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.

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.
Acknowledgements

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.
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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

xi
\( g = \text{gravitational acceleration} \)
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
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, Shepadson & 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 auxiliary 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 model-based instruction. 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:

\textit{[i]t 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:

\textit{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 mathematics 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 activity and strategy (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

<table>
<thead>
<tr>
<th>Ten Strategies</th>
<th>Fourteen Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Analogy</td>
<td>1. Checking</td>
</tr>
<tr>
<td>2. Brainstorming</td>
<td>2. Clarifying</td>
</tr>
<tr>
<td>3. Envisioning</td>
<td>3. Comparison</td>
</tr>
<tr>
<td>4. Forward strategy</td>
<td>4. Declaring Quantities</td>
</tr>
<tr>
<td>5. Generate and test</td>
<td>5. Pictorial Representation</td>
</tr>
<tr>
<td>6. Heuristic search</td>
<td>6. Resolving Difficulties</td>
</tr>
<tr>
<td>7. Means-end analysis</td>
<td>7. Qualitative Analysis</td>
</tr>
<tr>
<td>8. Problem abstraction</td>
<td>8. Qualifying</td>
</tr>
<tr>
<td>10. Working backward</td>
<td>10. Question Reading</td>
</tr>
<tr>
<td></td>
<td>11. Recapitulation</td>
</tr>
<tr>
<td></td>
<td>12. Reference</td>
</tr>
<tr>
<td></td>
<td>13. Relating Quantities</td>
</tr>
<tr>
<td></td>
<td>14. Symbol Usage</td>
</tr>
</tbody>
</table>
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 forward 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 construct, 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; Pfund & 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. Boeia, 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 learning 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 students to construct their own concepts]. Operationalism and constructivism are contradictory 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 programme.”

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 generalizations 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 ofAusubel (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

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 problemsolving 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 meaningful 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
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 (o: 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 \([-5,0 \text{ s} ; 10,5 \text{ s}]\), 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:
\[ \text{duration} = t_{\text{end}} - t_{\text{begin}}. \]
The duration of \([-5,0 \text{ s}; 10,5 \text{ s}]\) 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:

![Figure 3.1: The position for movements in a straight line.](image)

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: \( 5 + 5 = 10 \text{ m} \) (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:

\[
a = \frac{v_{\text{end}} - v_{\text{begin}}}{\text{time taken}}
\]

\[
= \frac{(-5) - (-20)}{6 - 3}
\]

\[
= 5 \text{ m/s}^2
\]

**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/s² 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.

\[
\text{Change in the quantity} = \text{final value of the quantity} - \text{initial value of the quantity} \\
\text{or} \\
\text{final value of the quantity} = \text{the initial value of the quantity} + \text{change in the quantity}
\]

Students can do simple exercises on acceleration. E.g., Given the velocity at two different times students can apply the algorithm: \( a = (v_{\text{final}} - v_{\text{initial}})/\text{time required} \) 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:

\[
\text{Rate of change in velocity} = \text{acceleration} = \frac{\text{velocity change}}{\text{time required}}
\]

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.

\[
\begin{align*}
\text{Change in velocity} & = \text{final velocity} - \text{initial velocity} \\
\Delta v & = v_{\text{final}} - v_{\text{initial}} \\
\text{or} \\
v_{\text{final}} & = v_{\text{initial}} + \Delta v
\end{align*}
\]
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: \( a = \frac{\Delta v}{t} = \frac{3,0}{3,0} = 1,0 \) m/ s²

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 \( \Delta v \): - The tail of \( \Delta v \) is at the head of \( v_{initial} \) (dotted line Q).
   - the head of \( \Delta v \) is at the head of \( v_{final} \) (dotted line R).
It is clear from the diagram above that: \( v_{\text{final}} = v_{\text{initial}} + \Delta v \).

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:

\[ \text{velocity}_{\text{average}} = \frac{\text{displacement}}{\text{time}} \]

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

\[ \text{velocity}_{\text{instantaneous}} = \text{velocity}_{\text{average}} = \frac{\text{displacement}}{\text{time}} \]

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 $v_A = 6 \text{ m/s}$”, which is incorrect. A further 5.8% of the students obtained the solution as “displacement = 8 m and $v_A = 4 \text{ m/s}$”, 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 $v_A = 3 \text{ m/s}$”, 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. **QUESTION 2**
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. **Question 2 - Analysis and discussion**
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. **QUESTION 3**
When does an object have velocity?

4.2.3.1. **Question 3 - Analysis and discussion**
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
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. **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.

