac{1}{2} at^2$

$5 = 10t + \frac{1}{2}(-10)t^2$

$5t^2 - 10t + 5 = 0$

$t^2 - 2t + 1 = 0$

$t = 1$ s

U03 - $s = vt$

$1 = 10t$

$t = 0{,}1$ s

U04 - $t = 1$ s

U05 - $t = 0{,}5$ s

U06 - 5 m takes 1 s

1 m takes: $y = \frac{1m x 1s}{5m} = 0{,}2s$

U07 - $v^2 = u^2 + 2as$

$10^2 = 0^2 + 2(10)s$

$s = 5$ m

U08 - $v = 10$ m/s

U09 - $v = u + gt$

$$t = \frac{20m/s - 10m/s}{10m/s} = 10s$$

U10 - $v^2 = u^2 + 2as$

$= 0^2 + 2(10)(1)$

$= 20$ m/s

$v = 4{,}5$ m/s

U11 - Solution: $time = \frac{distance}{velocity} = \frac{1m}{10m/s} = 0{,}1m$

U12 - $s = ut + ½\, at^2$
$= o + ½\,(10)(1)^2$
$= 5$ m

U13 - $s = 5$ m

U14 - $s = ut + ½\, at^2$
$5 = 0 + ½\,(10)t^2$
$t = 1$ s

U15 - Insufficient information given

U16 - Solution: $s = \frac{(v+u)}{2}t$
$t = 0{,}04s$

U17 - $v^2 = u^2 + 2as$
$= 10^2 + 2\,(10)(1)$
$= 10{,}5$ m/s

Correct response

QUESTION 11 (f) - *Responses of students (1-86)*

1. U03	21. U01	41. U02	61. U08	81. U01
2. U00	22. U02	42. U02	62. U02	82. U06
3. U04	23. U09	43. U05	63. U11	83. U05
4. U05	24. U13	44. U14	64. U00	84. U00
5. U06	25. U14	45. U11	65. U05	85. U05
6. U06	26. U02	46. U00	66. U17	86. U00
7. U02	27. U02	47. U00	67. U05	
8. U07	28. U04	48. U15	68. U04	
9. U01	29. U02	49. U02	69. U06	
10. U08	30. U14	50. U00	70. U11	
11. U09	31. U10	51. U02	71. U00	
12. U02	32. U00	52. U16	72. U14	
13. U00	33. U06	53. U00	73. U14	
14. U01	34. U00	54. U04	74. U05	
15. U10	35. U14	55. U00	75. U08	
16. U08	36. U11	56. U00	76. U00	
17. U11	37. U00	57. U04	77. U00	
18. U01	38. U01	58. U00	78. U00	
19. U12	39. U14	59. U00	79. U00	
20. U11	40. U02	60. U00	80. U01	

QUESTION 11 (f) - *Summary of percentages*

	Number of students	Percentage
U00	22	25.6%
U01	7	8.1%
U02*	12	14.0%
U03	1	1.2%
U04	5	5.8%
U05	7	8.1%
U06	4	4.7%
U07	1	1.2%
U08	4	4.7%
U09	1	1.2%
U10	2	2.3%
U11	5	5.8%
U12	1	1.2%
U13	1	1.2%
U14	6	7.0%
U15	1	1.2%
U16	1	1.2%
U17	1	1.2%

***Correct response**

<u>QUESTION 11 (g)</u> - ***Coding of responses***

V00	-	No response
V01	-	Uncodable

V02* - $v^2 = u^2 + 2as$

$= 10^2 + 2(-10)(-1)$

$= 100 + 20$

$= 120$

$= 10,96$ m/s

V03 - $v = u + gt$

$= 10 + 10(1)$

$= 20$ m/s

V04 - $v = 10$ m/s

V05 - $v = u + gt$

$v = 10 - 10(2.2)$

$= -12,2$ m/s

V06 - $v^2 = u^2 + 2as$

$= 0^2 + 2(10)(1)$

$= 20$

$= 4,5$ m/s

V07 - $v = u + gt$ (Equation only)

V08 - Solution: $v = \frac{s}{t} = \frac{5m}{2s} = 2,25m/s$

V09 - $v^2 = u^2 + 2as$

$= 10^2 + 2(-10)(1)$

$= 100 - 20$

$= 80$

$= 8,7$ m/s

V10 - Insufficient information given

V11 - $s = u\,t + \frac{1}{2}\,at^2$

$1 = u(1) + \frac{1}{2}\,(10)(1)^2$

$u = 4$ m/s

V12 - $v^2 = u^2 + 2as$ (Equation only)

V13 - 0 m/s

**Correct response*

QUESTION 11 (g) - ***Responses of students (1-86)***

1. V11	21. V04	41. V00	61. V08	81. V04
2. V03	22. V06	42. V03	62. V04	82. V13
3. V13	23. V04	43. V04	63. V05	83. V04
4. V04	24. V02	44. V09	64. V00	84. V04
5. V05	25. V01	45. V00	65. V04	85. V04
6. V05	26. V06	46. V00	66. V12	86. V00
7. V00	27. V00	47. V00	67. V05	
8. V06	28. V08	48. V10	68. V00	
9. V00	29. V02	49. V10	69. V06	
10. V04	30. V06	50. V00	70. V08	
11. V00	31. V01	51. V00	71. V00	
12. V00	32. V00	52. V11	72. V04	
13. V00	33. V04	53. V00	73. V00	
14. V01	34. V00	54. V04	74. V00	
15. V01	35. V00	55. V00	75. V00	
16. V06	36. V02	56. V00	76. V04	
17. V04	37. V00	57. V00	77. V00	
18. V07	38. V04	58. V00	78. V00	
19. V06	39. V04	59. V00	79. V00	
20. V03	40. V07	60. V05	80. V04	

