THE USE OF AN EXPERT SYSTEM TO IDENTIFY PUPILS' MISCONCEPTION IN SCIENCE : A PROTOTYPE AND EVALUATION

by

WAN SALIHIN WONG ABDULLAH

A Doctoral Thesis
submitted in partial fulfilment of the requirements
for the award of the Doctor of Philosophy degree of
Loughborough University of Technology

July 1995

DECLARATION

This is to certify that, unless otherwise acknowledge or referred to the published literature, the work reported in this thesis is that of the author. Neither the thesis nor the original work contained therein has been submitted to this or any other institution for consideration of a higher degree.

Wan Salihin Wong Abdullah

DEDICATION

To

My wife :

Zuliani Ghazali

and our children :

Khairul Nizar Syazwan

NurFarah Liyana

Khairul Syamim

Khairul Syafeeq

for their love, encouragement and perseverance.

ACKNOWLEDGEMENTS

In the name of ALLAH, Most Beneficent, Most Merciful.

The author would like to thank many individuals and organisations who have made possible the development of the thesis.

He would like to express his gratitude to his Director of Research, Mr. Derek Blease and Supervisor, Dr. Phil Wild, whose guidance and support made the effort possible and worthwhile. Their time, advice and useful criticisms throughout the research period is very much appreciated.

He is also grateful to the teachers and pupils from surrounding schools who spared their time to take part in this research.

Special appreciation to the Commonwealth Association of Universities for providing the scholarship and the University Technology of Malaysia for other financial support and for granting the study leave. Also to the British Council's staff for their support and advice during the stay in Loughborough.

Last but not least, the author owes his deepest gratitude and indebted to his wife and children who gave him the love, encouragement and support throughout the years of his study. And to both their parents and families for the blessings, endurance and patience during the period they were away from home.

Title : The use of an expert system to identify pupils' misconception in science : A prototype and evaluation

Abstract

In this research, the author proposes a development which contributes towards a knowledge of linking research in diagnosing student misconception in science education and the expert systems technology. Specifically, the thesis will describe the development and evaluation of a prototype diagnostic system to become a supportive tool for classroom teachers.

Three topics of electricity, speed and motion graphs, and floating and sinking were selected to explore the use of expert systems technology in diagnostic testing in science. For each topic, the strategy for building the rule-based diagnostic knowledge representation is discussed. The main steps are analysis of past research literature in pupil misconceptions, building a matrix table consisting of various parameters and logical relationship between these parameters, designing the questions for eliciting the understanding and building the rule base. Finally the rule base has to be organised for encoding into a format suitable for inclusion into a generic expert system shell (Leonardo).

In general, the two forms of rules contained in the knowledge base are diagnostic rules and the question sequence rules. The diagnostic rule consists of if-then statements which describes the patterns of typical science misconceptions found in the literature. Detection of a specific pattern results in descriptive diagnostic feedback. The question sequence also consists of if-then rules which are used to support the branching of questions according to previous responses. In the topic of floating and sinking, the diagnostic rule makes use of the certainty factors feature of the shell in making a decision.

Both school pupils and teachers were used to validate the program. The analysis of pupils' responses suggests that the program is capable of diagnosing pupil's misconception and that new diagnosis rules can be added to the program to cater for new patterns of understanding detected by the system. The teachers responded favourably to a questionnaire regarding the user interface, the accuracy and outcomes of the questions used in the program and the accuracy of the diagnostic feedback provided by the program. In conclusion, within the limitation of the scope of the diagnosis rule base contained in the program, the research shows that such a methodology for using the available expert knowledge is feasible.

CONTENTS

Page

Page

Page

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Overview of the Research

In the early days of educational testing, tests were developed for the purpose of making quantitative assessments of an individual's general level of ability and achievement relative to others within a group. The use of such norm-referenced tests was principally for selecting students to enter university or for assessing the final outcomes of an instruction. Recently, criterion-referenced testing was introduced into the educational environment with the goal of promoting individualised, adaptive testing (Glaser, 1963). From the cognitive perspective, such tests were able to provide knowledge of a student's prior mental models, misconceptions, or problem solving skills (Frederiksen and White, 1990).

There has been a wealth of published research identifying misconceptions in the understanding of scientific concepts by students. Recent findings from cognitive research show that teaching cannot be based on any notion that implies the absence of prior knowledge in the minds of students (Mestre and Touger, 1989). However, a problem exists in applying the findings of this research to the classroom (Treagust, 1988). A number of educators, in order to apply the findings into classroom practice, have suggested the use of diagnostic tests to evaluate students' misconceptions in science. In research, the usual method for obtaining information about student's misconceptions has been individual student interviews. For example, Osborne and Gilbert (1980) have suggested a variety of interview formats for conducting these interviews. This interview methodology has been criticised by a few researchers in terms of its practicality. As a result of this, a number of researchers have suggested alternative ways such as using multiple choice diagnostic tests as a way to probe students' misconceptions (Tamir, 1989, 1990; Helm, 1980).

The introduction of micro computers into the educational system has provided an opportunity for researchers to develop computerised diagnostic tests. For example, McDermott (1990) has described a computer program to be used as an investigatory tool for conducting research on student understanding in science.

Recently, computer technology has incorporated the principle of Artificial Intelligence (AI). Artificial Intelligence, which consists of natural language processing, robotics and expert systems research, offers education a means to achieve increased productivity. This Artificial Intelligence technology, especially expert systems development, has been utilised in educational research. The expert systems are artificial intelligence programs that specialise in symbolic processing, simulating expert decision making and problem solving. As described by Michaelsen (1985),

Expert systems are a class of computer programs that can advise, analyse, categorise, communicate, consult, design, diagnose, explain, explore, forecast, form concept, identify, interpret, justify, learn, manage, plan, present, retrieve, schedule, test and tutor.

Within this perspective, the process of diagnosing a student's misconceptions may be regarded as something amenable to an expert system approach, that is, to formalising that knowledge computationally. This research will be concerned with identifying the knowledge of the researchers in the diagnosis of students' misconceptions and then formalise this expertise in an expert system approach.

1.2 Aims of the Research

The main purpose of this research is to explore and examine the use of expert system technology in science diagnostic testing. It is intended as an experiment to link previous research in science misconceptions and the techniques of diagnosing those misconceptions with the expert systems technology. The end product of the research is a prototype expert system-based diagnostic program to help students or teachers discover misunderstandings in the science classroom. It is concerned primarily with detecting or isolating students' misunderstandings in a specific topic or area. No attempt is made to provide a remedial process to the detected misunderstandings in this research. This prototype will be developed by using a commercially available expert system shell.

It is believed that this study correlates strongly with the notion proposed by McDermott (1990). The author propagates the idea of establishing relationships between results from past research and a computer program development. In the specific domain of science misconception, the information from past research can be used to guide the development of a computer program that addresses the misconceptions identified. Furthermore, this developed computer program can then drive further research in that particular domain.

1.3 Research Justification

This research project is funded by The Commonwealth Association of Universities under the Fellowship and Scholarship Plan. It is important especially in the context of a developing nation such as Malaysia where the future direction is towards a more systematic and reliable school based testing. In implementing this vision, there is a need for diagnostic expertise among normal classroom teachers which is still very much lacking in Malaysia. One possible solution is to employ the technological method which is concurrent with the Malaysian's Ministry of Education plans to supply computers to all the secondary schools (Shariffadeen, 1991).

The author proposes the use of expert system technology in this research because theoretically the diagnostic system is within the general uses of expert system technology as an Instructional Decision Making, Instructional Feedback and Job Aids as proposed by Jonassen and Grabinger (1992). With respect to technological reason, it provides the following advantages :

1. The availability of an expert system shell on a PC makes it easier to be distributed and used in the classroom.

2. Compared to conventional programming, it is very much easier to build and modify the prototype expert system knowledge base.

3. It also provides a relatively easy way to formalise and centralise the diagnostic knowledge.

1.4 Research Questions

The general structure of the research questions are as follows :

The first general question is :

1. How can expert systems technology be used as a science misconception diagnostic testing program ?

This first general question can be split into 4 objectives :

a. to identify and organise into a suitable form a sample of pupils' misconception in a specified Physics topic of basic electric current by analysing previous research in science misconception in that particular topic.

b. to develop and maintain a diagnostic question database for the above topic at GCSE level.

c. to organise the diagnosis expertise and knowledge into a format suitable for expert system implementation.

d. to develop and implement a prototype expert system diagnosing program which incorporates the above formalism by using a personal computer based shell.

The second general research question is :

2. Can the methodology proposed in question 1 be extended into other topics ?

The second general question can be split into 2 objectives :

a. To extend the knowledge base of the prototype developed in part 1 with the topic of speed and motion graphs which extensively employs the graphic capability of the shell.

b. To extend the knowledge base of the prototype developed in part 1 with the topic of floating and sinking which explores the use of the 'certainty factors' feature of the shell.

The third general research question is :

3. What can be learned from the evaluation of the prototype expert system diagnostic program ?

The third general question can be split into 3 objectives :

a. To carry out a trial with local school pupils in order to validate and investigate the effectiveness of the prototype program.

b. To analyse pupils' responses to the questions in order to confirm and then enhance further the diagnostic capability of the program.

c. To elicit teachers comments on the effectiveness of the program and the correctness of the program's feedback by running sample cases of the pupils' responses.

1.5 Outline of the Contents

The thesis consists of eight chapters. Chapter 2 presents a review of the literature in key areas of relevance to the thesis. It consists of discussion on background of the research in pupil misconception, expert systems technology and applications in education, some aspects of the computerised diagnostic testing in science education, and finally the expert system shell.

Chapter 3 describes the research method and design. It discusses how to link research in science misconceptions and diagnostic testing with the expert systems technology. The overall design framework of the prototype program which has taken into consideration the practicality of system adoption into present classroom settings is described.

Chapters 4, 5, 6 and 7 present the results of the research.

Chapter 4 begins by describing the steps taken in developing the proposed expert system diagnostic prototype program with an initial topic of basic electricity. It explains the proposed strategy adopted in building the knowledge representation in the prototype program. The architecture of the diagnosing program is described and the results of an initial pilot study are also discussed.

Chapter 5 discusses further exploration in building the knowledge representation with two more topics. The two topics selected are Speed and Motion Graphs and Floating and Sinking. These two topics were selected in order to further explore and use the graphics and 'certainty factors' capabilities of the shell.

Chapter 6 reports the results of the analysis of pupils' responses in a school based evaluation. In this respect, two forms of analysis were carried out. The first form is the analysis of the general pattern of pupils' responses to all the questions, whereas the second form of analysis provides several typical samples of individual pupil's responses. Both forms of analysis were employed to validate the prototype program.

Chapter 7 reports the results of an evaluation of the prototype program with teachers. Several selected cases from the pupils' answers were used as an example for teachers to view the program. Teacher comments are elicited by using a questionnaire with closed and open questions.

Chapter 8 summarises the key findings of chapters 4, 5, 6 and 7 by discussing the significance of these findings, the limitations of the study and suggests avenues for further research.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Overview

This background chapter is designed to provide the reader with a grounding in areas of relevance to the thesis. It represents a wide area of related background and literature review. A search of the literature conducted by the author revealed little literature in the educational or computing journals that linked research in science misconception diagnosis with expert systems technology. It is hoped that this study will act as a catalyst to further research in these areas.

Section 2.2 provides an overview of research in pupils' conception in science and the diagnostic testing methodologies for investigating the conception. Section 2.3 presents an introduction to the expert systems technology that discusses their nature and underlying architecture.

As this research is concerned with linking expert systems and diagnostic testing in an educational environment, it is appropriate to review the applications of expert systems in education and testing. These are described in Section 2.4 and Section 2.5. Section 2.6 discusses the expert system shell as a development tool used in this study. The general aspects of evaluation of an expert system based program is discussed in Section 2.7.

2.2 Research In Science Misconceptions

In science subjects, there already exists an extensive body of empirical research about student misconception. Most of the research has focused on studies of students' ideas about a particular topic area or class of phenomena. Specific topic investigations of student misconception include kinematics, gravity, force, heat and temperature, friction, and electric current and circuits. This research has successfully established extensive information regarding students' conceptions and misconceptions in those particular topics. For example, the Children's Learning in Science Research Group (CLIS) at the University of Leeds published a bibliography (CLIS Group, 1990) which documented and categorised the research that has been undertaken into pupils' conception in science.

Hewson and Hewson (1988) have reported that research in science education that is based on conceptual change ideas makes an important contribution to the conception of teaching science by identifying key points in instructional strategies that help students overcome their misconceptions. The authors suggested that it is necessary for teachers to be able to diagnose their students' conception of science topics by using a pre-test based on prior research.

A variety of methods have been developed to obtain in-depth descriptions of aspects of a student's cognitive structure. In research, a common way of eliciting students' ideas has involved the use of interview techniques on a one-to-one basis, often built around a suitable stimulus situation e.g. a small scale experiment on a picture of an everyday situation (Osborne and Gilbert, 1980). This interview technique consists of discussion between a researcher and a student focusing on the student conception of a particular concept.

For the classroom teacher, the issues are how to elicit students' ideas and how to cause them to challenge their own interpretation of events. The alternative of teachers interviewing their students to identify misconception is not practical (Treagust, 1988) since not only is interviewing time consuming, it also requires substantial training (Fensham et al., 1981). Tamir (1989), in criticising the interview method, stated that although it provides excellent in-depth information about the individual pupil's conception, it has serious practical limitations if the findings are to be generalised to large groups of pupils. It also cannot be employed by teachers as part of their regular classroom activity.

The development of multiple choice tests on pupils' misconceptions has a potential value to assist science teachers in using the findings of research to improve their teaching provided that the problem of not actually impinging on teachers' time can be overcome.

A number of researchers have utilised multiple choice tests in their study. Halloun and Hestenes (1985) have developed a multiple choice diagnostic test instrument to assess student's knowledge-state before and after instruction. The questions in the instrument were selected to assess the student's qualitative conceptions of motion and its causes, and to identify common misconceptions which had been noted by previous researchers.

Treagust and Smith (1989) developed a paper and pencil diagnostic test to determine students' understanding of gravity and planetary motion. To develop the test, 24 students were interviewed using a set of cards which assessed knowledge of gravitational force, planetary rotation and planetary revolution. On the basis of the interview data, the authors produced a paper and pencil test with questions identical to those found on the cards used in the interview. The authors concluded that the results of the diagnostic test supported interview data.

Haslam and Treagust (1987) have reported a study to diagnose secondary student's misconception by using a two-tier multiple choice instrument. This two-tier multiple choice instrument is described as a reliable and valid diagnosis of student misconception. The first tier relates to the content based on prepositional knowledge statements. The second tier consists of reasons that included identified misconceptions and correct answers.

In supporting the use of multiple-choice questions to diagnose students' conception, Tamir (1989) stated that:

Although multiple choice tests, as commonly used, can be rightly criticised, their structure, when wisely used, makes them excellent diagnostic tool for identifying students' conception, including misconceptions.

Recently, computers have become a dominant area of research and development in educational technology. This computer technology has emerged as a major facilitator in the enhancement and improvement of the educational process. The introduction of computers into our education system provides an opportunity to rethink the whole relationship between testing and learning. Olsen (1990) has listed various advantages of the use of computers in testing over paper and pencil tests:

1. Greater standardisation of administration;
2. Enriched display capabilities;
3. Providing equivalent scores with reduced testing time;
4. Ability to measure response latencies and patterns; and
5. Immediate test scoring and reporting.

A number of researchers have developed computerised diagnostic tests. For example, Okey and McGarity (1982) have developed a software package for classroom diagnostic testing. They have suggested that such a use may relieve many teachers of much of the burden of routine classroom testing.

Hicks and Laue (1989) suggested that a computer program can provide an interactive program that facilitates the learning of fundamental concepts by detecting the misconceptions.

The software was developed by the authors with emphasis on the multiple choice questions to engage the student in an active way, where the questions and possible answer sequences of the program are structured around common misconceptions.

Another computer program has been developed by Hewson (1985) to diagnose and remedy an alternative conception of velocity. The author reported that the program has been successful in providing a consistent diagnosis of student's conceptions.

2.3 What Is An Expert System ?

Expert systems owe their origins to the area of study known as Artificial Intelligence (AI). Artificial Intelligence is the attempt to create computer programs that do things that, if they were done by people, would be considered intelligent. Although AI has yet to deliver what it has promised, it has found practical application in the form of expert systems. Expert systems are a branch of AI that combine knowledge representation with problem-solving techniques. In other words, an expert system manipulates information or knowledge with the intention of solving a particular application problem.