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. **QUESTION 7**
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. **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."

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:  
\[
\text{distance} = \text{velocity} \times \text{time} = 5,0 \text{ m/s} \times 7,0 \text{ s} = 35 \text{ m}
\]
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.

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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 ascertaining 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 \( t = 2 \text{ s} \)."
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 $t = 1 \text{s} + 1 \text{s} = 2 \text{s}$.

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

\[
\text{velocity}_{\text{average}} = \frac{\text{displacement}}{\text{time}}
\]

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.

<table>
<thead>
<tr>
<th>Assessing information given</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>So, the boy accelerates from start, then moves uniformly, slows down and finally stops.</td>
<td>Qualifying</td>
</tr>
<tr>
<td>If the boy starts from rest, his initial velocity is zero.</td>
<td>Declaring quantity</td>
</tr>
<tr>
<td></td>
<td>Clarifying</td>
</tr>
</tbody>
</table>
TABLE 5.1: Number of Participants Using the General Methods

<table>
<thead>
<tr>
<th>General Methods</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assessing information</td>
<td>7</td>
</tr>
<tr>
<td>2. Transformation of information</td>
<td>10</td>
</tr>
<tr>
<td>3. Attempting one-step solution</td>
<td>9</td>
</tr>
<tr>
<td>4. Generalizing information application</td>
<td>8</td>
</tr>
<tr>
<td>5. Solution assessment</td>
<td>5</td>
</tr>
</tbody>
</table>
Assessing information to determine the next step

<table>
<thead>
<tr>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declaring quantities</td>
</tr>
<tr>
<td>Clarifying</td>
</tr>
<tr>
<td>Qualitative analysis</td>
</tr>
<tr>
<td>Resolving difficulty</td>
</tr>
<tr>
<td>Relating quantities</td>
</tr>
</tbody>
</table>

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.

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).

<table>
<thead>
<tr>
<th>One-step solution expectation</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>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 \text{ s} ).</td>
<td>Declaring quantities</td>
</tr>
<tr>
<td></td>
<td>Relating quantities</td>
</tr>
<tr>
<td></td>
<td>Resolving difficulty</td>
</tr>
<tr>
<td></td>
<td>Quantitative representation.</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Generally applying information without discrimination</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>It means the motion is characterized by a change in velocity and a constant acceleration. But, what about the displacement covered?</td>
<td>Declaring quantities Qualitative analysis</td>
</tr>
</tbody>
</table>

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

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.

<table>
<thead>
<tr>
<th>Assessing solution at the end</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>This is realistic because the gravitational force will make it possible for the raindrop to reach the ground.</td>
<td>Clarifying</td>
</tr>
<tr>
<td></td>
<td>Qualifying</td>
</tr>
<tr>
<td></td>
<td>Declaring quantity</td>
</tr>
<tr>
<td></td>
<td>Checking</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assessment while performing the solution</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>Declaring quantities</td>
</tr>
<tr>
<td></td>
<td>Clarifying</td>
</tr>
<tr>
<td></td>
<td>Checking</td>
</tr>
<tr>
<td></td>
<td>Recapitulating</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Analogy</td>
<td>7</td>
</tr>
<tr>
<td>2. Envisioning</td>
<td>6</td>
</tr>
<tr>
<td>3. Forward strategy</td>
<td>2</td>
</tr>
<tr>
<td>4. Generate and test</td>
<td>4</td>
</tr>
<tr>
<td>5. Means-end analysis</td>
<td>8</td>
</tr>
<tr>
<td>6. Problem decomposition</td>
<td>4</td>
</tr>
</tbody>
</table>
TABLE 5.3: Summary of Information Used by the Participants

**THE KINEMATIC CONSIDERATIONS**

**CONCEPTS:**

- Displacement
- Velocity
- Acceleration
- Time

**KINEMATIC EQUATIONS:**

\[ v = u + at \]
\[ s = ut + \frac{1}{2}at^2 \]
\[ v^2 = u^2 + 2as \]
\[ s = \left[ \frac{v + u}{2} \right]t \]