QUESTION 11 (g) - *Summary percentages*

	Number of students	Percentage
V00	32	37.2%
V01	4	4.7%
V02*	3	3.5%
V03	3	3.5%
V04	19	22.1%
V05	5	5.8%
V06	7	8.1%
V07	2	2.3%
V08	3	3.5%
V09	1	1.2%
V10	2	2.3%
V11	2	2.3%
V12	1	1.2%
V13	1	1.2%

***Correct response**

QUESTION 12 (a) - *Coding of responses*

W00 - No response

W01 - Uncodable

W02*- The solution is as follows: $s = \frac{(v+u)}{2}t = \frac{(0+10)(5)}{2} = 25m$

W03 - distance = velocity x time

= 10 m/s x 5 s

= 50 m

W04 - $v = u + at$

$10 = 0 + a(5)$

$a = 2$ m/s^2

But, $s = ut + ½ at^2$

$= (0)(5) + ½ (2)(5)^2$

$= 25$ m

W05 - $v^2 = u^2 + 2as$

$10^2 = (0)^2 + 2(10)s$

$100 = 20s$

$s = 5$ m

W06 - $s = ut + ½ at^2$

$s = (10)(5) + ½ (10)(5)^2$

$= 50 + 125$

$= 175$ m

W07 - $s = ut + ½ at^2$

$= 0 + ½ (10)(5)^2$

$= 125$ m

W08 - Then, $s = \frac{v}{t} = \frac{10m/s}{5s} = 2m$

W09 - $s = 50$ m

W10 - Insufficient information given.

W11 - s =25 m

***Correct response**

QUESTION 12 (a) - ***Responses of students (1-86)***

1. W03
2. W04
3. W05
4. W06
5. W03
6. W03
7. W07
8. W04
9. W04
10. W03
11. W08
12. W08
13. W08
14. W03
15. W02
16. W04
17. W03
18. W03
19. W04
20. W03
21. W09
22. W03
23. W04
24. W05
25. W06
26. W04
27. W04
28. W03
29. W03
30. W05
31. W06
32. W04
33. W03
34. W03
35. W04
36. W05
37. W01
38. W03
39. W02
40. W04
41. W04
42. W03
43. W04
44. W03
45. W03
46. W03
47. W05
48. W10
49. W10
50. W03
51. W06
52. W02
53. W00
54. W11
55. W03
56. W03
57. W03
58. W02
59. W00
60. W03
61. W09
62. W03
63. W03
64. W07
65. W03
66. W03
67. W07
68. W03
69. W07
70. W03
71. W01
72. W04
73. W03
74. W11
75. W07
76. W03
77. W01
78. W00
79. W07
80. W03
81. W09
82. W03
83. W03
84. W03
85. W10
86. W00

QUESTION 12 (a) - *Summary percentages*

	Number of students	Percentage
W00	3	3.5%
W01	3	3.5%
W02*	4	4.7%
WC3	35	40.7%
W04	14	16.3%
W05	5	5.8%
W06	4	4.7%
W07	6	7.0%
W08	3	3.5%
W09	3	3 [illegible]%
W10	3	3.5%
W11	2	2.3%

***Correct response**

<u>QUESTION 12 (b)</u> - ***Coding of responses***

X00 - No response
X01 - Uncodable

X02* - $v = u + at$
$10 = 0 + a(5)$
$10 = 5a$
$a = 2 \text{ m/s}^2$

X03 - $a = -10 \text{ m/s}^2$

X04 - Then, $a = \frac{v}{t} = \frac{10m/s}{5s} = 2m/s^2$

X05 - $v^2 = u^2 + 2as$
$(10)^2 = 0^2 + 2a(125)$
$100 = a(250)$
$a = 0{,}4 \text{ m/s}^2$

X06 - $s = ut + ½ at^2$
$5 = (0)(5) + ½ (a)(5)^2$

$5 = \frac{25a}{2}$

$a = 0{,}4m/s^2$

X07 - $a = 2 \text{ m/s}^2$

X08 - Uniform acceleration.

****Correct response***

QUESTION 12 (b) - *Responses of students (1-86)*

1. X02
2. X02
3. X03
4. X04
5. X04
6. X04
7. X05
8. X04
9. X04
10. X01
11. X02
12. X04
13. X02
14. X02
15. X02
16. X05
17. X04
18. X04
19. X02
20. X04
21. X04
22. X04
23. X04
24. X06
25. X06
26. X02
27. X05
28. X04
29. X02
30. X02
31. X04
32. X04
33. X02
34. X01
35. X05
36. X02
37. X02
38. X04
39. X04
40. X05
41. X04
42. X04
43. X02
44. X02
45. X04
46. X02
47. X04
48. X02
49. X07
50. X06
51. X04
52. X02
53. X00
54. X07
55. X04
56. X04
57. X04
58. X02
59. X00
60. X04
61. X04
62. X04
63. X04
64. X01
65. X04
66. X04
67. X04
68. X04
69. X05
70. X08
71. X02
72. X04
73. X04
74. X07
75. X02
76. X02
77. X04
78. X00
79. X02
80. X02
81. X07
82. X02
83. X04
84. X02
85. X04
86. X00

QUESTION 12 (b) - *Summary percentages*

	Number of students	Percentage
X00	4	4.7%
X01	3	3.5%
X02*	26	30.2%
X03	1	1.2%
X04	38	44.2%
X05	5	5.8%
X06	3	3.5%
X07	4	4.7%
X08	1	1.2%

Correct response

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