2.3.1 Definition Of An Expert System

According to Goodall (1985), there are two approaches to defining what an expert system is:

- the human/AI oriented approach
- the technology-oriented approach

The human/AI approach defined expert systems as:

A computer system that uses a representation of human expertise in a specialist domain in order to perform functions similar to those normally performed by a human expert in that domain.

In this approach, the emphasis is on the way in which expertise is represented. This approach is normally used by the computer scientists.

The technology approach puts more emphasis on the techniques used to implement the system. In this approach, an expert system is defined as:

A computer system that operates by applying an inference mechanism to a body of specialist expertise represented in the form of 'knowledge'.

From this approach, the fundamental structure of an expert system is 'an inference mechanism' operating on a particular 'knowledge'.

In this report, the author prefers to choose the definition of expert system in the technology approach. This approach is more suitable in respect of the application of an expert system in another area. Within this technology approach, Raglan and McFarland (1987) defined an expert system as

A computer program that combines knowledge in the form of rules and an "inference engine" that uses the rules to draw inferences or conclusions and recommendations about a problem presented to the system.

Morris (1990) provides a more general definition of an expert system as :

Computer-based systems that use knowledge and reasoning techniques to solve problems that would normally require human expertise.

2.3.2 State Transition Model

The basic operation of an expert system can be described as a state transition model (Marshall, 1990). A state can be defined as

An event which may have occurred, may be happening or may be waiting to occur

During any specific activity, a state will move or transit from one state to the others. An initial state represents the beginning of an activity. Based upon the response to a state, the transition to a successor state will occur until it reaches the final or goal state. A set of rules that govern the progress of an activity can then be built to represent the states.

A simple state transition illustration is shown in **Figure 2.1**.

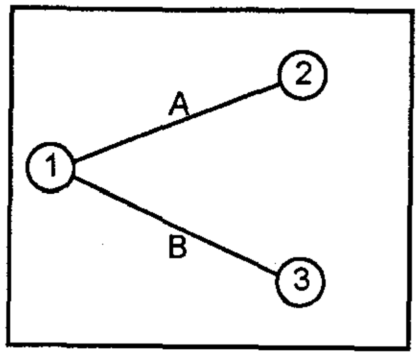


Figure 2.1
An abstract state transition model

From the simple illustration, a set of possible rules is:

- If the system is in state 1 and action taken is A then the system will move to state 2.
- If the system is in state 1 and action taken is B then the system will move to state 3.

It can be stated in a more formal way as:

- If state = 1 and action = A then state = 2
- If state = 1 and action = B then state = 3.

2.3.3 The structure of an expert systems

The general structure of an expert system is shown in **Figure 2.2**. In terms of its architecture, expert systems basically have four components:

1. Knowledge Base Component

This part of the system contains the knowledge associated with a specific domain. The knowledge exits in the form of set rules or frames.

2. Interface Component

This part will facilitate communication between the expert system and its user. Normally it consists of end-user interface (e.g. screen design), developer's interface (editing and diagnostic facilities) and external program interface (relation with external data or programs).

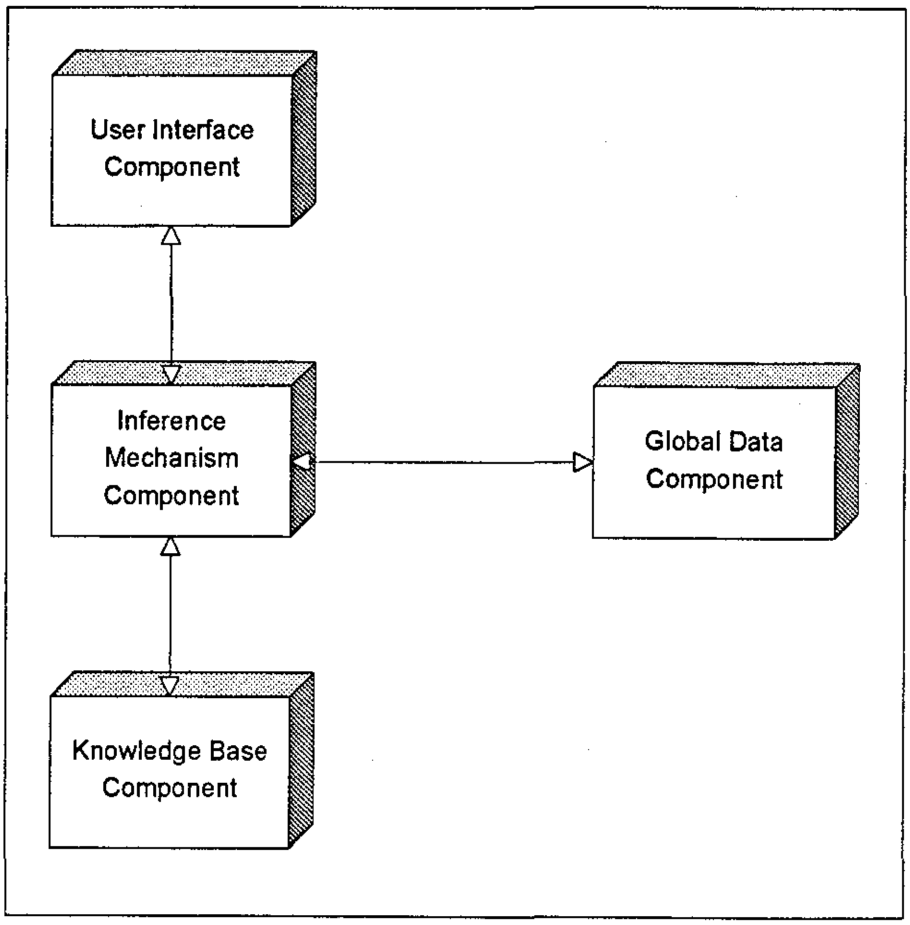


Figure 2.2
The general structure of an expert system

3. Inference Mechanism Component

This part is responsible for solving the problem posed by users. It generates inferences by using a set of rules or decision-making strategies that are held in the knowledge base. Sometimes it requests information from the user in order to arrive at the inferences. Usually the control strategies consist of forward chaining, backward chaining or both. Additional features include the ability to deal with uncertainty.

4. Global Data Component

This part keeps track of the problem by storing data, for example the user's answers to questions.

2.3.4 Knowledge Representation

In expert systems technology, there are various methodologies to represent the knowledge in an organised and consistent manner by imitating the domain of the expert. The most frequently used methodologies are:

- Production Rules
- Frames

2.3.4.1 Production Rules

Knowledge is stored in the knowledge base by using production rules that consist of a set of conditions and corresponding actions. Its general form is:

IF condition THEN action

If the condition is met, then the action is invoked. Usually, the condition is a form of clause which can be tested to see whether it is true or false. The condition of a rule may have multiple clauses joined by the keywords AND and OR. The action of a rule may also have multiple clauses. For example:

IF	condition - 1
AND	condition - 2
AND	condition - 3

THEN	action - 1
AND	action - 2

IF	condition - 1
OR	condition - 2
THEN	action - 1
AND	action - 2

Generally, the rules also allow a mixture of AND and OR in the condition part of it.

2.3.4.2 Frame

Another way to represent knowledge in a knowledge base is by using a frame. A frame represents an object or situation by describing the collection of attributes that it possesses. This is normally done by providing slots. Slots and their values are used to store information about the object.

For example, a slot may contain :

- a default value
- a range of permitted values for the slot
- a procedure for filling the slot

2.3.5 The Inference Engine

The inference engine is the workhorse of an expert system. It consists of the processes that manipulate the knowledge base, do analyses, form hypotheses, and control the processes according to some strategy. The inference engine asks for new information, combines it with the knowledge base, considers the relationships in the knowledge base, and proceeds to solve the problem using its established reasoning and search strategies.

There are two inference mechanisms which are most commonly used in expert systems. These are:

- Backward chaining
- Forward chaining

2.3.5.1 Backward Chaining

This is also known as goal-directed reasoning. In this type of chaining, the inferencing starts with the goal and reasons backward through the rules looking for facts that will establish the goal.

2.3.5.2 Forward Chaining

This is also known as data-driven reasoning because the inferencing starts from the known data and reasons forward as far as possible with that data.

2.3.6 User Interfaces

According to Harmon and Sawyer (1990), there are two different kinds of interfaces involved in expert system development. On one hand, there is the interface supplied by the development tools for application developers who will use it to develop an expert systems application. Usually this interface is a friendly one and application developers can make sense of its purpose and function in a relatively short time. On the other hand, there is the interface that the application developer creates that is used by the end-user. The development tools normally provide the developer with a number of features with which to customise the user interface : graphics, windows, menus, forms and more.

2.3.7 Summary of Expert System Technology

From the above definitions, it can generally be stated that an expert system consists of a set of rules or frames, often called a 'knowledge base'. This knowledge base includes facts about the object, information about the relationship between objects and a set of rules for solving problems in a specific domain. An attempt is made to represent in this knowledge base the human experts reasoning processes when they solve problems in that knowledge domain in the form of "If..., then..." rules. For example,

IF	weather is wet
AND	temperature is cold
AND	car is outside
THEN	stay inside

When the expert system program is executed, it will then request the facts or answers it needs to make a decision.

What is the weather?
What is the temperature?
Where is the car?

After the users provide the answers, the 'inference engine' will use this rule set as data. The programs make inferences by using both the rule set and specific answers to the question it asks about properties of the current situation. When it finds a rule that matches the facts the rule 'fires' and provides the answers or advice to the user.

Several expert systems permit certainty factors that specify the likelihood of some conclusion, given imperfect data or an approximate rule. For example, in MYCIN, a famous early expert system for the diagnosis of bacterial infections, one of the rules is :

IF: the stain of an organism is gram positive,
AND the morphology of the organism is COCCUS,
AND the growth conformation of the organism is CLUMPS,
THEN the identity of the organism is STAPHYLOCOCCUS (0.07).

The number 0.07 indicates the degree to which the conclusion follows from the evidence on a scale of 0 to 1 (cited in Goodall, 1985).

2.3.8 Differences Between Conventional Programs and Expert System Programs

Bielawski and Lewand (1991) contrasted conventional programs and expert systems by stating that :

Conventional programs are algorithmic, and they produce unique and certain answers. Expert systems, by their nature, are heuristic, and the results they produce are not always unique nor are they necessarily certain.

Goodall (1985) stated that in a conventional language (like COBOL) the knowledge of the subject area and the processing mechanism (control) are not separated as they are in an expert system. In order to change the rules in a conventional system, the whole program had to be edited at the correct position and recompiled. This is different from the expert system where the knowledge bases do not mix with the inference mechanism (control). So the rule in the knowledge base can be added to without worrying about the program's control system. In addition, an expert system program is able to explain its reasoning in reaching the conclusions. In other words, it can show all the rules that led to a conclusion or action.

2.3.9 Knowledge Acquisition

One of the main issues in the development of expert systems is the process of extracting the expert's knowledge. This process is known as knowledge acquisition.

Knowledge acquisition is the process of locating, collecting and refining the knowledge from human experts or other sources relevant to a particular domain (Beynon-Davies, 1993). There are a variety of knowledge sources. The knowledge could be obtained from human experts or from other sources such as textbooks, journal articles, manuals or databases (Morris, 1990). With respect to knowledge acquisition from human experts, the knowledge base is typically constructed by interviewing one or more experts in some domain of knowledge. This interview technique has been viewed as too time consuming. Lately, there is another method of knowledge base development, that is using the already compiled knowledge that is available in cases (Chadha et al., 1991). In this method, cases are defined as descriptions of problems and their resolutions. Chadha argued that using case studies has the following knowledge elicitation advantages:

1. The knowledge source is standardised and relatively unambiguous.
2. Less involvement with a domain expert is required.

Within the education environment, McFarland and Parker (1990) suggested that the findings from research in a particular domain could form the basis for knowledge acquisition.

2.4 Expert Systems And Education

The prospects of using expert systems technology in education have been supported by several educators. This section describes the general main ideas described in the literature which relates to conceptual proposals and the applications of expert systems technology in educational environments.

McFarland and Parker (1990) stated that an expert system and Intelligent Computer Aided Instruction (ICAI) are the two related areas of AI application which merge with research and development in education and training. These applications use concepts and techniques from AI to improve education and consultation. They argued that overlaps exist between the development of expert systems and ICAI systems in that the expert system may serve as a module for an ICAI system. For example, an expert system based program named as GUIDON that teaches medical diagnosis began with the development of MYCIN, a diagnostic expert system.

The use of expert systems in education has many possibilities. For example, Jonassen and Grabinger (1992) have proposed that expert systems technology could be useful in helping teachers or learners in the following ways :

- Instructional decision making

A teacher may develop a knowledge base to help make decisions when designing instruction.

- Instructional feedback

Expert systems can be created to help learners complete tasks by providing instant access to the feedback of an expert.

- Job Aids

Expert systems may be used to provide access to expert advice and build a high degree of consistency in the decision making process.

- Cognitive tools

Expert systems can be used as cognitive tools for engaging learners in higher order thinking skills.

Raglan and McFarland (1987) have listed the possible areas of potential interest in education:

1. Diagnosis and labelling of exceptional learners;
2. Consultation related to due process procedures;
3. Assessment of skill strength and weaknesses;
4. Recommendation of behavioural intervention;
5. Recommendations to increase instructional effectiveness;
6. Staff evaluation for employment and retention;
7. Deciding whether to retain a student in grade; and
8. Counselling students into programmes of study.

Wolfgram et el. (1987) also described the possible applications of expert systems in education in the areas of :

1. Learning disability classification advisor;
2. Student behaviour consultant;
3. Test result interpreter;
4. Textbook selection advisor;
5. Careers advice; and
6. Course selection;

Forcheri and Molfino (1995), in discussing the realisation of expert systems or knowledge based systems technology for teaching and learning mathematics, described the various aims and approaches in application of such systems in an educational setting which includes :

- to analyse pupils' behaviour in order to diagnose their difficulties on a specific topic;
- to monitor and predict pupil's behaviour
- to build a system to help pupils in learning through the examples of an expert's behaviour; and
- to build a tutor capable of giving explanations and learning from the pupil's behaviour.

Within the application of expert systems technology in education, Ben-David and Ben-Shalom (1994) discussed the development of an expert system program for helping teachers in evaluating examination criteria (educational objectives, scoring method and other factors) to suit the formal evaluation procedures stated by the federal educational authority. In conclusion, the authors suggested that the expert system program could serve as a tool for supporting the decision-making process where a decision maker could compare his or her own judgement with the one provided by the program.

In developing an expert system based academic advisory system named IEADVICE, Occena and Miller (1993) have described an attempt to represent undergraduate course advising expertise into an expert system knowledge base with the intention of releasing the time-consuming burden on the human advisor. The results of the verification and validation processes showed that the program is capable of providing high accuracy advice.

White (1993) reported the use of expert systems in a school situation. One example given is the use of an expert system shell to identify a suitable site for Anglo-Saxon settlement in History subject matter. This program has been developed by using the shell ADEX from

Hatfield Polytechnic. The author was also looking into the possibility of expanding the system by experimenting with a more powerful commercial shell.

Settle (1987) described the construction and use of an expert system by using a commercially available shell in the chemistry laboratory. The programs were developed mainly in the area of chemical analysis involving the identification of chemical substances and qualitative analysis of metal ions. This program is not used to replace laboratory operations and observations, but as a tool to assist the students in examining their results and conclusions. Some of the important advantages of expert systems as educational tools reported are:

- Delivery of specific information to meet the needs of individual students;
- Patient, tireless response to student needs;
- Ease of design and modification;
- Organisation of information and educational functions required to develop an expert system; and
- Convenient storage of knowledge on a particular subject.

Raglan and McFarland (1987) reported that teachers make many critical decisions in the lives of their students each day. Some decisions such as when to reinforce or punish, how to teach specific tasks effectively, and how to take remedial action are often made without the consultation of others. Often these decisions are made without applying a knowledge of best practices or research findings. Recent research in interactive decision making is beginning to identify information, rules, and procedures that teachers think about when making classroom choices. If "intelligent" computers can be programmed to assist teachers with record keeping and decision making using the knowledge from research and "best-practices", then teaching and learning can be improved.