**OTHER EQUATIONS:**

\[ \text{velocity}_{\text{average}} = \frac{\text{displacement}}{\text{time}} \]

\[ \text{acceleration} = \frac{\text{velocity}_{\text{change}}}{\text{time}} \]
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.
<table>
<thead>
<tr>
<th>Activities</th>
<th>Excerpt</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp.</td>
<td>&quot;No difference because displacement is the same in both cases. Motion is characterized by constant velocity and constant acceleration&quot;.</td>
<td>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.</td>
</tr>
<tr>
<td>Clarifying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualifying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declaring quantities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activities</th>
<th>Excerpt</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declaring quantity</td>
<td>&quot;So, the boy's velocity increases, decreases and finally stops&quot;.</td>
<td>The boy accelerates from start, moves uniformly, slows down and finally stops.</td>
</tr>
<tr>
<td>Qualitative analysis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activities</th>
<th>Excerpt</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relating quantities</td>
<td>&quot;So, I can use the expression that contains v, u, a and t&quot;.</td>
<td>v = u + at</td>
</tr>
<tr>
<td>Declaring quantities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantitative representation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean-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.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Excerpt</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declaring quantities</td>
<td><em>So, displacement and velocity in case (a) are greater than those in case (b).</em></td>
<td><em>The direction of displacement and velocity are different in the two cases.</em></td>
</tr>
</tbody>
</table>

*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 participants decomposed the problem into sub-parts. Initially, qualitative analysis, clarifying, and qualifying were performed and only subsequently were the quantitative aspects used.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Excerpt</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 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

<table>
<thead>
<tr>
<th>Activity</th>
<th>Participants</th>
<th>“Physical” Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Checking</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2. Clarifying</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>3. Comparison</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4. Declaring Quantities</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>5. Pictorial Representation</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6. Resolving Difficulties</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>7. Qualitative Analysis</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>8. Qualifying</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>9. Quantitative Representations</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10. Question Reading</td>
<td>4</td>
<td>“Cognitive” Activities</td>
</tr>
<tr>
<td>11. Recapitulation</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>12. Reference</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13. Relating Quantities</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>14. Symbol Usage</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
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 the 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 homework 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/s.
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

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

1. A02 21. A02 41. A02 61. A18 81. A02
2. A02 22. A02 42. A08 62. A02 82. A02
3. A03 23. A02 43. A02 63. A02 83. A02
5. A02 25. A02 45. A02 65. A02 85. A02
6. A02 26. A02 46. A02 66. A02 86. A02
7. A02 27. A02 47. A02 67. A02
10. A02 30. A02 50. A14 70. A21
12. A08 32. A02 52. A17 72. A02
13. A02 33. A12 53. A00 73. A02
14. A09 34. A03 54. A02 74. A02
15. A02 35. A12 55. A12 75. A22
16. A09 36. A15 56. A02 76. A02
17. A02 37. A02 57. A02 77. A02
20. A05 40. A02 60. A02 80. A02
**QUESTION 1(a) - Summary percentages**

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

<table>
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<td>Displacement of A = 0 m; average velocity $v_A = 0$ m/s.</td>
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<td>Displacement of A = 12 m; average velocity $v_A = 6$ m/s.</td>
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<td>Displacement of A = 10 m; average velocity $v_A = 5$ m/s.</td>
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<td>Displacement of A = 8 m; average velocity $v_A = 4$ m/s.</td>
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<td>Displacement of A = 3 m; average velocity $v_A = -0.15$ m/s.</td>
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<td>Displacement of A = 6 m; average velocity $v_A = 5$ m/s.</td>
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<td>Displacement of A = -6 m; average velocity $v_A = -6$ m/s.</td>
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<tr>
<td>B26</td>
<td>Displacement of A = 1.0 m; average velocity $v_A = 2.0$ m/s.</td>
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*Correct response*
**QUESTION 1(b)** - Responses of students (1-86)

2. B05  22. B02  42. B21  62. B02  82. B03
7. B02  27. B02  47. B09  67. B02
13. B02  33. B17  53. B00  73. B02
17. B12  37. B03  57. B02  77. B02
20. B11  40. B03  60. B02  80. B03

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### QUESTION 1 (b) - Summary percentages

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*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)

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
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**

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*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)**

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**QUESTION 2 - Summary percentages**

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*Correct response*
QUESTION 3 - 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 | E05 | 37 | E08 | 57 | E08 | 77 | E05 |   |   |
| 18 | E04 | 38 | E03 | 58 | E02 | 78 | E03 |   |   |
| 19 | E0d | 39 | E02 | 59 | E00 | 79 | E13 |   |   |
| 20 | E05 | 40 | E12 | 60 | E08 | 80 | E05 |   |   |

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### QUESTION 3 - Summary percentages

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*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
**QUESTION 4 - Summary percentages**

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*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
**QUESTION 5 - Responses of students (1-86)**