2.5 Expert Systems And Diagnostic Testing

With the emergence of microcomputer technology, it is possible to use this technology in helping to identify pupils' conceptions in various subject matter. It also provides the advantage of individualised instruction or testing. As stated by Niedderer et al. (1991), science education should take the chance to link the established research with dealing with students' conception and new teaching strategies with the use of modern information technology tools. Otherwise the findings of educational research may fail to change teaching, and the potential of information technology tools will not be implemented to promote understanding and learning.

There are still very few applications of AI or expert systems to educational measurement, assessment, and testing (Olsen, 1990). The present research has found that related literature on expert systems in diagnostic testing is rather scant. Recently, a few researchers have developed computerised diagnostic testing by incorporating expert systems or artificial intelligence technology.

The idea of applying expert system strategy or technology in diagnosing students' errors has materialised especially in Mathematics Education. Attisha and Yazdani (1984) developed a computer-based expert system dealing with the diagnosis of student's errors in subtraction. Then, later on, the authors developed a similar but more complex system for the diagnosis of students' errors in multiplication. Both the systems have been designed for all the known systematic errors which students make. As the systems have been designed using programming language, the structure of the system is very complex and hence it cannot be directly transferred to other subjects or topics.

Mestre and Touger (1989) have designed a computer-based, expert-like problem analysis environment called Hierarchical Analysis Tool (HAT). This software was used to analyse the problems in a calculus-based classical mechanics course at university level. In the analysis, the student answers well-defined questions by making selections from menus that are generated by HAT. When the analysis is complete, the HAT provides the student with a set of equations that is consistent with the analysis conducted by the students. If the analysis is carried out incorrectly, the final equations are consistent with the student's selection but are inappropriate for solving the problem.

Nachmias et al. (1990) has developed a microcomputer-based diagnostic system (MBDS) to identify students' conception in the domain of heat and temperature. The author reported that the evaluation of the MBDS software showed that the students' knowledge profiles produced by the system were at least as good as those of experts in science teaching diagnostics. He suggested that MBDS could be used as a diagnostic device in the classroom to provide the teacher with the knowledge status of his students of a specific topic.

Boohan (1992) has produced DIAG, a computer program to diagnose a students' conceptual model of a simple electrical circuit. The author reported that preliminary work with students suggests that the program makes reasonable diagnoses. In fact, the author suggested that further work be carried out in another area or topic. The drawback of DIAG is that it is incapable of including graphics in its questions.

Both Nachmias and Boohan have implemented a diagnostic strategy by using the methodology of artificial intelligence tutoring systems but not specifically expert system technology. These methods of identifying the errors of individual learners have so far been successful in several domains, e.g. algebra (Gisolfi and Moccaldi, 1986), and programming (Anderson et al., 1985). In contrast, Beaumont (1989) worked within the expert system environment on a project to diagnose the errors committed by students in performing arithmetic skills. He used an expert system shell called Crystal to store the diagnostic procedures that had already been established through previous research.

2.5.1 Reasons For Using Expert Systems In Diagnostic Testing

Diagnosis is probably the field where most of the empirical expert systems work has been undertaken. For example, medical diagnostic systems encompass a substantial proportion of the pioneering attempts in articulating expertise. Malfunctioning devices, other than the human body, have also attracted attention in recent years (Johnson and Keravnou , 1988).

Within the education setting, using expert system technology as a means to the diagnosis of pupil understandings or conceptions has been proposed by various educators as described in section 2.4. The most important process of a diagnostic system is the process of moving from known items of information to unknown information. In this perspective, the pupil or user will submit their knowledge state to the system by answering the sequence of questions. Based on this known information the system makes inferences.

It is anticipated that the advantages of expert systems as diagnostic tools are:

- Careful examination of a diagnostic knowledge domain required in the design of an expert system may lead to improvement of existing methods or to the development of new ones;
- Delivery of specific information to meet the needs of the individual pupil;
- Convenient storage of diagnostic knowledge; and
- Organisation of diagnostic information.

In addition, the process of developing the knowledge base provides means of collecting together the knowledge on pupils' understanding in a more organised way than ever before.

2.6 Expert System Shell

One of the most important steps in building an expert system application is the selection of software tools. A variety of tools exist, ranging from general-purpose programming languages such as Lisp, Pascal, and Fortran, to a more general-purpose representation language such as EMYCIN.

Recently, expert system technology has come in the form of 'shell'. Expert system shells are expert system development tools. The term expert system shell is used to refer to a piece of computer software which provides a user interface and inference mechanism but no knowledge base (Galpin, 1989). In other words, it is a kind of framework into which expertise about a particular topic or subject can be entered. This tool leads a developer through the process of incorporating knowledge into an expert system in a particular knowledge domain to be used by another user. This expert system shell can be used as a tool to create and subsequently improve the knowledge base, as well as the use of the complete expert system to give advice or conclusions. In addition to making expert system technology available to the micro-computer user, these shells have significantly reduced the development time of expert systems and allow applications to be built in less time than with a conventional AI language such as LISP or PROLOG (Bielawski and Lewand, 1991).

There are obviously a large number of commercially available shells on the market. For example Crystal, Leonardo, GURU and Expert-Ease.

2.6.1 Leonardo Shell

Leonardo shell is proposed as the tool for developing the prototype system because it is already available in the University. The choice is also supplemented by the result of an evaluation of expert system tools carried out by Drenth and Morris (1992). The authors carried out an evaluation of four commercially available expert system tools that can be used for prototyping. The four tools are Crystal, Leonardo, GURU and ART-IM. The authors concluded that Leonardo:

- is easy and quick to use for development and consultation;
- has a frame structure which provides simple knowledge representation and maintenance; and
- has extensive procedural programming language to support complex designs.

Bodkin and Ian (1989) also carried out a review of Leonardo features. The authors summarised the important features of Leonardo which includes :

- execution speed is good;
- window management is very sensibly designed and flexible;
- the ability to partition the rules and associate rulesets with any object was regarded as an excellent feature;
- The facilities provided by the frame's slot proved invaluable e.g. the expansion slot permits the easy inclusion of an unlimited amount of text which is automatically available to the user at almost any point, at a single keystroke and without any coding other than the text itself;
- the allowed-value slot similarly supports codeless menu generation; and
- the free form rule editor allows easy editing.

Leonardo is one of the leading British-produced expert system shells. It is developed and supported by Software Directions and has been used to produce a range of expert system applications in fields as diverse as brain scanning, scheduling in robotics manufacture, and export control.

There are two versions of Leonardo: a PC-version running under DOS and a VAX-VMS version. A PC with 640K and a hard disk is sufficient to run Leonardo. The latest version available in the market is version 4.0. Version 4.0 offers several improvements over the older version (3.25) with a combination of bug fixes and functionality updates. The Graphics Package, Statistic functions, Lotus and dBase interfaces are now included in the latest version.

There are two main forms of knowledge representation in Leonardo, that is production rules and frames. In other words, knowledge can be represented in a combination of rules, rulesets and frames with multiple and multi-level inheritance. At the heart of Leonardo is the inference engine which allows full and controllable forward and backward chaining; the latter is essential for typical diagnostic/advice giving systems, the former for configuration/selection systems.

Since much of the information resident in the knowledge base of a typical expert system is imprecise and incomplete, Leonardo also provides support for uncertainty management. This option adds flexibility and power to the applications that deal with inexact information. The features available for managing uncertainty include :

- Multi-valued objects
- Certainty factors
- Bayesian logic

One of the outstanding features of Leonardo is its integrated procedural language. These enable procedures to be run at virtually any point which is very helpful in application development. The procedures language of Leonardo has simple syntax, yet it is possible to develop sophisticated applications including compound conditional rules, multi-valued variables, explanations, graphics, colour, and other features. Moreover, it is possible to build applications which interface with database and spreadsheet applications or with other programs. Many of these features could be used to improve both its capabilities and its interaction with users.

Leonardo also provides several supportive utilities to help the developer build and support the system. Development tools provided by Leonardo include :

- rule's editor and Object/Frame editor;
- run-time tracing and diagnostics;
- screen layout and forms editor;
- screen designer, hypertext and graphics; and
- on-line context sensitive help, extensible by the developer.

A number of important and related features of the Leonardo shell are described below. These features are used in this application.

2.6.2 The Knowledge Base

This knowledge base consists of main rules, objects and object frames. All of these are used by Leonardo to represent expertise for a given application.

The *main rule* is the basic component of the knowledge base. Every application starts with these main rules. In Leonardo, it is called MainRuleSet. It consists of a list of IF-THEN statements.

Object is the logical entity to which a value may be assigned. When the rules are checked by the system, the objects used in the rules are automatically generated.

Object frame contains all information relating to an object. It is comprised of slots. The slots are used to store information about any specific object. These slots are also used to control methods of value derivation, input screens and output screens.

For example, if there is one simple rule in the MainRuleSet:

IF	traffic_light is green
THEN	car_action is go

When this simple rule is checked by the Leonardo system, two objects are created in the knowledge base, traffic_light and car_action. The object frames of these two objects store the information or value in their slots.

2.6.3 The Editor

Leonardo editor provides the facilities necessary to create and edit rules for the knowledge base, and also to edit information into object frames.

2.6.4 Procedural Programming Language

This procedural programming language provides facilities for constructing a complex system through, for example, access to external files, performing computations and printing complex reports and so on.

2.6.5 Productivity Tool Kits

Among the productivity tool kits provided by Leonardo are screen design utility, graphics package and external program interface package. These tools are provided as integrated Procedure Language functions.

2.6.6 Multiple RuleSet

A RuleSet is a set of rules which is associated with a particular object. These rules are placed in that specific object frame. These rules are considered when the value of the object is sought by the system. This multiple ruleset system provides a way to design a modular structure of an application. According to the Leonardo User Guide (Software Directions, 1992) this modular design provides the following advantages :

- overall structure of the system is clearer;
- ease of maintenance; and
- faster compilation and efficient execution of the system.

2.6.7 Object and Value

One of the basic features of Leonardo is the object and its value. An object is considered as a logical entity representing a concept in a specific problem. This object may be assigned a value or provided with a specific rule, procedure or function in order to get its value during execution of a program. In Leonardo, an object mainly consists of five types.

- Text Object
- Real Object
- List Object
- Procedure Object
- Screen Object

The characteristic of each type of object is summarised in **Table 2.1**.

Object Type	Characteristic
Text	Holding string values
Real	Holding numerical values
List	Holding list of items
Procedure	Consists of a large number of built-in procedures and functions which perform various tasks such as file access and printer control
Screen	For creating user interface customised screen

Table 2.1

Type of object and its characteristic

2.6.8 Object Frame

For each object, there is a related frame to keep all the information about the object. The object frames are comprised of slots. Each slot describes an attribute of the object. In other words, the frame slots are used to store all the information about the object. The standard frame slots for several types of objects are listed in **Appendix B1**.

2.7 Aspects of Validation and Verification in Program Evaluation

In the literature, there exist two important factors which need to be considered in the process of expert system program evaluation. The two factors are system's verification and validation. For example, Berry and Hard (1990) proposed that verification and validation are needed for expert system evaluation throughout the development process. Preece (1990) discussed the logical evaluation (verification of system's knowledge base) and empirical evaluation (validation of the system).

O'Keefe et al. (1987) distinguished between verification and validation. The authors suggested that validation refers to the utility of the system whereas verification refers to building a consistent and complete system with respect to its specification.

Verification of expert systems is the process carried out to determine their internal consistency and completeness. Consistency ensures that the rules are in agreement and that one rule does not negate or conflict with any other rule. Completeness ensures that all possible situations and combinations are taken into account in a particular domain. In other word, any user who consults the expert system should be able to get accurate and reliable results or advise.

Verification could be carried out by the system developer or the real user of the system. In the process of developing the prototype system, the developer should manually check the accuracy and consistency of the rules inside the knowledge base. A flow diagram can be used to check the completeness of the rules. Users could be involved in verification of the system with the objective of checking the system run-time errors and comparing the system decision with known results.

Validation is a term used to refer to the system's overall satisfactory or acceptable performance. This includes usability or utility of the system. There is a need to validate :

- the quality and reliability of the system's decision;
- the quality of the human computer interaction; and
- the overall system efficiency and ease of use.

With respect of expert system validation, there are several methods suggested in the literature. For example, Berry and Hart (1990) proposed that interviews, questionnaires, user diaries, system logging and formal observation and simple experiments could be carried out to validate the system performance and also to evaluate user acceptance.

The background and the results of the literature review discussed in this chapter will form a basis in developing the research methodology used in this study. In the next chapter, a research methodology and expert system based prototype program design framework is proposed. The aspects of program verification and validation suggested in the literature will be used in this research.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter describes the research methods used in the conduct of this study. Section 3.2 describes how to link past established knowledge of science misconception with expert systems technology. It discusses the strategy of knowledge analysis and representation to be adopted in building an expert system based diagnosis model. It also describes the design framework proposed in the development of the prototype program. Section 3.3 discusses the methodology to be adopted in this study in order to carry out the process of verification and validation in the evaluation of the prototype program.

3.2 The Proposed Conceptual Model

On the basis of the past established knowledge of science misconception research, an expert system approach is suggested to be developed as a supportive tool for classroom use in diagnosing pupils' understanding in science. These expert systems will consist of a set of multiple choice questions and a diagnosis knowledge base. The inference engine of the expert system shell will then use the answers to the questions and the diagnosis knowledge base to provide diagnostic feedback to teachers and pupils.

As in other system development, the initial step in the process of building the prototype design involved the formulation of the application requirement. There is no well-accepted approach for accomplishing this design structure. However, the author believes that most educators would likely agree that the following general design objectives and consideration should be included in the system. It is suggested that the system should :

1. be efficient in terms of user input and program output requirement;
2. involve a certain amount of visual interaction with the user;
3. be efficient and flexible in terms of allowing different topics to be diagnosed;
4. be relatively easy to modify by allowing changes to be made as required; and
5. be practical and easily adopted into current classroom practice.

3.2.1 The Proposed Methodology:

Assumption:

Under the assumption that the process of diagnosing student's misconception is amenable to an expert system approach, the literature suggests that a possible methodology might be :

Step One:

Carefully study past research in students' misconception in science education, especially research that has used multiple-choice questions to detect misconceptions in a specific topic or area. From this study, a set of possible student misunderstanding or understanding in a selected topic will be recognised and a question generator or item bank will be developed and organised. The various identified forms of understanding within a selected topic will then be used to define the parameters and the logical relationships between these parameters for developing the knowledge base.

Since the research is exploratory and there is a need for a quick way to build a general conceptual model, the rule based formalism is suggested to be used as a basis for diagnostic knowledge representation.

Step Two:

The knowledge or rules used by the researchers (expertise) to infer understanding in selected topics will be formalised in an expert system approach. The general knowledge base of the expert system will look like this:

IF	the student's answer to a certain set of questions is incorrect
AND/OR	the student's answer to another set of questions is correct
THEN	the probable understanding is recognised.

Step Three:

Develop a prototype expert system-based diagnostic program using a PC based expert system shell.

The proposed structure of the program :

1. The researcher's expertise in step two will be coded into the knowledge base components of the shell.
2. The question bank will be kept in a special file which is accessible by the expert system interface component.
3. The user interface component will be used to allow easy access of user's input-output. This interface is responsible for representing the information to the user, for presenting the conclusion, and for seeking additional information from the user.
4. The program will display a sequence of questions and uses the answers to attempt to diagnose the student's understanding.
5. The graphic facility provided by a shell will be used to draw diagrams in the questions.

3.3 Verification and Validation of the Prototype Program

One of the important factors in order to determine the success of an expert system program is that its knowledge base and general usability can be formally evaluated. There is a high level of agreement in the literature that expert system evaluation is a crucial issue in its development (for example O'Keefe et al., 1987 and Preece, 1990). In order for an expert system program to be able to supplement or support users in any specific applications, the knowledge base must be thoroughly checked and the usability must be at least at the acceptable level.

In any traditional CAI programs, the evaluation processes carried out are mainly for improving overall program design and to determine the program's instructional effectiveness and efficiency. The special capability of the program to handle a specific process such as the correctness of its contents or inferencing mechanism is not specifically evaluated (Park and Seidel, 1987). In contrast, in an expert system program, the specific features or processes, such as the knowledge base, is an important criterion to be evaluated. Although there exists some overlapping criterion to be evaluated (for example, the quality of interaction), expert system program evaluation goes one step further in that the knowledge base can be specifically examined.

3.3.1 Proposed Evaluation Procedures of the Prototype System

It is proposed that the evaluation of the developed prototype system should include both the verification and validation methods. The verification and validation process used this work follows that suggested by Preece (1990) :

- apply both verification and validation methods in expert system evaluation as they are complementary;
- Verification should be applied first to ensure that the knowledge base of the system is error-free; and
- Validation should be applied after verification to check the system performance and user acceptance of the overall system.

It is suggested that the prototype program verification and validation consists of two stages:

1. Developmental Stage
2. End-Product Stage

3.3.2 Developmental Stage

At the developmental stage, the following verification processes need to be performed :

1. *Checking that the production rules are syntax error-free as the prototype program is developed.*

When coding the diagnosis knowledge into the shell's knowledge base, a variety of coding errors could occur. The built-in expert system shell editor will be used to check for syntax errors during coding.

2. *Checking that the knowledge base is consistent and 'complete'.*

In this respect, the 'completeness' of the prototype system is that the rules built into the system cover all the stated objectives of the diagnosis process in a particular domain. Drawing of flow diagrams provides a way to check the completeness of the production rules. There is also a need to manually check the production rules for any inconsistency.

3. *Verify that the sequencing of the questions is correct.*

A questioning flow diagrams will be developed as a way to check that the questioning sequence rule inside the knowledge base is correct.

3.3.3 End-Product Stage

The prototype program will be validated by the results of pupil trials and teacher evaluation.

1. Pupil trial

The objectives of pupil trial are to :

1. check that the production rules are able to correctly identify student's understanding in a given topic.
2. verify that the diagnosis feedback information is correctly applied.
3. verify that the questions used are capable of eliciting student's understanding in a particular domain.

The evaluation method suggested is to log all the pupil's responses and program feedback in the form of external text files. For each pupil, the input and output interaction will be stored in a unique file based on the pupil's name. Further analysis will then be carried out on these data to check the correctness of the diagnosis rules.

2. Teacher evaluation

The objectives of teacher evaluation are to :

1. compare the pupils' responses to the diagnostic questions with the diagnosis feedback and conclusions generated by the prototype program.
2. examine the usability and user acceptance of the program.
3. comment on the accuracy and outcomes of the questions used in the system.

The evaluation methods suggested to be used are :

1. teachers work through the program with a selection of sample cases from the pupil trial.
2. teachers examine the specific important attributes of the program.

At the end of the evaluation, teachers will complete a questionnaire which addresses the following characteristics of interest:

- ease of use;
- quality of on-screen instructions;
- quality of on-screen diagrams;
- clarity and usefulness of system results/decision; and
- accuracy and outcomes of the questions used in the system.

Teachers will also be requested to provide general comments in the form of open questions on the use and usefulness of the system.

CHAPTER 4

DEVELOPMENT OF THE PROTOTYPE PROGRAM

4.1 Overview

To demonstrate how the diagnostic program works in the area of science misconception, a prototype program has been implemented. This prototype program deals with the misconceptions in basic electric current. This Direct Current (DC) system was selected for the prototype because its simplicity allows the author to model fully the misconceptions, yet it is complicated enough to provide some interesting situations.

The main steps in development of this prototype program consist of five main parts:

1. Collection of list of models and their related conceptions from the literature.

A literature review was carried out to gather the list of models and related conceptions in the area of basic electricity. The information was then summarised in table form.

2. Developing the diagnostic questions database

Questions need to be devised which sufficiently cover the topic in terms of the misconceptions identified in the literature.

3. Analysis of the diagnosis knowledge base

An analysis was carried out on the collected information in order to formalise it in an expert system approach. This includes the process of defining the parameters (conceptions) and logical relationship between these parameters, and representing the knowledge in a suitable form for easier references.

4. Building the prototype knowledge base

This knowledge base section contains a collection of rules. There are two main kinds of rules proposed to be implemented in the prototype program's knowledge base:

- Diagnosis Rules

These rules are concerned with the principal diagnostic process to be performed by the prototype program.

- Questions Sequencing Rules

These rules are concerned with the order of questions to be sequentially displayed on the screen.

5. Utility and interface procedures

These are general purpose facilities such as displaying questions and diagrams, accepting answers or inputs from the user. A general computer routine can be written that will perform the facilities. It is also concerned with the user interface design to be incorporated into the expert system. The user interface design is chosen depending to a great extent upon the facilities offered by the particular shell or tool being used. In this research, the user interface issue is only limited to some aspects, that is

- effective screen layout;
- displaying the diagram or graphic;
- allowing minimum user input to key in answer, revise the answer if require; and
- prompting the user if the wrong key is pressed by displaying notes and sounding a bell.

4.2 Misconceptions In Basic Electricity

A review of the literature in the area of science misconception provides extensive material in students' models of misconception in basic electricity (McDermott and Shaffer, 1992; Karrqvist, 1984; Shipstone, 1985, 1988; Osborne, 1983; Fredette and Lochhead, 1980). Eight distinctly different models have been cited in the literature. These models are:

- Sequential Model
- Sharing Model

Model	Related Conceptions
Sequential Model	current flow in one direction only. current is 'used up' in sequence of components. only part of the current used up by components.
Sharing Model	battery always gives out the same amount of current. current is shared out amongst the components.
Battery as a Constant Source of Current	battery is a constant source of current. battery gives out the same amount of current independent of circuit components.
Current as Entity	current is stored in a battery. strong relationship between current and energy.
Unipolar Model	current flow in one direction only. all current is used up in the component.

Table 4.1

Misconception models and related conceptions

Model	Related Conceptions
Wrong Direction Model	current flows in one direction only. current flows from negative to positive terminal of battery.
Clashing Model	current leaves battery through both terminals. all current is used up.
Science Model	current is the same in all parts of circuit current is conserved. current flows in one direction only. current flows from positive to negative terminal. current is not shared amongst components

Table 4.1

Misconception models and related conceptions (Continued)

- Unipolar Model
- Battery as a Constant Current Source
- Current as Entity
- Clashing Model
- Science Model
- Wrong Direction Model

Each of these models is characterised by several related conceptions. For example, the Sharing Model is characterised by the misconceptions that the battery always gives out the same amount of current, independent of the circuit and the current is shared out amongst the components in the circuit.

A complete list of models and their respective related conceptions are given in **Table 4.1** which provides a substantial amount of information that can be organised according to certain rules and principles which will then form the basis for building a diagnostic knowledge base.

4.3 Developing the Diagnosis Questions Database

The strategies used to elicit the student's idea is either interview, paper and pencil test involving structured and multiple-choice questions or a mixture of interview and test. Although each strategy looks different the basic essence is the use of a series of questions in order to probe the student's idea. In this research, the author used the strategy of multiple-choice diagnostic testing as suggested by Helm (1980) and Tamir (1989, 1990).

The question database for the topic of basic electricity consists of seventeen multiple-choice questions. The questions were based on the list of models and their related conceptions as given in Table 4.1. Some questions are related in a sense that they are used to measure similar conceptions. It covered the following main areas of diagnosis:

1. Sources of current;
2. Flow of current in a series circuit;
3. Conservation of current in a circuit;
4. Brightness of bulbs in a simple series circuit
    (a) comparing of identical circuit with one bulb and two bulbs
    (b) comparing two bulbs on a series circuit; and
5. Function of resistor in a simple series circuit.

The question format consists of a mixture of simple yes/no answers and simple 'one-word' answers with the normal type of two or three possible alternative answers. Some of the questions have the alternative of "I am not sure". This alternative provides a way for the student who is not sure of his or her answer. This overall format was influenced by the work of previous researchers (for example, Trollip et al., 1992) and basic introductory books on expert systems. The complete questions used in this topic are listed in **Appendix D1**.

The use of appropriate language which includes sentence structure, vocabulary and overall shape of the sentences and the diagrams in the question was reviewed by a local science education lecturer.

4.4 Building the Diagnostic Knowledge Bases

In the field of expert systems, building a knowledge base or knowledge representation implies some systematic means of encoding what experts know about a knowledge domain. In this particular case, knowledge about diagnosing misconception is found in a variety of sources. The most common of these are research journals and research reports. This information may come in the form of tables, a summary list or diagrams. This knowledge can then be organised and coded in a production rule-based formalism. The proposed prototype program can thus utilise this knowledge as the basis for the diagnosis process.

In the following sections, the author focuses on gathering, identifying and organising the diagnostic knowledge. Then this knowledge will be represented in a form that is matched to an expert system.

4.4.1 Analysis of the Diagnostic Knowledge

This section involves the procedure of analysing the knowledge acquired and subsequently representing the knowledge into a format for building the diagnostic rule base.

To refine the diagnostic knowledge, a tabular matrix was constructed for each diagnostic area to ensure that the rules derived from it were consistent and complete.

For example, a tabular matrix for diagnosing area (2) is listed in **Table 4.2**.

Rule	Parameters			Model
	Current leaves both battery terminals ?	Current leaves one end and return to the other end ?	Current leaving	
Rule 2(a):	yes	-	-	Clashing
Rule 2(b):	no	yes	positive to negative end	Science
Rule 2(c):	no	yes	negative to positive end	Wrong Direction

Table 4.2

Example of tabular matrix for diagnosing area 2

From the information provided in **Table 4.2**, it is suggested that the main diagnostic knowledge is to determine whether the list of parameters (misconceptions or conceptions) related to flow of current in a circuit is present or absent for any particular pupil. The relationships between the various conceptions or misconceptions then provides a means to determine the existence of a specific misconception model.

The lists of the parameters (conceptions) identified need to be coded into a form suitable for building the rule base. Since the main idea is to determine whether the conception is present or absent, it is proposed that the coding format is as follows:

Conception	Object-Code	Value
Current leaves both terminal	current_both_terminal	present/absent
Current leaves one end and returns to the other end ?	current_is_unidirection	present/absent
Current flows from negative to positive terminal	current_neg_pos	present/absent
Current flows from positive to negative terminal	current_pos_neg	present/absent

The Object-Code is a means to represent the conception in a form of variable which is suitable for building the diagnosis production rules in a later section (coding into Leonardo shell). The conceptions and their related object codes correspond to the questions used in this program.

The complete tabular matrices for this topic is listed in **Appendix D2**.

4.4.2 Diagnosis Production Rules

Expert system development is normally described as being evolutionary, incremental or interactive (Paul Beynon-Davies, 1992). The emphasis is on developing a small prototype of a system which has undergone a number of improving stages.

4.5 Stages of Prototype Development

4.5.1 Stage One

In developing rules in this program, the author applies the concept of incremental development. It began with a single rule that applies directly to the goal of the program 'DIAGNOSIS'. For example, from the tabular matrix listed in **Table 4.2**, an initial rule is build as follows:

Rule 1:

SEEK DIAGNOSIS

IF	current_both_terminal is absent
AND	current_is_unidirection is present
AND	current_neg_pos is present
THEN	misconception_model is 'Wrong Direction Model'
	diagnosis is done

When this rule is entered into the Leonardo knowledge base by using the shell's editor and then compiled, the shell automatically creates a list of objects related to the Rule 1 in the knowledge base. In this case, the objects created are:

current_both_terminal
current_neg_pos
current_is_unidirection
misconception_model
diagnosis

For each of the objects created, there is a related frame to store all the information or values regarding the specific object. For instance, the frame and default slot for the object "current_both_terminal" is shown in **Figure 4.1**. Several extra optional slots are also available.

When the program is executed, it poses a series of questions in order of a linear sequence about the premises of the rules.

Please enter a value for current_both_terminal
Please enter a value for current_is_unidirection
Please enter a value for current_neg_pos

When answer "absent" is supplied to the first question and answers "present" are supplied to the next two questions, the program displays the conclusion as:

diagnosis is done

By using the frame editor, the values' slot of the related objects can be checked. The values are listed as follow :

current_both_terminal	: absent
current_neg_pos	: present
current_is_unidirection	: present
misconception_model	: Wrong Direction Model
diagnosis	: done

For this particular example, as the pattern of answers supplied corresponds exactly with the initial rule stated above, the value slot of the misconception_model object frame is returned with " Wrong Direction Model ".

If the answers supplied are not in the pattern as described above, the program displays the conclusion as:

I am unable to draw any conclusion on the basis of the data

And the value slot of the misconception_model frame is blank.

Object Number : 137
Name: current_both_terminal

1 :	Name	: current_both_terminal
2 :	LongName	:
3 :	Type	: text
4 :	Value	:
5 :	Certainty	:
6 :	DerivedFrom	:
7 :	DefaultValue	:
8 :	FixedValue	: absent
9 :	AllowedValue	:
10 :	ComputeValue	:
11 :	OnError	:
12 :	QueryPrompt	:
13 :	QueryPreface	:
14 :	Expansion	:
15 :	Commentary	:
16 :	Introduction	:
17 :	Conclusion	:

Figure 4.1

Object frame and its slot value

With this small program of just one rule, the program manages to exhibit a simple diagnosis process. In order to extend the program capability, more rules could be added. The rules are derived from the complete tabular matrix as listed in **Appendix D2**. The complete diagnostic rule base for this topic is shown in **Figure 4.2**.

In order to expand the program beyond this simple stage and to mimic the real situation in the diagnosis process, some form of abstraction needs to be included or added to the program's knowledge base. In this case, abstraction is manifested by some form of intermediate rules that actually make inferences about the user's input.

For instance, in order to infer that "current_both_terminal" conception is present or absent, the program should be able to display some form of questions as is normally done in the diagnosis process in the classroom. By displaying the question, the program will be able to detect whether "current_both_terminal" conception is present or absent based on the user's answer.

The Leonardo development tool allows the question texts to be attached to the frame's slot attribute, which means that the exact question texts are displayed on the screen when the program needs to query the user for the value of an object. Although this facility is very convenient, the main problem is to display text (question) together with a graphic (diagram). At the same time, the program needs to display some form of prompt to accept the user's answer. In this application, it is necessary that the user interface part of the shell be refined and modified to make full use of the graphic's interface provided by the Leonardo Shell in order to enhance the features of the prototype program.

4.5.1.1 Graphic Screen

The Leonardo graphics package contains a number of useful graphics built-in procedures and functions. The position of the pixel on the screen is described by its X and Y co-ordinates in the matrix of pixels which makes up the screen. The X co-ordinate is the position of the pixel across the width of the screen and the Y co-ordinate is the position of the pixel down the height of the screen. The base co-ordinate for the screen is (0,0) which is the top left corner of the screen. The bottom right corner of the screen is the highest (X,Y) co-ordinate, which depends on the type of screen. For example, the maximum co-ordinate on an VGA screen is (639, 479).

In this prototype, the graphic screen has been divided into 4 main areas as shown in **Figure 4.3**.