2. G03  22. G03  42. G05  62. G02  82. G05
5. G05  25. G02  45. G04  65. G03  85. G02
7. G08  27. G03  47. G03  67. G02
10. G09  30. G03  50. G00  70. G26
12. G02  32. G04  52. G02  72. G02
13. G02  33. G14  53. G00  73. G02
14. G10  34. G20  54. G03  74. G02
17. G03  37. G02  57. G03/G12  77. G03
18. G17  38. G02  58. G03  78. G02
20. G03  40. G22  60. G03  80. G02
**QUESTION 5 - Summary percentages**

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*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)**

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82. H15
83. H20
84. H02
85. H16
86. H22
67. H07
68. H06
69. H07
70. H24
71. H01
72. H23
73. H06
74. H25
75. H15
76. H07
77. H26
78. H18
79. H20
80. H27
**QUESTION 6 - Summary percentages**

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*Correct response*
QUESTION 7 - Coding of responses

100 - No response.
101 - Uncodable.
102* - Acceleration and velocity are in opposite direction.
103 - Direction of acceleration and velocity will be the same.
104 - Direction will be towards the left.
105 - Velocity decreases and acceleration becomes negative.
106 - They are directly proportional to each other.
107 - Direction of velocity and acceleration will depend on the direction of an object.
108 - Velocity of the object is negative and therefore acceleration would be negative and is called deceleration.
109 - Direction of acceleration will be negative and velocity will be increasing backward.
110 - Direction of velocity and acceleration will be changing.
111 - Velocity will be negative.
112 - Direction of acceleration will be negative and velocity will have no direction since velocity is a scalar quantity.
113 - Direction of acceleration will be opposite to that of motion but velocity will have the same direction.
114 - Acceleration and deceleration are opposite in direction.
115 - Acceleration will be negative.
116 - Direction of the velocity is towards the decelerating object.
117 - Acceleration and velocity have no direction since they are scalar quantities.
118 - Acceleration opposes gravity.

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

1. 103 21. 113 41. 102 61. 102 81. 103
2. 102 22. 114 42. 102 62. 102 82. 118
3. 103 23. 102 43. 102 63. 102 83. 103
4. 102 24. 107 44. 102 64. 103 84. 103
5. 104 25. 103 45. 103 65. 103 85. 103
6. 105 26. 102 46. 105 66. 103 86. 113.
7. 106 27. 102 47. 100 67. 103
8. 102 28. 103 48. 102 68. 102
9. 107 29. 103 49. 102 69. 102
10. 102 30. 106 50. 103 70. 111
11. 108 31. 102 51. 102 71. 103
12. 109 32. 102 52. 117 72. 102
13. 102 33. 102 53. 100 73. 102
14. 102 34. 115 54. 102 74. 102
15. 110 35. 116 55. 102 75. 103
16. 111 36. 103 56. 102 76. 102
17. 112 37. 103 57. 103 77. 103
18. 102 38. 102 58. 113 78. 102
19. 102 39. 102 59. 100 79. 102
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**QUESTION 7 - Summary percentages**

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*Correct response*
QUESTION 8 (a) - 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 \( \text{velocity} = \frac{\text{displacement}}{\text{time}} \)
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.
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  
2. J02  
3. J06  
4. J07  
5. J05  
6. J08  
7. J05  
8. J09  
9. J02  
10. J04  
11. J07  
12. J16  
13. J11  
14. J12  
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162
QUESTION 8 (a)- Summary percentages

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*Correct response
**QUESTION 8 (b) - Coding of responses**

K00 - No response
K01 - Uncodable
K02* - Average velocity; it is given by \[ \text{velocity} = \frac{\text{displacement}}{\text{time}} \]

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)**

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### QUESTION 8 (b) - Summary percentages

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*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 \( \text{velocity} = \frac{\text{displacement}}{\text{time}} \)
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 \( \text{velocity} = \frac{\text{displacement}}{\text{time}} \)

*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. L09 
28. L12 
29. L09 
30. L13 
31. L09 
32. L07 
33. L07 
34. L03 
35. L00 
36. L03 
37. L03 
38. L03 
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. L14 
52. L07 
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. L12 
72. L03 
73. L09 
74. L03 
75. L01 
76. L17 
77. L16 
78. L07 
79. L01 
80. L18
**QUESTION 8 (c) - Summary percentages**

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*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*

**QUESTION 9 - Responses of students (1-86)**

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**QUESTION 9 - Summary percentages**

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*Correct response*
QUESTION 10 (a) - Coding of responses