DIAGNOSTIC PRODUCTION RULES

if battery_stored_current is present
and current_as_energy is present
then misconcept_model is 'current as entity'

if current_both_terminal is present
then misconcept_model is 'clashing model'

if bulb_used_current is present
and bulb_used_all_current is present
and other_term_passive is present
and current_both_terminal is absent
then misconcept_model is 'unipolar model'

if bulb_used_current is present
and term1_more_current_term2 is present
and bulb_used_part_current is present
and bulb1_bright_than_bulb2 is present
and current_both_terminal is absent
and bulb12_used_current is present
and r1_inc_bulb_dimmer is present
and r2_inc_bulb_same_bright is present
then misconcept_model is 'sequential model'

if current_both_terminal is absent
and current_neg_pos is present
and current_is_unidirection is present
then misconcept_model is 'wrong direction model'

if bulb1_same_bright_bulb2 is present
and bulb12_share_current is present
and 2bulb_dimmer_than_1bulb is present
and 2bulb_share_current is present
and current_both_terminal is absent
then misconcept_model is 'sharing model'

Figure 4.2

Diagnostic production rules

if current_both_terminal is absent
and current_is_unidirection is present
and current_neg_pos is present
and bulb1_dimmer_than_bulb2 is present
then misconcept_model is 'sequential model';
misconcept_model is 'wrong direction model'

if current_same_amt_D1D2 is present
and constant_current_source is present
then misconcept_model is 'battery as a constant source of current'

if battery_stored_current is absent
and current_from_pd is present
and current_both_terminal is absent
and current_pos_neg is present
and bulb_used_current is absent
and current_is_conserve is present
and bulb1_same_bright_bulb2 is present
and 2bulb_dimmer_than_1bulb is present
and current_is_unidirection is present
and 2bulb_share_current is absent
and current_same_amt_D1D2 is absent
and bulb12_share_current is absent
and r1_inc_bulb_dimmer is present
and r2_inc_bulb_dimmer is present
then misconcept_model is 'science model'

Figure 4.2

Diagnostic production rules (Continued)

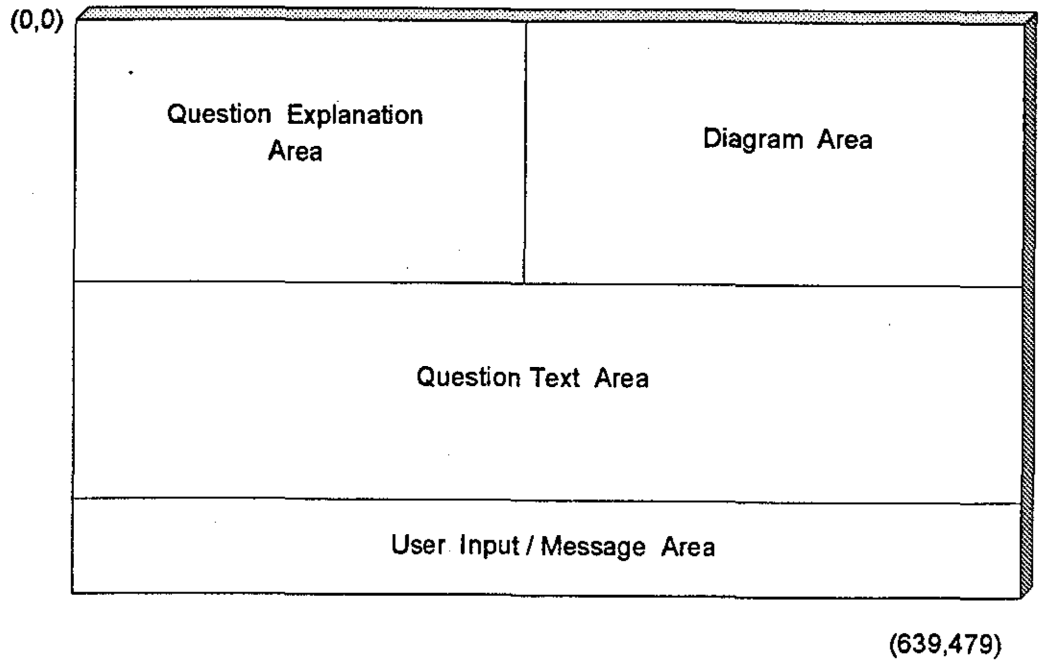


Figure 4.3
Display Screen Areas

1. Question Explanation Area

This area displays text to give an explanation about the question to the user.

2. Diagram Area

This area is used to display diagrams associated with the question.

3. Question Text Area

This area displays the question text.

4. User Input Area

This part of the screen is used for prompting user 's input, displaying the user 's answer and for error messages.

4.5.1.2 Question Text

Text for display in the Question Explanation Area and Question Area are stored outside the main program in a question data file. The question data file which is used in this program is created and edited by any text editor which produces an ASCII text file. Leonardo's routines read from the external text file and load the text into the appropriate position on the graphic screen. This facility provides a convenient way to edit or change the questions or to display questions of another topic while maintaining a standard screen design.

4.5.1.3 Question Diagram

The diagrams were drawn by using the Leonardo graphics package. This graphics package is comprised of a number of useful graphics built-in procedures and functions which are called into the program from the Procedural Programming Language. The procedures and functions provided include drawing of lines, circles, boxes and also filling an area with colour.

Three diagrams, shown in **Appendix D1**, have been designed for this topic.

4.5.2 Stage Two

In this second stage, the main modifications to the previous program are:

- Designing the multiple RuleSet system; and
- Branching of questions.

4.5.2.1 Designing The Multiple RuleSet system

In stage one, the principal components of the diagnostic program are identified and fully functional. In order to create a more efficient and sophisticated prototype program, the Main RuleSet needs to be modified. By using the principle of Leonardo's Multiple RuleSet, it is possible to modify the program to comprise a multiplicity of small modules. In other words, the knowledge base will contain a Main RuleSet and multiple RuleSets for the various objects. Each of these RuleSets (modules) has a specific function. According to Leonardo's user guide, this modular structure provides the following advantages to the knowledge base:

- A clearer overall structure of the program.
- Ease of on-going maintenance of the knowledge base.
- A faster compilation of the program.
- A more efficient execution of the program.

For example, the general Main RuleSet may consist of :

```
IF          rule_1 is done
AND         rule_2 is done
----------
----------
THEN        program is finished
```

In this simple illustration, the Main RuleSet refers to two objects, rule_1 and rule_2. There are no specific rules in the Main RuleSet to provide values for these objects. Instead, the rules which generate the required values are held in RuleSets' slot of the respective objects. In other words, in order to check that the object rule_1 is "done", the Main RuleSet has to proceed to the object frame's slot to perform the specific rules in the module. These specific rules in the module will then determine whether the rule_1 is "done" or not. If rule_1 is done (or "fire"), then this process continues to the next rule in the Main RuleSet. This Multiple Ruleset structure is shown in **Figure 4.4**.

By using the multiple RuleSet format, this prototype program utilised the advantages of a more elegant representation of knowledge as facilitated by the Leonardo expert system shell.

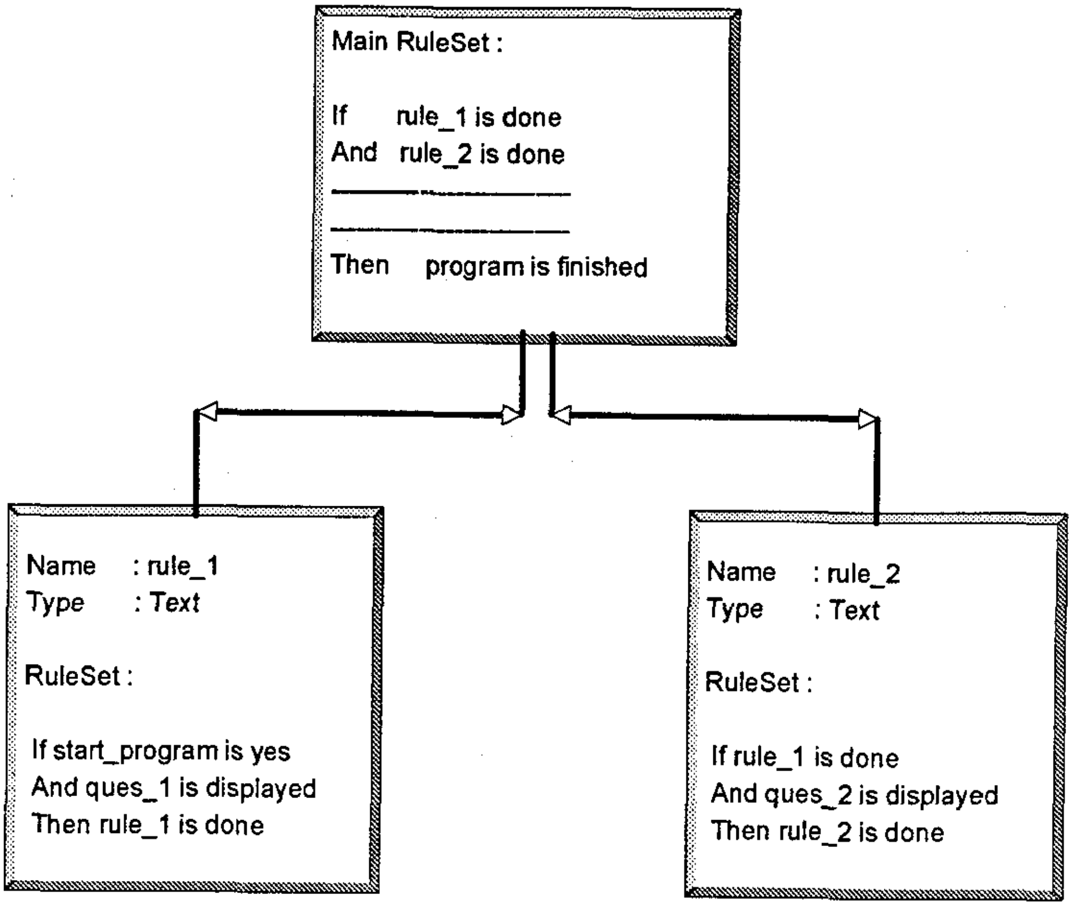


Figure 4.4

Main RuleSet With Two Subsidiary RuleSets

In the beginning of the second stage of development, the Main RuleSet consists of the following form of simple rules, that is :

IF	display_question is done	(displaying all diagnostic questions)
AND	answer_analysis is done	(analysing all the responses)
AND	misconception_model is finished	(determining the model of misconception)
THEN	diagnosis is finished	(diagnosis has been carried out successfully)

When the program is executed, it needs to determine whether "display_question" is done or not. Assuming at this stage that all the questions have been displayed by the program (this will be further discussed in next section), when the program has determined that the "display_question" is fired, it then proceeds to the next rule.

When the Main RuleSet needs to determine if the "answer_analysis is done", the flow of the program jumps to the RuleSet slot within the "answer_analysis" object. The RuleSet slot of this object contains the rules for analysing the question responses from the user. For example, for the answer to question 1:

Rule 1: check_ans1

```
if ans1 is "a"
then battery_stored_current is present;
check_ans1 is finished
if ans1 is "b" or ans1 is "x"
then check_ans1 is finished
```

When all the responses have been checked, the rule "answer_analysis is done" is fired. The program then returns to the MainRuleSet where the next rule needs to be analysed. The complete rules for analysis of responses to all the questions for this topic are listed in **Appendix D3**.

As in the previous case, in order to determine that the "misconception model is finished" or detected, the program needs to proceed to the specific diagnostic production rules' module as listed in **Figure 4.2**. After the misconception models are detected and the rule "misconception_model is finished" is fired in the module, the flow of the program then returns back to the MainRuleSet.

4.5.2.2 Branching of Questions

Another important modification at this stage is regarding the order of questions to be displayed. Basically, there are two ways of displaying the questions:

1. Linear Sequence

The conventional programmed instruction systems are mostly linearly sequenced. In this structure, every user steps through the identical materials in the identical sequence. The complex structure of programming in using the conventional software prohibits the developers from providing a sophisticated sequencing of materials in their programs.

2. Branching or Adaptive Sequence.

One of the good characteristics of a computer based application is the capability to provide multiple paths through a program (Steinberg, 1991). In this particular program, it is a good feature if the next sequence of questions to be displayed is based on the previous response. Expert system technology has the capacity and facility to implement this branching or adaptive strategy in an easier and more sophisticated way than conventional programming.

This adaptive capability also mimics the real questioning situation in a classroom where a human expert (the teacher) asks the next question based on the previous response of a pupil.

In this prototype, it is proposed that the order of questioning is based on a branching strategy. Although a complex Bayesian Probabilistic Model exists as proposed by Park and Tennyson (1983), it is still in the research stage and is not widely applied in real instructional settings (Steinberg, 1991). So it is proposed that a simple branching strategy be implemented in the prototype program which uses the simple if-then rule of the shell.

The concept used is illustrated as follows:

```
IF      display_Q1 is finished
AND     ans1 is "a"
THEN    display_Q2
        display_Q2 is finished

IF      display_Q1 is finished
AND     ans1 is "b"
```

THEN display_Q3
display_Q3 is finished

By placing this set of rules in the RuleSet of the "display_question" object, the program will, after accepting input for question number 1, check whether the answer to question 1 (ans1) is "a" or "b". If the answer is "a", then it will display question 2 next or if the answer is "b", it will display question 3 next.

This set of rules can be extended to include all the questions and their respective answers. The flowchart and complete set of question sequencing rules is listed in **Appendix D4**. The flowchart is drawn to make sure that the sequencing rules are complete as discussed in the program verification section.

In order to accommodate this branching capability, the question sequencing rules as listed in **Appendix D4** is placed in the RuleSet's slot of the "display_question" object.

4.5.3 Stage Three

At the end of stage two, the program is capable of diagnosing the user's answers to the branching sequence of questions. The models of misconception and the various values of objects detected during consultation are stored in the slots of the respective objects of the knowledge base. In this third stage of development, the aspect of how to display the result of the diagnosis to the user is discussed.

One simple way of providing feedback of the diagnosis results to the user is to display the models of misconception detected at the end of the diagnostic session. This strategy has been implemented in the DIAG program (Boohan, 1992). A procedure was written with Leonardo's Procedure Programming Language in order to read the value of "misconception_model" object in the knowledge base and then to be able to print it as hard copy, print to screen or print to file. Since it is possible that a pupil could have more than one model of misconception, this "misconception_model" object was set to be able to accommodate multiple values.

4.5.4 Stage Four

This last stage is concerned with the ability of the prototype program to repeat the execution of the knowledge base. This facility provides a convenient way for the program to be used continuously by a group of students rather than to start afresh for each student.

The proposed format is to display a menu which allows the user to select either to continue with consultation or to exit from it. In order to provide this facility, the MainRuleSet needs some modification by adding the following rule:

IF	askprint is done
AND	recycle is check
THEN	diagnosis is done

The object *recycle* has the value of "stop" or "continue". If the value of *recycle* is "stop", the execution of the program halts. Otherwise, the execution will continue if the value of *recycle* is "continue".

At the end of this last stage, the various modification to the Main RuleSet has been completed. A complete Main RuleSet of this program is listed in **Appendix D5**.

4.6 Building the User Interface

It is very important to have an interface that is user-friendly and easy to use, otherwise the program might fail to be used successfully. In other words, there is a need for good Human Computer Interaction.

In this prototype program, several aspects of user friendly interfaces have been proposed to be included into the program. These are :

1. During consultation with the program, the screen display is divided into four main sections or areas. This form of screen layout can facilitate the user understanding of the question by directing the user's attention to the main part of the screen.

2. Interactive environment: The program is not only capable of displaying questions, but also judges the users' responses. The program has been designed to provide appropriate feedback to different responses. For example, if a question has only two alternative answers (A or B) and if the user responds by hitting another key (for example, C), the program will make a bell sound and display a message or prompt to draw the mistake to the user's attention.

3. The diagrams used in the screen layout of this program can facilitate question comprehension.

4. The printing facility of this program provides three forms of printout, that is as a hard copy, print to a file, or just print to the screen.

4.7 The Structure of the Prototype Program

The following is the description of the proposed diagnostic program. It consists of four major parts.

1. The initialisation unit

The initialisation unit starts the program by displaying a welcome screen describing the purpose of the program. It then prompts for a user name.

2. The input unit.

The input unit displays a series of questions which branch according to the user's answer to the previous question. The user is required to press a key corresponding to the choices provided by the question. If there is a key-in error in the user's input, the user is reminded of the mistake and then the program waits for a new input.

3. The diagnosis unit

Every time the user gives an answer to a specific question, the program places a value of either present or absent to the corresponding conceptions and misconceptions. Based on the collection of user's conceptions and misconceptions, the program checks every rule in the rule-base of the program. It then matches them with the suitable models of misconception.

4. The output unit

The output unit provides feedback to the user. Three output alternatives are provided that is to print as hard copy, print to screen, or print to file. Each alternative will show a collection of a student's conceptions or misconceptions. It then asks whether the user wishes to continue with the consultation. If yes, the program is returned to the input unit. Otherwise, the consultation finishes with a conclusion screen.

The complete structure of the prototype program is shown in flowchart form in **Figure 4.5**. Several snapshots of the program's screen are shown in **Appendix D6**.

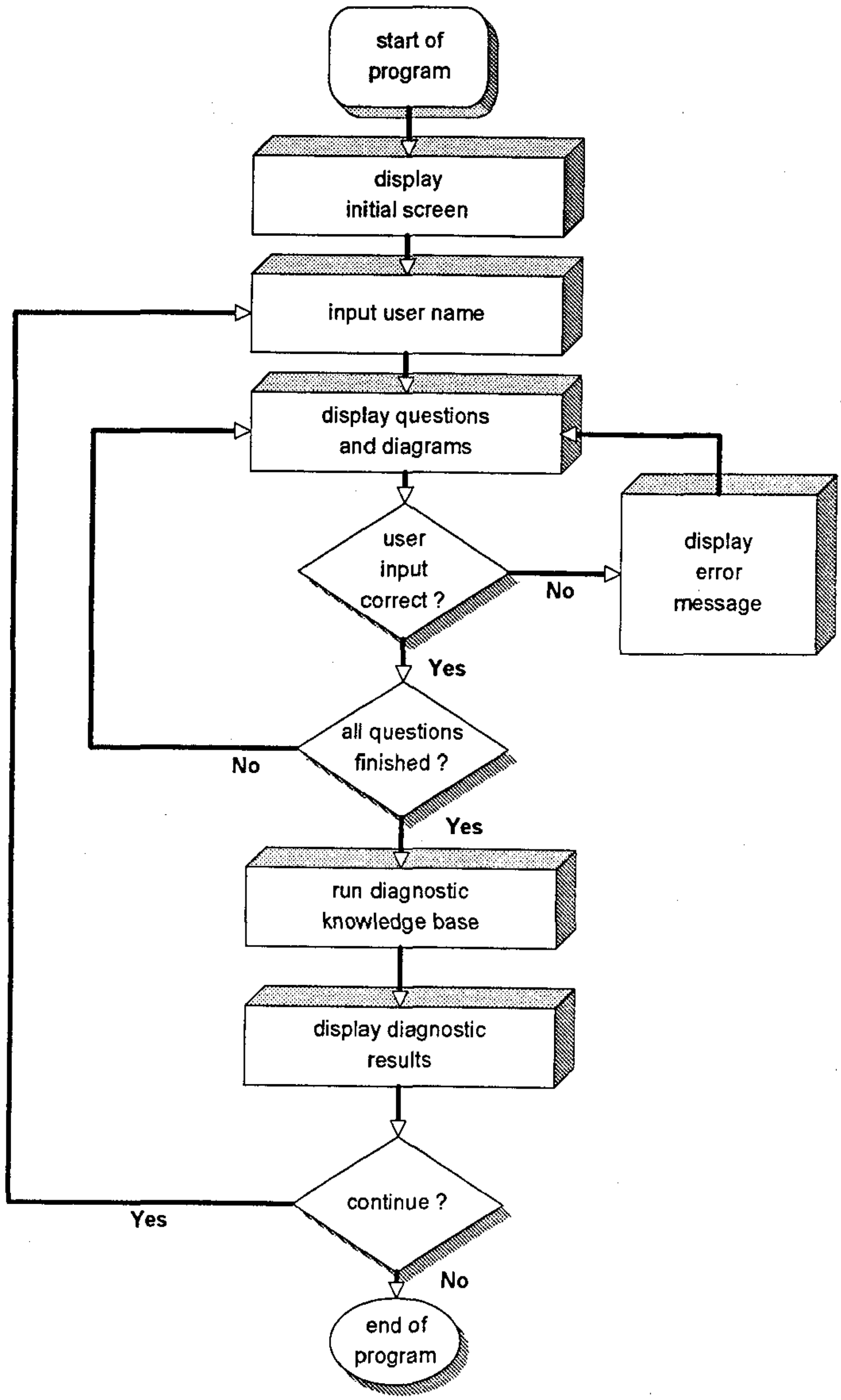


Figure 4.5 : Structure of the prototype system

4.8 *Evaluation of the Prototype Program*

Two forms of simple studies have been carried out as an initial evaluation of the prototype program. In the first case, a group of students and a teacher from a local college were asked to use the program. The next evaluator was a science education lecturer from a university.

A small pilot study was carried out with eight pupils and a teacher from a local college. This study was carried out by using a stand-alone microcomputer with a colour monitor. The purposes of this study were clearly explained to the students and teacher before they started using the program. The objectives of this pilot study were:

1. to evaluate the usability of the program; and
2. to detect any bugs in the program.

In terms of the usability of the program, it is perceived that the users experienced little difficulty in using the program as a whole. Specifically, it is observed that the users managed to :

- key in their answers to the questions quite easily except that some users showed difficulty in locating the correct keys on the computer keyboard corresponding to the letters "A", "B" and "C" used in the alternative answers to the questions;
- readily read the textual information and graphics displayed on the screen; and
- responded correctly to the program's prompts.

With the exception of the method of lettering the alternative answers to the questions, which may need to be reviewed, this study generally showed that the user interface objectives part of the program has been achieved.

A small bug was detected during the try out. It is related to the way the program accepts the input of the user's name and then tries to create a text data file based on that particular user's name. In order to successfully create the data file, the user's name must be limited to a maximum of eight characters.

The responses from the students and teacher during execution of the program were stored in the form of several text files. A simple analysis was carried out on these responses and the result is shown in **Table 4.3**. This data provides a way for the author to make a simple comparison with respect to the capability of the program to detect misconceptions with the

Object Code	Question	P1	P2	P3	P4	P5	P6	P7	P8	T1
battery_stored_current	1(a)	1	1	1	1	1	1	1	1	0
current_as_energy	1(b)	0	1	1	1	0	0	0	0	0
current_from_pd	1(c)	0	0	0	0	0	0	0	0	0
current_from energy	1(c)	0	0	0	0	0	0	0	0	1
current_both_terminal	1(d)	1	0	0	0	0	0	0	0	0
bulb_used_current	1(e)	1	1	1	1	1	1	0	0	0
term1_more_current_term2	1(f)	0	1	1	1	1	1	0	0	0
bulb_used_all_current	1(g)	1	0	0	0	0	0	0	0	0
bulb_used_part_current	1(g)	0	1	1	1	1	1	0	0	0
other_term_passive	1(h)	0	0	0	0	0	0	0	0	0
current_is_conserve	1(i)	0	0	0	0	0	0	1	2	1
current_is_unidirection	1(j)	0	1	1	1	1	1	1	1	1
current_pos_neg	1(k)	0	1	1	1	1	1	1	1	1
current_neg_pos	1(k)	0	0	0	0	0	0	0	0	0
2bulb_bright_than_1bulb	2(a)	0	0	0	0	0	0	0	0	0
2bulb_dimmer_than_1bulb	2(a)	1	1	1	1	1	1	1	1	1
2bulb_same_bright_1bulb	2(a)	0	0	0	0	0	0	0	0	0
2bulb_share_current	2(b)	1	1	1	1	1	1	0	1	0
current_same_amt_d1d2	2(c)	1	1	1	1	1	1	1	1	0
constant_current_source	2(d)	0	0	0	0	0	0	0	0	0
bulb1_bright_than_bulb2	2(e)	0	0	0	0	0	0	0	0	0
bulb1_dimmer_than_bulb2	2(e)	0	0	0	0	0	0	0	0	0
bulb1_same_bright_bulb2	2(e)	1	1	1	1	1	1	1	1	1
bulb12_share_current	2(f)	1	0	1	1	0	1	1	1	0
bulb12_used_current	2(g)	0	0	0	0	0	0	0	0	0
r1_inc_bulb_brighter	3(a)	0	0	0	0	0	0	0	1	0
r1_inc_bulb_dimmer	3(a)	1	0	1	1	1	1	1	0	1
r1_inc_bulb_same_bright	3(a)	0	1	0	0	0	0	0	0	0
r2_inc_bulb_brighter	3(b)	0	0	0	0	0	1	0	0	0
r2_inc_bulb_dimmer	3(b)	1	1	0	0	0	0	1	0	1
r2_inc_bulb_same_bright	3(b)	0	0	1	1	1	0	0	1	0
Misconception Model(s)		C	E	E,S	E,S	X	S	X	E,S	X

Keys:
1 : Present
0 : Absent
2 : Not Sure

Sample:
P1-P8 : Pupils
T1 : Teacher

Misconception Models:

C : Clashing Model
Z : Science Model
E : Current as Entity
U : Unipolar Model
B : Battery as a Constant Source of Current
W : Wrong Direction
X : No Specific Model
S : Sharing Model
Q : Sequential Model

Table 4.3

Summary of pilot study data

results from previous studies in science misconception. Several important preliminary aspects found from the analysis are discussed below

1. Generally this study confirmed the existence of the form of misconceptions found in previous studies in basic electricity.

2. One interesting phenomenon is the existence of contradictory ideas in the students' conceptions. These contradictory ideas result in the failure of the program to suggest any specific model. For example a number of students, in the case of question 1(e) (one bulb in a circuit), answered that the bulb used current as it flows through it. When answering question 2(e) (two bulbs in series), they hold the idea that the two bulbs are of the same brightness. This second idea clearly contradicts the first idea.

3. With respect to the teacher's responses, it was found that the responses are consistent with the "science model" except regarding the question 1(e) where there is a confusion about the wording of the question.

One important consequence from this analysis is that there is a need to modify the knowledge base of the prototype program to provide a deeper link between the various forms of misconception diagnostic rules. This deeper link will hopefully accommodate the various contradictory ideas in the users' conceptions.

This prototype program was also reviewed by a science education lecturer from a university. The specific areas reviewed were:

1. The wording and format of the questions

From this review, it is suggested that some wording of the questions used in the program need to be changed. This will hopefully make the questions more precise and accurate in order to probe the users' conceptions. The format of some of the questions also needs to be modified to allow greater user understanding. For example, rather than just using the alternative answers as "yes" or "no", it is suggested that the format is changed to a normal type of multiple-choice responses.

2. The branching capability of the program with respect to the order of question display.

There is an argument regarding the branching feature of the program. The evaluator suggested that in order to give a fairer diagnostic test, the order of question displays should be linearly sequenced. The author believes that the branching feature of the program is in line with the notion of the diagnostic researchers' expertise to guide and narrow down the diagnostic process onto a specific conception which is being probed. This feature also forms a basis for a complete intelligent computerised adaptive testing as suggested by Olsen (1990). Since expert system technology provides a relatively easy format to carry out this branching feature, it is proposed that this feature be included in the prototype program.

4.9 *Modification of The Prototype Program*

Based on the results of the pilot study, several aspects of the prototype program have been proposed to be modified for the purpose of further school-based evaluation.

1. It could be argued that the type of feedback as used by Boohan (1992), which displays the models of misconception at the end of the session, only provides a surface level of feedback information. It is possible that a complete model is not detected because not all characteristics of that specific model are present in the student's mind. The alternative strategy is to provide feedback in the form of a descriptive student's knowledge profile. This profile consists of a description of each student's conception and misconception for all the questions. This method of profiling has been used by Nachmias and his colleague (1990) in their microcomputer-based diagnostic system.

The new complete descriptive feedback for the topic of basic electricity is listed in **Appendix D7**.

2. For the development of further diagnostic topics (chapter 5), more standard multiple-choice stems are proposed to be used.

CHAPTER 5

EXTENDING WITH TWO MORE TOPICS

5.1 Overview

Two further topics were developed with the intentions of experimenting and exploring the capability of the prototype system with different topics. The two selected topics were:

5.1.1 Speed and Graphs

This speed and graphs topic is a sub-topic within the main Linear Motion section in a Physics Syllabus. One of the objectives for this topic is for pupils to interpret the motion of an object by using a simple graph. The ability to interpret graphs is an important criterion in developing an understanding of many topics in physics. There exist a number of investigations into pupil's understanding of graphs interpretation reported in the literature (for example, Swatton and Taylor, 1994; Padilla et al., 1985).

Within the development of the expert system diagnostic system, this topic provides a way to diagnose some of the errors in graph interpretation made by the student. At the same time, it can be used to exploit and examine the graphical capability of the shell.

5.1.2 Floating and Sinking

Selley (1993) reported that in a buoyancy explanation of an object floating or sinking in water, there is a stage in the development of understanding of this phenomenon when a pupil puts forward the following hypotheses in reasoning why an object floats :

- objects float if they contain enough air
- objects float if they are light

For this topic, a strategy that uses the 'incomplete reasoning knowledge' is suggested to be employed for this topic. In this strategy, any specific response that indicates an understanding of a particular reasoning pattern will cause the probability of that particular reasoning to occur to be increased. In other words, it does not depend on a clear and 'completely consistent' pattern of reasoning in order to reach a decision. Since it is expected that not all pupils usually have a clear and consistent reasoning pattern in understanding a specific concept, this strategy is suitable for this topic in order to make a decision between the two groups of reasoning as stated above. In this perspective, the 'certainty factors' feature, which is a common feature of expert system shells, will be used.

For both topics, the overall structure of the prototype system was kept intact to ensure consistency of user interface. Only the diagnosis rule base, feedback descriptive texts, and the questions controlling rule were changed to represent the new information.

5.2 Speed and Graphs

5.2.1 Diagnosis Area

The diagnosis area for the topic of Speed and Graphs included in the expert system's knowledge base can be generalised into 6 main areas.

1. Interpreting a series of dot positions on a ticker-time tape in order to determine whether an object is moving with steady, increasing or decreasing speed.

2. Interpreting two sets of series of dot positions on two ticker-timer tapes in order to compare the relative motion of two objects.

3. Interpreting two sets of series of dot positions on two ticker-timer tapes to determine whether two objects are ever travelling at a same speed.

4. Diagnosing the pupil's understanding in interpreting the motion of an object represented by various positions of slopes on a distance-time graph.

5(i). Diagnosing the pupil's tendency in using the 'position' criterion when interpreting intercepting and non-intercepting lines on a distance-time graph, that is whether two objects are ever at the same place at the same time.

5(ii). Diagnosing the pupil's tendency in using the 'position' criterion when interpreting intercepting and non-intercepting lines on a distance-time graph, that is whether two objects are ever travelling at the same speed.

5(iii).Diagnosing the pupil's tendency in using the 'position' criterion when interpreting two parallel line graphs on a distance-time graph. That is whether two objects are ever travelling at the same speed.

6. Diagnosing the pupil's understanding in determining the points where the motion is slowest and the object is turning around by interpreting a variable line graph on a distance-time graph.

5.2.2 Set of Questions

There are 22 multiple-choice questions with 2, 3 or 4 alternative answers developed for this topic. Grouping of questions with respect to the diagnostic areas described in section 5.2.1 is listed in **Table 5.1**.

Diagnostic Area	Question Number
1	1(A), 1(B), 1(C)
2	2(A), 2(B), 2(C)
3	3(A), 3(B)
4	4(A), 4(B), 4(C)
5(i)	5(A), 5(B), 5(E), 5(F)
5(ii)	5(C), 5(D), 5(G), 5(H)
5(iii)	5(I)
6	6(A), 6(B)

Table 5.1 Grouping of questions according to the diagnostic areas

The complete list of questions used in the question bank for this topic can be found in **Appendix E1**.

5.2.3 Questioning Format

The branching format of questioning is used in the test. With this respect, some of the questions will not be answered by every pupil. The flowchart and rules for questions sequencing is listed in **Appendix E2**.

5.2.4 Knowledge Representation

To refine the diagnostic knowledge into a rule-based format suitable for expert system application, a tabular matrix was constructed for each diagnostic area as describe in section 5.2.1

For example, a tabular matrix for diagnosing area (4) is listed below.

Rule	Parameters			
	Slope Ascending	Slope Descending	Horizontal	
Rule 4(a): Speed is ...	increasing	decreasing	constant	Descriptive 4(A)
Rule 4(b): Speed is ...	constant	constant	constant	Descriptive 4(B)
Rule 4(c): Speed is ...	decreasing	increasing	constant.	Descriptive 4(C)

Table 5.2 Tabular matrix for diagnostic area 4

The form of general rule derived from the above tabular matrix is :

IF	speed is increasing when slope is ascending
AND	speed is decreasing when slope is descending
AND	speed is constant when slope is horizontal
THEN	shows descriptive A

This form of rule could then be extended to include all the options as listed in the tabular matrix.

Descriptive A is in the form of a descriptive feedback regarding the conception of the pupil in the specific area. For this case, the descriptive feedback is :

1. *When the slope is positive, the speed of object is increasing.*
2. *When the slope is negative, the speed of object is decreasing.*
3. *When the slope is horizontal, the speed of object is constant.*

Conclusion: *There is a relation between slope of graph and change of speed.*

The complete tabular matrices of knowledge representation for this topic is listed in **Appendix E3**. The complete diagnosing rules suitable for coding into the expert system shell for this topic is listed in **Appendix E4**. The complete descriptive feedback for this topic is listed in **Appendix E5**.

5.3 Floating and Sinking

5.3.1 Diagnostic Area

An expert system diagnosis program was developed for classifying pupil into either of these three groups:

1. "heaviness or lightness" reasoning group
2. "amount of air contained" reasoning group
3. indecisive group

5.3.2 Set of Questions

There are 19 multiple-choice questions with 2 or 3 alternative answers developed for this topic. The questions are grouped into following headings:

1. Testing pupil understanding in hypothesising whether a sealed glass bottle full of air will float or sink in water. Reason of the choice is requested.

2. If the pupil responded that the glass bottle will sink in 1, testing further the understanding with a smaller glass bottle and plastic bottle.

3. Pupil understanding is further explored by adding sand into the glass bottle.

4. Test whether pupils agree or disagree with general statements regarding the effect of "heaviness or lightness" and "amount of air contained" on object's sinking or floating on water.