N00 - No response
N01 - Uncodable

N02* -
\[ s = ut + \frac{1}{2} at^2 \]
\[ 500 = ut + \frac{1}{2} at^2 \]
\[ v = 0 + 10(10) \]
\[ v = 100 \text{ m/s} \]
\[ t = 10 \text{ s} \]

N03 -
\[ s = ut + \frac{1}{2} at^2 \]
\[ = (10)(5) + \frac{1}{2} (10)(5)^2 \]
\[ = 50 + 125 \]
\[ = 175 \text{ m} \]

N04 -
\[ s = ut + \frac{1}{2} at^2 \]
\[ 500 = 0 + \frac{1}{2} (10)t^2 \]
\[ t = 10 \text{ s} \]
\[ v = \frac{d}{t} = \frac{500\text{ m}}{10\text{ s}} \]

N05 -
\[ s = ut + \frac{1}{2} at^2 \]
\[ 500 = 0 + \frac{1}{2} (10)t^2 \]
\[ 5t^2 = 500 \]
\[ t = 10 \text{ s} \]

N06 -
\[ s = ut + \frac{1}{2} at^2 \]
\[ 500 = 0 + \frac{1}{2} (10)t^2 \]
\[ 5t^2 = 500 \]
\[ t = 10 \text{ s} \]
\[ v^2 = u^2 + 2as \]
\[ = 0^2 + 2(10)(500) \]
\[ = 10000 \]
\[ = 100 \text{ m/s} \]

N07 -
\[ v^2 = u^2 + 2as \]
\[ = 0^2 + 2(10)(500) \]
\[ = 10000 \]
\[ v = 100 \text{ m/s} \]
\[ \frac{v}{t} = g \]
\[ \frac{100\text{ m/s}}{10\text{ m/s}^2} \]

173
N08 - \( s = 500 \text{ m} \); \( v = 500 \text{ m/s} \)

N09 - \( t = 0.05 \text{ s} \); \( v = 10000 \text{ m/s} \)

N10 - Insufficient information given.

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

N12 - \( v = 0 \text{ m/s} \)

N13 - \( t = 10 \text{ s} \); \( v = 0 \text{ m/s} \)

*Correct response*

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

2. N02 22. N06 42. N01 62. N02 82. N01
7. N06 27. N02 47. N02 67. N02
12. N05 32. N10 52. N02 72. N02
14. N02 34. N00 54. N02 74. N10
15. N02 35. N05 55. N12 75. N05
20. N02 40. N06 60. N06 80. N06
**QUESTION 10 (a) - Summary percentages**

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

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<td>002*</td>
<td>No, the raindrop will reach a terminal velocity.</td>
</tr>
<tr>
<td>003</td>
<td>No, because force of friction will disturb the raindrop.</td>
</tr>
<tr>
<td>004</td>
<td>Yes, the drop is very small and it can penetrate through air.</td>
</tr>
<tr>
<td>005</td>
<td>No, raindrop can’t take so much time to fall.</td>
</tr>
<tr>
<td>006</td>
<td>No, because raindrop can’t travel at that speed from the cloud.</td>
</tr>
<tr>
<td>007</td>
<td>Yes, gravitational force will make it possible for the raindrop to reach the ground.</td>
</tr>
<tr>
<td>008</td>
<td>Yes, because the time taken by the raindrop to reach the ground is unknown.</td>
</tr>
<tr>
<td>009</td>
<td>No, because air resistance will disturb the raindrop.</td>
</tr>
<tr>
<td>010</td>
<td>No, because the initial and final time are not known.</td>
</tr>
<tr>
<td>011</td>
<td>Yes, because of the effect of air resistance on the drop.</td>
</tr>
<tr>
<td>012</td>
<td>No, the cloud cannot be at a height of 500 m above the ground.</td>
</tr>
<tr>
<td>013</td>
<td>No, because the raindrop will accelerate uniformly and decelerate when hitting the ground.</td>
</tr>
<tr>
<td>014</td>
<td>Yes, because the displacement is large and it will need much time to complete that journey.</td>
</tr>
<tr>
<td>015</td>
<td>Yes, no reason given.</td>
</tr>
<tr>
<td>016</td>
<td>No, because the raindrop cannot take the same time and same velocity to cover same displacement.</td>
</tr>
<tr>
<td>017</td>
<td>No, because the velocity is very small.</td>
</tr>
<tr>
<td>018</td>
<td>No, because the velocity large.</td>
</tr>
<tr>
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<td>Yes, because the velocity is large.</td>
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<td>020</td>
<td>No, no reason given.</td>
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<td>021</td>
<td>Yes, because the initial velocity is zero and final velocity is the one after the initial velocity.</td>
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<tr>
<td>022</td>
<td>No, because the velocity is unknown.</td>
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<tr>
<td>023</td>
<td>No, because wind affects the velocity of the raindrop.</td>
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*Correct response*
**QUESTION 10 (b) - Responses of students (1-86)**

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### QUESTION 10 (b) - Summary percentages

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*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
\[ t = 2 \text{ s} \]

P03 - \[ v = u + gt \]
0 = 10 - 10t
\[ t = 1 \text{ s} \]

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

P05 - \[ v = u + gt \]
0 = 10 + 10t
\[ t = -1 \text{ s} \]

P06 - \[ v = u + gt \]
0 = 10 - 10t
\[ t = 1 \text{ s} \]

Since the object takes 1 s to go upwards and 1 s to go downward, then \[ t = 1 \text{ s} + 1 \text{ s} = 2 \text{ s} \]

P07 - The solution is as follows:
\[ t = \frac{v_b}{g} = \frac{10 \text{ m/s}}{10 \text{ m/s}^2} = 1 \text{ s} \]

P08 - It will take -10 m/s.

P09 - \[ s = ut + \frac{1}{2} gt^2 \]
5 m = 10t + \frac{1}{2} (-10)t^2
5t^2 - 10t + 5 = 0
\[ t^2 - 2t + 1 = 0 \]
\[ t = 1 \text{ s} \]
P10 - It will take 2 seconds.

P11 - The solution is as follows: \[ t = \frac{2 \sin 90^\circ}{9.8 \text{ m/s}^2} \]

P12 - After 1 second.

P13 - The solution is as follows: \[ t = \frac{2u}{g} = \frac{2 \times 10 \text{ m/s}}{9.8 \text{ m/s}^2} = 2.03 \text{s} \]

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

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 - \[ t = 10 \text{ m/s} / 10 \text{ m} = 1 \text{ s} \]

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

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**QUESTION 11 (a) - Summary percentages**

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*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:
\[ h = \frac{v^2}{2g} = \frac{(10)^2}{2(10)} = 5 m \]

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:
\[ h_{\text{max}} = \frac{u^2 \sin(2 \times 90^\circ)}{2g} = \frac{(10m/s)^2 \sin(2 \times 90^\circ)}{2(10m/s)^2} \]

*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
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19. Q02, 39. Q03, 59. Q00, 79. Q02
20. Q06, 40. Q05, 60. Q02, 80. Q03
**QUESTION 11 (b) - Summary percentages**

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*Correct response*
QUESTION 11 (c) - Coding of responses

R00 - No response
R01 - Uncodable

R02* - \[ v = u + at \]
\[ 0 = 10 - 10t \]
\[ 10t = 10 \]
\[ t = 1 \text{ s} \]

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

R04 - \[ t = 1 \text{ s} \]

R05 - \[ t = 2 \text{ s} \]

R06 - \[ v^2 = u^2 + 2gs \]
\[ (10)^2 = (0)^2 + 2(10)s \]
\[ s = 5 \text{ m} \]

R07 - \[ s = \frac{1}{2} at^2 = \frac{1}{2} (10) \times (1)^2 = 5 \text{ m} \]

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

R09 - Solution:

R10 - \[ s = 10 \text{ m} \]
\[ t_{\text{max}} = \frac{v_b}{2g} = \frac{10}{20} = 0.5 \text{ s} \]

R11 - \[ t = 3 \text{ s} \]

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

R13 - \[ x = vt \]
40 = 10t
\[ t = 4 \text{ s} \]

R14 - \[ t = 0.5 \text{ s} \]

R15 - Solution:
\[ s = \frac{(v + u)}{2} t = \frac{5(10 + 0)}{2} t \]
\[ t = 1 \text{ s} \]

R16 - Solution:
\[ t = \frac{\sin 90^\circ}{g} = \frac{\sin 90^\circ}{10} \]

R17 - Insufficient information given.