5. After the program made a decision whether a pupil is grouped into "heaviness or lightness" reasoning or "amount of air contained" reasoning, several extra questions

were posed in order to explore further pupil understanding with regards to the diagnosed choice.

The complete list of questions used in the question bank for this topic can be found in **Appendix E6**. Grouping of questions with respect to the respective headings is listed in **Table 5.3**.

Heading	Question Number
1	1(A), 1(B), 1(C), 1(F)
2	1(D), 1(E)
3	2(A), 2(B), 2(C), 2(D)
4	2(E), 2(F), 2(G)
5	3(A), 3(B), 3(C), 3(D), 4(A), 4(B)

Table 5.3 Grouping of questions according to diagnostic heading

5.3.3 Questioning Format

The branching format of questioning is used in the test. With this respect, some of the questions will not be answered by every pupil. The flowchart and rules for questions sequencing is listed in **Appendix E7**.

5.3.4 Knowledge Representation

For this topic, the diagnostic knowledge base was built with the objective of determining to which of the two groups of reasoning (as described above) a pupil belongs, by referring to the pattern of responses to the pre-set questions. If the overall pattern of the responses did not firmly show any hint toward any particular group, the program then suggests that it could not make a decision.

In order to reach a decision, the program normally requires a complete pattern of reasoning for each case. Since it is expected that not all pupils usually have a clear and consistent reasoning pattern in understanding this specific concept, the diagnosis rule which uses an 'incomplete reasoning pattern' is proposed. This strategy will allow the program to be able to make a decision although there is no complete pattern of reasoning in the pupil's responses to the questions.

5.3.4.1 Certainty Factors Knowledge Representation

In this approach, a response that shows an understanding of a specific reasoning pattern will cause the probability of that particular reasoning to be increased. Finally, the probabilities of the various reasoning patterns will be compared with each other in order to reach a decision. In other words, the rule does not require a clear and 'completely consistent' pattern of reasoning in order to reach a specific decision.

The diagnosis rule employed the 'certainty factors' feature of Leonardo expert system shell. According to the Leonardo Tutorial book (Software Directions, 1992),

Certainty factors are an ad hoc method for dealing with uncertainty. Unlike Bayesian Logic, there is no underlying body of mathematics for explaining certainty factors. Certainty factors are a subjective method for assigning certainty to a value backed by an arithmetic for manipulating the certainties.

In order to employ the certainty factors strategy, two certainty index values are used in the diagnosis knowledge base. The values are :

- "Heaviness/lightness" certainty index (HI)
- "Amount of air" certainty index (AI)

For every related response that corresponds with the "heaviness or lightness" reasoning, the program will then increase the certainty index of HI. Likewise, for every related response that corresponds with the "amount of air" reasoning, the program will increase the certainty index of AI. In this program, the certainty index for each related response was set initially to a value of 0.5.

The general syntax for the certainty factor rule is as follows:

IF	response showing 'heaviness or lightness' reasoning is detected
THEN	reasoning is HI {certainty factor increased by 0.5}
AND	reasoning is AI {certainty factor increased by 0.0}

IF	response showing 'amount of air' reasoning is detected
THEN	reasoning is AI {certainty factor increased by 0.5}
AND	reasoning is HI {certainty factor increased by 0.0}

For example, if all or nearly all of a pupil's responses indicated a 'heaviness or lightness' reasoning, then the value of HI will be much greater than the value of AI. This happens because the certainty factor for the HI will be incrementally accumulated for each response that indicates 'heaviness or lightness' reasoning, whereas the value of AI will be zero or very small.

Only certain questions in the question bank were set to affect the value of HI and AI. This was logically correct as only those questions that asked for the reason of why the object floats or sinks will determine the classification group. **Table 5.4** shows the relationship between the responses to questions and the certainty index. For example, for the question 1(F):

If the reason given for the bottle to float is "it is lighter", then the HI will increase by 0.5 and AI will not be increased. Similarly if the reason is "it is full of air", then the AI will increase by 0.5 and HI will not be increased.

5.3.4.2 Diagnosis Rule

The diagnosis rule-base was developed from the above knowledge matrix. For example,

for question 1(C):

IF	bottle sinks because it is heavy
THEN	HI increased by 0.5 and AI increased by 0.0
IF	bottle sinks because it is made of glass and glass sinks in water
THEN	HI increased by 0.5 and AI increased by 0.0
IF	bottle sinks because of other reason
THEN	HI increased by 0.0 and AI increased by 0.0

Question	Reason	HI	AI
1(C) Why bottle sinks ?	It is heavy It is made of glass Other reason	0.5 0.5 0.0	0.0 0.0 0.0
1(D) Smaller bottle will float ?	Smaller bottle floats Smaller bottle not float Not sure	0.5 0.0 0.0	0.0 0.0 0.0
1(E) Plastic bottle will float ?	Plastic bottle floats Plastic bottle not float Not sure	0.5 0.0 0.0	0.0 0.0 0.0
1(F) Why bottle floats ?	It is lighter It is full of air Other reason	0.5 0.0 0.0	0.0 0.5 0.0
2(B) Why bottle (with sand) floats ?	It still has enough air Not enough sand Other reason	0.0 0.5 0.0	0.5 0.0 0.0
2(D) Why bottle (with sand) sinks ?	It is heavier Not enough air	0.5 0.0	0.0 0.5
2(E) Statement : "heaviness" or "lightness" causes object to sink or float.	Agree Not agree	0.5 0.0	0.0 0.0
2(G) Statement : "amount of contained" inside causes object to sink or float.	Agree Not agree	0.0 0.0	0.5 0.0

Table 5.4 Relationship between the responses to questions and the certainty index

For question 2(D)

IF	bottle (with sand) sinks because it is heavier
THEN	HI increased by 0.5 and AI increased by 0.0
IF	bottle (with sand) sinks because not enough air inside
THEN	HI increased by 0.0 and AI increased by 0.5

The complete diagnostic rules for this topic is listed in **Appendix E8**.

5.3.4.3 Classification Rule

For the case where the pupil's responses indicates a clear and complete pattern of reasoning for a particular group, the value of the certainty factor for that particular reasoning group will clearly be greater than the value of the certainty factor of the other group. In this case, a decision can easily be made. A problem will arise for the case where the values of the two certainty factors are not much different. The question of how much difference there needs to be between the two values of certainty factor for the program to be able to make a decision for either group needs to be decided. In this case, a cut-off value is suggested. If the differences between the two values of certainty factor is below the cut-off value, then the program should return an indecisive response.

In order to be able to make a decision, a cut-off number is suggested for the absolute difference between HI and AI. In this program, an arbitrary cut-off number is set at 0.35. That is the absolute difference between HI and AI must be greater than 0.35 for the program to be able to make a decision. If the absolute difference is equal to or less than 0.35, the program could not form a decision with regard to the two possible groups. The difference value was chosen from trial and error after a test run with sample hypothetical answers based on the author's experience which was carried out in the development stage. This value was later validated with the real pupil answers collected during school trials.

In this program, the classification rule is generally stated as follows:

IF	HI is greater than AI by more than 0.35 THEN case is "heaviness or lightness" reasoning
IF	AI is greater than HI by more than 0.35 THEN case is "amount of air contained" reasoning
IF	absolute(HI-AI) is less or equal then 0.35 THEN case is "undecided"

The complete classification rule is listed in **Appendix E9**.

5.3.5 Descriptive Feedback

For this topic, the descriptive feedback consists of three forms.

1. For the "heaviness or lightness" reasoning, the descriptive feedback is :

> Diagnostic Test: Floating and Sinking
>
> ------------------------------------
>
> Date:
> Student Name:
>
> This program detected that you believe :
>
> HEAVINESS
>
> is the reason that causes objects to float or sink in water.

2. For the "amount of air contained" reasoning, the descriptive feedback is :

> Diagnostic Test: Floating and Sinking
>
> ------------------------------------
>
> Date:
> Student Name:
>
> This program detected that you believe :
>
> AMOUNT OF AIR CONTAINED
>
> is the reason that causes objects to float or sink in water.

3. For the either of the above reasoning, the descriptive feedback is :

<table>
<tr><td>

Diagnostic Test: Floating and Sinking

Date:
Student Name:

This program COULD NOT detect any specific reason between :

HEAVINESS AND AMOUNT OF AIR CONTAINED

</td></tr>
</table>

CHAPTER 6

EVALUATION OF THE PROTOTYPE PROGRAM WITH PUPILS' PERFORMANCE

6.1 Overview

The purpose of this analysis was to assess the quality of the diagnosis carried out by the system, and the reliability of its results. It forms a basis for summarising the performance of the expert system in diagnosing pupil misconception.

Some caution must be considered when interpreting the data. As always in a testing situation, it is assumed that what the pupil gave as an answer to a given question represents the real understanding of pupil in that specific concept. No further investigation has been taken in this research to probe the pupil's understanding in detail. This strategy is in line with the objective of the research, as it is the program that was under investigation, not the pupil. No attempt was made to classify the sample into for example age groups or class groups as it is justified from the literature that this form of science misconception is prevalent across all age groups (Driver, 1984). It is important to state that, although this study does not attempt to replicate the previous study of diagnosing student misconception, this analysis will provide a way to prove that the prototype program in general is successful in being able to be used as a diagnostic tool.

6. 2 Evaluation Methodology

6.2.1 Method of Data Collection

The sample consisted of thirty pupils from two locally situated secondary schools, their ages ranging from 14 years to 16 years old. The sample used the program individually on a single personal computer. All the pupils were hand picked by their classroom teachers. No specific criterion has been specified to the teachers, except that the sample should cover a range of ability. Each pupil was given a brief description of what they were to do and what to expect. It was made clear that it was the program under test rather than the pupil. The pupils were encouraged to think carefully before answering, to take as long as they wished and any difficulties were to be taken as shortcomings of the system.

As the pupil used the program, all the correspondence between the pupil and the program was logged automatically into two text files. One file was used to accumulatively store all the pupils' answers to all the questions for each topic. Pupil name and time/date of use are used as an index of reference. These data were then coded into the SPSS statistical package for further analysis. Two simple analyses of frequency distribution and cross-tabulation were carried out with the data. Another text file was used to store the result of the program diagnosis for each pupil.

6.2.2 Method of Analysis of Results

The analysis for each topic was carried out using two separate but related methods.

1. The general pattern of pupils' responses to all the questions

This analysis was carried out in order to show that the questions used in the program were valid and capable of eliciting pupils' understanding in a particular topic. It also provided a means of confirming the existence of the misconception in a specific topic as reported in the literature. The various inter-connections between the responses could be detected and considered for future inclusion into the program's knowledge base.

2. Typical sample of individual pupil's responses

This section provided an analysis of the pattern of a number of typical pupils' answers and diagnostic feedback as a method of showing how a pupil interacted with the program. This was carried out by showing the program feedback or diagnostic result, the pupil's answers to all the questions and a descriptive illustration of the interaction. The data for this analysis was obtained from the program diagnosis feedback which logged the pupils' profiles as they used the system. This analysis also provided the author with a means to make a diagnosis using his own judgement (not the computer rule) on all the responses and to compare it with the computer's diagnosis.

The complete lists of pupils' responses for all the diagnostic topics are shown in **Appendix F1**.

6.3 Results of Analysis by Topics

The analysis was carried out for each of the three diagnosis topics developed in the prototype program. For each topic, the structure of analysis was according to methods described in section 6.2.1. The topics were :

- Electricity
- Speed and Graphs
- Sinking and Floating

6.3.1 Table Notation

Where appropriate, symbols are used in the table to represent the following meaning :

" x " : the specific pupil was not prompted with the question due to the adaptive feature of the questioning.

" - " : not applicable

6. 4 *Electricity*

Summary of characteristics of questions on electricity :

- The test consisted of 17 multiple choice questions with 2 or 3 alternatives answers. The complete list of questions is shown in **Appendix D1**.
- The branching format of questioning is used in the test. With this respect, some of the questions will not be answered by every pupil.
- The test involved understanding of these following concepts:

1. Source of current;
2. Flow of current in a series circuit;
3. Conservation of current in a circuit;
4. Brightness of bulbs in a simple series circuit :
   (a) Comparing of identical circuit with one bulb and two bulbs;
   (b) Comparing two bulbs in a series circuit; and
5. Function of resistor in a simple series circuit.

In this analysis, questions are grouped according to the above statements.

6.4.1 The General Pattern of Pupils' Responses to All the Questions

1. Source of current

Question	Answer			Total
	a	b	x	
1(A)	16	14	-	30
1(B)	8	8	14	30
1(C)	13	1	16	30

Table 6.4.1

The data in **Table 6.4.1** shows that 16 pupils believed that current flowing in the circuit is stored in the battery. Out of these 16 pupils, 8 pupils believed that the current is stored in the battery the same as the energy is stored in the battery. Whereas, 8 pupils do not believe this. Of the remaining 14 pupils who believed that current is NOT stored in the battery, 13 pupils answered that potential differences (voltage) in the battery cause the current to flow in the circuit. Only one answered the energy in the battery caused the current flows.

Summary :

These results are consistent with the previous studies. For example :

- the battery is a source of current (McDermott and Zee, 1984).
- the current and energy mean roughly the same thing. Energy in the form of current is stored in the battery and is transmitted by a wire to a bulb (Karrqvist, 1984).

2. Flow of current in a serial circuit

Question	Answer			Total
	a	b	x	
1(D)	3	27	-	30
1(J)	27	0	3	30
1(K)	21	6	3	30

Table 6.4.2

Question 1(D), 1(J) and 1(K) are trying to diagnose pupils' understanding about the flow of current in a simple circuit. As shown in **Table 6.4.2**, out of the 30 pupils, 27 pupils have a correct understanding of current flowing by leaving one end of the battery and then return to the other end. But only 21 out of these 27 pupils answered that current is flowing from the positive terminal to the negative terminal. Six pupils may have a confused idea between the flow of current and the flow of electrons in the circuit. Interestingly, the program detects 3 pupils having the common misconception of current flowing from both terminals and meet in the bulb to make it glow.

Summary :

These results are consistent with the results of previous studies, for example :

- current leaves the battery through both terminals (Osborne, 1983; Shipstone, 1988). This form of misconception is known as Clashing Currents.

3. Conservation of current in a circuit

Question	Answer				Total
	a	b	c	x	
1(E)	15	15	-	-	30
1(G)	3	12	-	15	30
1(F)	8	4	-	18	30
1(H)	-	3	-	27	30
1(I)	10	3	2	15	30

Table 6.4.3

Questions 1(E), 1(F) and 1(G) related to the common misconception in electricity, that is "does the current get consumed as it flows through the bulb ?" The program detected that half of the total sample have this misconception. 12 of those pupils believed that only part of the current is consumed, while only 3 pupils believed that all the current was consumed by the bulb. Quite confusingly, out of the 12 pupils who answered that current is consumed, only 8 pupils believed that more current is leaving one end of the battery than returns to the other end. Only 3 pupils do not believe this should be the case.

Question 1(H) is related to question 1(G). When pupils answered that the bulb consumed all the current, the function of question 8 is to test whether pupils believed that the wire to the other side of the bulb is passive (no current flows through it). All the 3 pupils who answered "a" in question 1(G) still believed that there is current in the other part of the wire.

Question 1(I) is related to question 1(E). Out of the 15 pupils who answered that current is NOT consumed as it flows through the bulb, 10 believed that the amount of current entering the bulb is the SAME as the amount of current leaving the bulb, while 3 answered NOT the same and 2 pupils were not sure.

Summary :

This result is highly in agreement with previous studies (for example, Karrqvist, 1984) that current is used up as it flows through the bulb. A number of pupils believed that, although current is consumed, the amount of current leaving one end of battery is still the same as the amount of current returning to the other end. Similarly, a number of pupils believed that current is not consumed, but did not agree or were not sure that the amount of current entering the bulb is the same as the amount of current leaving it.

There were some contradictory responses from the pupils as described above for question 1(G) and 1(H). A number of pupils still believed that there is still current in all parts of the circuit, although they responded that all the current is used up by the bulb. An explanation for this contradiction is that the pupil could be one of the total 3 pupils who believed that the current leaves both ends of the battery terminal. A further analysis with the cross-tabulation for pupils answering 'a' to question 1(D) (current leaves both end of the battery terminal) revealed that only one pupil who believed that some current still exists in the other part of the wire and at the same time believed that the bulb used up all the current.

Cross-tabulation for question 1(G) and 1(H) with answer to question 1(D) is "a" (Total =3 pupils) is shown in **Table 6.4.4**.