*Correct response*

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

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
7. R06 27. R03 47. R00 67. R06
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
17. R07 37. R14 57. R03 77. R04
20. R03 40. R15 60. R04 80. R02
**QUESTION 11 (c) - Summary percentages**

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*Correct response*
QUESTION 11 (d)  - Coding of responses

S00  -  No response.
S01  -  Uncodable

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

S03  -  \[ t = 2 \text{ s} \]

S04  -  \[ t = 1 \text{ s} \]

S05  -  \[ v = u + at \]
\[ 0 = 10 - 10t \]
\[ t = 1 \text{ s} \]

S06  -  \[ s = 10 \text{ m} \]

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

S08  -  \[ x = vt \]
\[ = (10)(4) \]
\[ = 40 \text{ m} \]

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

S10  -  \[ t = 5 \text{ s} \]

S11  -  Solution:  \[ v = \frac{d}{t} \]
\[ t = \frac{10m}{10m/s} = 1 \text{ s} \]

Then it becomes, \( 1 \text{ s} + 1 \text{ s} = 2 \text{ s} \)
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*

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

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**QUESTION 11 (d) - Summary percentages**

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

T00 - No response
T01 - Uncodable

T02* - \[ v^2 = u^2 + 2as \]
\[ v^2 = 10^2 + 2(-10)(0) \]
\[ v^2 = 10^2 \]
\[ v = 10 \text{ m/s} \]

T03 - \[ v^2 = u^2 + 2as \]
\[ = 10^2 + 2(10)(15) \]
\[ = 100 + 300 \]
\[ = 400 \text{ m/s} \]

T04 - \[ v = u + gt \]
\[ = 10 - 10(2) \]
\[ = -10 \text{ m/s} \]

T05 - \[ v = u + gt \]
\[ = 0 + 10(2) \]
\[ = 20 \text{ m/s} \]

T06 - \[ v = u + gt \]
\[ = 10 + 10(1) \]
\[ = 20 \text{ m/s} \]

T07 - \[ v^2 = u^2 + 2as \]
\[ v^2 = 0^2 + 2(10)(5) \]
\[ v^2 = 100 \]
\[ v = 10 \text{ m/s} \]

T08 - \[ v = 10 \text{ m/s} \]

T09 - Solution: \[ t = \frac{s}{2} = \frac{5}{2} = 2.5 \text{ m/s} \]

T10 - \[ v^2 = u^2 + 2as \ (\text{Equation only}) \]

T11 - Insufficient information given.

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

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**QUESTION 11 (e) - Summary percentages**

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*Correct response*
QUESTION 11 (f) - Coding of responses

U00 - No response
U01 - Uncodable

U02* - 
\[ s = ut + \frac{1}{2} at^2 \]
\[ 5 = 10t + \frac{1}{2} (-10)t^2 \]
\[ 5t^2 - 10t + 5 = 0 \]
\[ t^2 - 2t + 1 = 0 \]
\[ t = 1 \text{ s} \]

U03 - 
\[ s = vt \]
\[ 1 = 10t \]
\[ t = 0.1 \text{ s} \]

U04 - 
\[ t = 1 \text{ s} \]

U05 - 
\[ t = 0.5 \text{ s} \]

U06 - 
5 m takes 1 s
1 m takes:
\[ \frac{1 \text{ m} \times 1 \text{ s}}{5 \text{ m}} = 0.2 \text{ s} \]

U07 - 
\[ v^2 = u^2 + 2as \]
\[ 10^2 = 0^2 + 2(10)s \]
\[ s = 5 \text{ m} \]

U08 - 
\[ v = 10 \text{ m/s} \]

U09 - 
\[ v = u + gt \]
\[ t = \frac{20 \text{ m/s} - 10 \text{ m/s}}{10 \text{ m/s}} = 10 \text{ s} \]

U10 - 
\[ v^2 = u^2 + 2as \]
\[ = 0^2 + 2(10)(1) \]
\[ = 20 \text{ m/s} \]
\[ v = 4.5 \text{ m/s} \]
U11 - Solution: \[ \text{time} = \frac{\text{distance}}{\text{velocity}} = \frac{1 \text{m}}{10 \text{m/s}} = 0.1 \text{m} \]

U12 - \[ s = ut + \frac{1}{2} at^2 \]
\[ = 0 + \frac{1}{2} (10)(1)^2 \]
\[ = 5 \text{ m} \]

U13 - \[ s = 5 \text{ m} \]

U14 - \[ s = ut + \frac{1}{2} at^2 \]
\[ 5 = 0 + \frac{1}{2} (10)t^2 \]
\[ t = 1 \text{ s} \]

U15 - Insufficient information given

U16 - Solution: \[ s = \frac{(v+u)}{2} t \]
\[ t = 0.04 \text{s} \]

U17 - \[ v^2 = u^2 + 2as \]
\[ = 10^2 + 2 (10)(1) \]
\[ = 10.5 \text{ m/s} \]

*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 |
| 4. U05 | 24. U13 | 44. U14 | 64. U00 | 84. U00 |
| 6. U06 | 26. U02 | 46. U00 | 66. U17 | 86. U00 |
| 7. U02 | 27. U02 | 47. U00 | 67. U05 |       |
| 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 |       |
| 20. U11 | 40. U02 | 60. U00 | 80. U01 |       |
**QUESTION 11 (f) - Summary of percentages**

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*Correct response*
**QUESTION 11 (g) - Coding of responses**

V00 - No response

V01 - Uncodable

V02* - 
\[ v^2 = u^2 + 2as \]
\[ = 10^2 + 2(-10)(-1) \]
\[ = 100 + 20 \]
\[ = 120 \]
\[ = 10.96 \text{ m/s} \]

V03 - 
\[ v = u + gt \]
\[ = 10 + 10(1) \]
\[ = 20 \text{ m/s} \]

V04 - 
\[ v = 10 \text{ m/s} \]

V05 - 
\[ v = u + gt \]
\[ v = 10 - 10(2.2) \]
\[ = -12.2 \text{ m/s} \]

V06 - 
\[ v^2 = u^2 + 2as \]
\[ = 0^2 + 2(10)(1) \]
\[ = 20 \]
\[ = 4.5 \text{ m/s} \]

V07 - 
\[ v = u + gt \] (Equation only)

V08 - 
Solution: 
\[ v = \frac{s}{t} = \frac{5m}{2s} = 2.25 \text{ m/s} \]

V09 - 
\[ v^2 = u^2 + 2as \]
\[ = 10^2 + 2(-10)(1) \]
\[ = 100 - 20 \]
\[ = 80 \]
\[ = 8.7 \text{ m/s} \]

V10 - Insufficient information given
\[ s = ut + \frac{1}{2} at^2 \]
\[ v = u(1) + \frac{1}{2} (10)(1)^2 \]
\[ u = 4 \text{ m/s} \]

\[ v^2 = u^2 + 2as \quad (\text{Equation only}) \]

\[ v = 0 \text{ m/s} \]

*Correct response*

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

2. V03 22. V06 42. V03 62. V04 82. V13
4. V04 24. V02 44. V09 64. V00 84. V04
7. V00 27. V00 47. V00 67. V05
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
20. V03 40. V07 60. V05 80. V04
QUESTION 11 (g) - Summary percentages

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*Correct response*
QUESTION 12 (a) - Coding of responses

W00 - No response
W01 - Uncodable

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

W03 - distance = velocity x time 
\[ = 10 \text{ m/s} \times 5 \text{ s} \]
\[ = 50 \text{ m} \]

W04 - \[ v = u + at \]
\[ 10 = 0 + a(5) \]
\[ a = 2 \text{ m/s}^2 \]
But, \[ s = ut + \frac{1}{2} at^2 \]
\[ = (0)(5) + \frac{1}{2} (2)(5)^2 \]
\[ = 25 \text{ m} \]

W05 - \[ v^2 = u^2 + 2as \]
\[ 10^2 = (0)^2 + 2(10)s \]
\[ 100 = 20s \]
\[ s = 5 \text{ m} \]

W06 - \[ s = ut + \frac{1}{2} at^2 \]
\[ s = (10)(5) + \frac{1}{2} (10)(5)^2 \]
\[ = 50 + 125 \]
\[ = 175 \text{ m} \]

W07 - \[ s = ut + \frac{1}{2} at^2 \]
\[ = 0 + \frac{1}{2} (10)(5)^2 \]
\[ = 125 \text{ m} \]

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

W09 - \[ s = 50 \text{ m} \]

W10 - Insufficient information given.
W11 - \( s = 25 \) m

*Correct response

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

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QUESTION 12 (a) - Summary percentages

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*Correct response
QUESTION 12 (b) - 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, \[ a = \frac{v}{t} = \frac{10 \, \text{m/s}}{5} = 2 \, \text{m/s}^2 \]

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

X06 - \[ s = ut + \frac{1}{2}at^2 \]
5 = (0)(5) + \(\frac{1}{2}\) (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  21. X04  41. X04  61. X04  81. X07
2. X02  22. X04  42. X04  62. X04  82. X02
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20. X04  40. X05  60. X04  80. X02

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**QUESTION 12 (b) - Summary percentages**

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*Correct response*
Author  Ramaila S M
Name of thesis  The Kinematic Equations: An Analysis Of Student Problem Solving Skills Ramaila S M 2000

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