1(G)	a	b	x	Total
1(H)				
a	0	0	0	0
b	1	0	0	1
x	0	1	1	2
Total	1	1	1	3

Table 6.4.4

4. Brightness of bulbs in a simple serial circuit

4a. Comparison of identical circuits but with one bulb and two bulbs

Question	Answer				Total
	a	b	c	x	
2(A)	1	23	6	-	30
2(B)	17	5	1	7	30
2(C)	22	6	2	-	30
2(D)	4	-	2	24	30

Table 6.4.5

Questions 2(A), 2(B), 2(C) and 2(D) are used to diagnose pupils' understanding when comparing a simple series circuit with one bulb and with two bulbs. Specifically, it diagnoses pupils' understanding about the brightness of the bulb and its relation to current distribution in the circuit. For question 2(A), only 1 pupil answered that the circuit with 2 bulbs is brighter than the circuit with 1 bulb, 23 pupils answered it is dimmer, and 6 pupils answered both have the same brightness.

Of 23 pupils who believed that the circuit with 2 bulbs is dimmer than circuit with 1 bulb, 17 gave the reason that current is shared between the two bulbs, while 5 do not believe this and 2 pupils are not sure.

Out of 6 pupils who answered that both bulbs from the two circuit are of the same brightness, 4 believed that this happens because the battery still provides the same amount of current in both diagrams, while 2 pupils were not sure of this reason.

Summary :

The finding is very much in agreement with previous studies that the battery will provide the same amount of current irrespective of the circuit or loads (bulbs). Sharing of current amongst the bulbs is also significantly detected in this analysis.

4b. Comparing two bulbs in a series circuit

Question	Answer				Total
	a	b	c	x	
2(E)	2	3	25	-	30
2(F)	21	4	-	5	30
2(G)	2	-	-	28	30

Table 6.4.6

Questions 2(E), 2(F) and 2(G) are used to diagnose pupils' understanding of current in a series circuit by comparing the brightness of 2 bulbs placed serially on that circuit. As shown in the table, 25 pupils had a correct understanding by answering that both are the same brightness. When diagnosed about the reason, 21 pupils agreed that both bulbs have the same brightness because the current is shared out equally between them. That means only 4 pupils did not agree with that reasoning. Of the 2 pupils who answered that L1 is brighter than L2, both agreed with the reason that it is because current is used up as it travels from the battery to L1 and then to L2. A cross-tabulation with question 1(E) shows that both pupils believed that current is consumed as it flows through a bulb.

Summary:

It is interesting to note that although a large number of pupils gave a correct answer to Question 2(E), this is then accompanied by an incorrect reason. The understanding that two bulbs shared the current is significantly shown in the response. Again this result is consistent with the result of previous studies (e.g. McDermott and Zee, 1984)

5. Function of a resistor in a simple serial circuit

Question	Answer			Total
	a	b	c	
3(A)	3	24	3	30
3(B)	4	17	9	30

Table 6.4.7

Table 6.4.8 shows the cross tabulation of question 3(A) by 3(B).

3(B)	a	b	c	Total
3(A)				
a	1	2	0	3
b	3	12	9	24
c	0	3	0	3
Total	4	17	9	30

Table 6.4.8

Questions 3(A) and 3(B) are used to diagnose the pupils' understanding of the resistor function in a series circuit. It was interesting to note that all the alternative stems were selected as answers, so it is best to describe the pattern of answers with a cross-tabulation carried out using a statistical package. As shown in the cross-tabulation **Table 6.4.8**, 12 pupils had the right understanding that the bulb becomes dimmer in both cases, 9 pupils understood that the resistor has affected the bulb only if it is placed before it. It was interesting to note that the program detected 3 pupils (out of 6 pupils detected who responded that current flows from the negative terminal to the positive terminal in the previous section) also had this understanding, but in the reverse direction.

Summary:

The understanding of the sequential flow of current through the bulb and that only the variable resistor placed before the bulb can affect it was detected in nearly half of the sample (12 pupils). The result corresponds with the notion of 'sequential reasoning' as described by Shipstone (1988).

6.4.1.1 Conclusion

Several points arise from these results.

(1) In general, for the majority of the cases, there is evidence from the result that showed a consistency with the results of previous studies.

(2) The analysis shows that there was a reasonable distribution of answers to all the questions. In general, the questions were well understood by the pupils.

(3) There is a majority of cases where the analysis showed that a reasonable number of pupil were detected as having a correct understanding or a misunderstanding which is consistent with those described in the literature. From this it can be inferred that the questions used in the program could be used successfully to diagnose pupil understanding.

(4) There were some cases of unexplainable responses from the pupils. It seems that some of the pupils do not have a consistent understanding or as stated by Shipstone (1984) that the pupils appeared to use more than one understanding in responding to the set of questions.

(5) There is a need to add new rules to the program knowledge base as the analysis shows that there are a few sets of responses which do not correspond exactly with any set of diagnostic rules given to the program. For example, as described in section (5), there exists an indication that pupils have an understanding that current flows from the negative to the positive terminal and showing a 'sequential reasoning' in a reverse direction. In general form, the new rule could be added as:

IF current flows from negative to positive terminal
AND bulb becomes dimmer when R2 is increased
AND bulb stays the same brightness when R1 is increase
THEN showing "sequential reasoning" pattern in REVERSE direction

6.4.2 Typical Sample of Individual Pupil's Responses

This section discusses the diagnosis feedback of three pupils representing typical cases diagnosed by the program. The pupil responses to the questions are illustrated as a basis for the author to compare them with the diagnosis feedback from the program. It forms a summary of the way three typical students used the program to provide some idea of the variation found.

6.4.2.1 Pupil E18

Diagnostic Test: Electricity ---------------------------- Date:10-June-94 10:45 Student Name: (name deleted) 1. Current is stored in the battery. 2. There is a relation between current and energy(current is energy). 1. Current flows in one direction. 2. Current flows from positive to negative terminal of the battery. 1. Current is consumed as it flows through the bulb. 2. Bulb consumed only part of the current. 1. Two bulbs in a series circuit have the same brightness. 2. The two bulbs SHARED the amount of current. 1. Battery giving out a constant current, independent of the circuit. 2. Circuit with two bulbs in series is dimmer than circuit with one bulb as the current now is shared. 1. When the resistor placed before a bulb in a circuit is increased, the bulb becomes dimmer. 2. When the resistor placed after a bulb in a circuit is increased, the bulb stays the same brightness. 3. Showing a strong sequential model.

Table 6.4.9 : Pupil E18 Diagnostic Feedback

(1) Source of current

Question	Q1(A)	Q1(B)	Q1(C)
Answer	a	a	x

Pupil E18 believed that :

- Current in the circuit is stored in the battery.
- Current stored in the battery is the same as energy stored in the battery.

(2) Flow of current in a series circuit

Question	Q1(D)	Q1(J)	Q1(K)
Answer	b	a	a

Pupil E18 believed that :

- Current is leaving one end of the battery and then returning to the other end. In other words, *current is flowing in one direction only*.
- Current is flowing from the positive terminal and back to the negative terminal of the battery.

(3) Conservation of current in a circuit

Question	Q1(E)	Q1(G)	Q1(F)	Q1(H)	Q1(I)
Answer	a	b	a	x	x

Pupil E18 believed that :

- current is used up as it flows through the bulb.
- Only part of the current is used up.
- More current is leaving one end of the battery than returns to the other end.

(4) Brightness of bulbs in a simple series circuit

4(a) Comparison of identical circuit but with one bulb and two bulbs.

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	b	a	a	x

Pupil E18 believed that :

- Bulb L1 in diagram II is dimmer than Bulb L1 in diagram 1 (Circuit with two bulbs in series is dimmer than similar circuit with only one bulb).
- Current is shared by the two bulbs.
- The amount of current flowing through diagram I is the same as the amount of current flowing through diagram II (Battery is a source of constant current).

4(b) Comparing two bulbs in a series circuit

Question	Q2(E)	Q2(F)	Q2(G)
Answer	c	a	x

Pupil E18 believed that :

- In diagram II, L1 and L2 are the same brightness.
- The reason for the same brightness is that the current is shared between both bulbs.

(5) Function of a resistor in a simple series circuit

Question	Q3(A)	Q3(B)
Answer	b	c

Pupil E18 believed that :

- When R1 is increased, the bulb becomes dimmer.
- When R2 is increased, the bulb stays the same brightness.

6.4.2.1.1 Summary of Pupil E18 responses

In general, the responses of pupil E18 were completely consistent throughout all the questions. The program's feedback clearly described the understanding of this pupil. There is a complete agreement between the pupil E18 responses with the program's diagnostic feedback. The understanding or rather the mis-understanding of these simple electricity concepts of this pupil is consistent with the findings from previous research.

6.4.2.2 Pupil E1

(1) Source of current

Question	Q1(A)	Q1(B)	Q1(C)
Answer	b	x	a

Pupil E1 believed that :

- current in the circuit is not stored in the battery.
- current is produced by the potential difference (voltage) in the battery.

(2) Flow of current in a series circuit

Question	Q1(D)	Q1(J)	Q1(K)
Answer	b	a	b

Pupil E1 believed that :

- Current is leaving one end of the battery and then returning to the other end. In other words, current is flowing in one direction only.
- Current is flowing from the negative terminal and back to the positive terminal of the battery.

Diagnostic Test: Electricity

Date: 7-June-94 9:16
Student Name: (name deleted)

1. Current is NOT stored in the battery.
2. Current is produced by the Potential Difference in the battery.

1. Current flows in one direction.
2. Current flows from negative to positive terminal of the battery.

1. Current is conserved as it flows through the bulbs.

1. Two bulbs in a series circuit have the same brightness.
2. The two bulbs SHARED the amount of current.

1. When the resistor placed before a bulb in a circuit is increased, the bulb becomes dimmer.
2. When the resistor placed after a bulb in a circuit is increased, the bulb becomes dimmer.

Table 6.4.10 : Pupil E1 Diagnostic Feedback

(3) Conservation of current in a circuit

Question	Q1(E)	Q1(G)	Q1(F)	Q1(H)	Q1(I)
Answer	b	x	a	x	x

Pupil E1 believed that :

- Bulb did not use up the current as current flows through it.
- The amount of current entering the bulb is the same as the amount of current leaving the bulb.

(4) Brightness of the bulbs in a simple series circuit

4(a) Comparison of identical circuit but with one bulb and two bulbs

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	b	a	b	x

Pupil E1 believed that :

- Bulb L1 in diagram II is dimmer than Bulb L1 in diagram 1 (Circuit with two bulbs in series is dimmer than similar circuit with only one bulb).
- Current is shared by the two bulbs in diagram II.

- The amount of current flowing through diagram I is not the same as the amount of current flowing through diagram II.

4(b) Comparing two bulbs in a series circuit

Question	Q2(E)	Q2(F)	Q2(G)
Answer	c	a	x

Pupil E1 believed that :

- In diagram II, L1 and L2 are the same brightness.
- The reason for the same brightness is that the current is shared between both bulbs.

(5) Function of a resistor in a simple serial circuit

Question	Q3(A)	Q3(B)
Answer	b	b

Pupil E1 believed that :

- When R1 is increased, the bulb becomes dimmer.
- When R2 is increased, the bulb becomes dimmer.

6.4.2.2.1 Summary of Pupil E1 responses

As shown in the program feedback, this pupil's understanding of simple electricity concepts is rather good. The confusion of the direction of current flows is clearly described in the feedback. It seems that the description or diagnosis for questions 2(A), 2(B), 2(C), and 2(D) is missing from the feedback. These can be easily added into the diagnosis knowledge base:

IF	two bulbs in series is dimmer than similar circuit with one bulb
AND	current is shared by the two bulbs
AND	the amount of current flows in diagram I is not the same as the one flows in diagram II
THEN	shows a descriptive feedback

Again, the program's feedback and the pupil's responses are in strong agreement.

6.4.2.3 Pupil E14

Diagnostic Test: Electricity ---------------------------- Date: 8-June-94 14:48 Student Name: (name deleted) 1. Current is stored in the battery. 2. There is a relation between current and energy(current is energy). 1. Current flows from both terminals of battery and then meets in the bulb to cause it to light up. 1. Two bulbs in a series circuit have the same brightness. 2. The two bulbs SHARED the amount of current.

Table 6.4.11 : Pupil E14 Diagnostic Feedback

(1) Source of current

Question	Q1(A)	Q1(B)	Q1(C)
Answer	a	a	x

Pupil E14 believed that :

- Current in the circuit is stored in the battery.
- Current stored in the battery is the same as energy stored in the battery.

(2) Flow of current in a series circuit

Question	Q1(D)	Q1(J)	Q1(K)
Answer	a	x	x

Pupil E14 believed that :

- Current is leaving from both ends of the battery and then meets in the bulb to cause it to light up.

(3) Conservation of current in a circuit

Question	Q1(E)	Q1(G)	Q1(F)	Q1(H)	Q1(I)
Answer	a	a	x	b	x

Pupil E14 believed that :

- Current is used up as it flows through the bulb.
- All the current is used up by the bulb.
- More current is leaving one end of the battery than returns to the other end.
- Although the bulb used up all the current, the pupil does not agree that the wire to the other end has no current passing through it.

(4) Brightness of bulbs in a simple series circuit

4(a) Comparison of identical circuit but with one bulb and two bulbs

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	c	x	a	a

Pupil E14 believed that :

- Bulb L1 in diagram II is the same brightness as bulb L1 in diagram 1.
- Battery still provides the same amount of current in both diagrams.
- The amount of current flowing through diagram I is the same as the amount of current flowing through diagram II (Battery is a source of constant current).

(b) Comparing two bulbs in a series circuit

Question	Q2(E)	Q2(F)	Q2(G)
Answer	c	a	x

Pupil E14 believed that :

- In diagram II, L1 and L2 are the same brightness.
- The reason for the same brightness is that the current is shared between both bulbs.

(5) Function of a resistor in a simple serial circuit

Question	Q3(A)	Q3(B)
Answer	b	a

Pupil E14 believed that :

- When R1 is increased, the bulb becomes dimmer.
- When R2 is increased, the bulb becomes brighter.

6.4.2.3.1 Summary of Pupil E14 responses

The program's diagnostic feedback could only provide relatively limited descriptive feedback to pupil E14. The reason is, as shown in the pupil responses, there exists several patterns of mis-understanding which are not typical. For example, on the function of the resistor section, this form of understanding is rather non-typical and not yet available in the program diagnostic knowledge base. The same argument was also applicable to the consumption of current section. At the present time, the diagnostic knowledge base only contains the typical pattern of understanding or mis-understanding as described in the research literature. Based on the results of this study, several non-typical patterns could easily be added to the knowledge base. For example, for the pattern of responses in part 4(a), a general form of new diagnosis rule could be :

IF	two bulbs in series is the same brightness as similar circuit with one bulb
AND	the amount of current flows in diagram I is the same as the one flows in diagram II
AND	battery provides the same amount of current in both diagrams
THEN	shows a descriptive feedback

6.4.2.4 Conclusion

Several points arise from these results.

1. With respect to typical sets of understanding, the diagnosis made by the program in general matches sufficiently with the pupils' responses. This agreement between the diagnostic feedback provides evidence that the program can act as a tool for providing a useful insight into pupil understanding.

2. The analysis showed that several patterns of pupil responses have not yet been made available in the diagnostic knowledge base. This is due to a non-typical contradictory set of responses given by the pupil, or to a set of consistent responses which do not correspond exactly with any set of diagnostic rules known by the program, as described for the cases of pupils E1 and E14.

6.5 Speed and Graphs

Summary of characteristics of questions on Speed and Graphs:

- The test consisted of 22 multiple-choice questions with 2, 3 or 4 alternative answers. The complete list of questions is shown in **Appendix E1**.
- The branching format of questioning is used in the test. Some of the question will not be answered by every pupil.
- The test involved the understanding in these following areas:

(1) interpreting the motion of an object in terms of the dot positions on a tape;

(2) comparing the motion of two identical objects in terms of the dot positions on a tape;

(3) determining whether two balls have the same speed by interpreting the dot positions on a tape;

(4) interpreting the motion of an object in terms of a distance-time graph;

(5) (i) determining whether two balls are ever at the same place at the same time with respect to motion on a distance-time graph;

(ii) determining whether two balls are ever travelling with the same speed with respect to motion on a distance-time graph; and

(6) interpreting a changing motion of an object in terms of a distance-time graph.

In this analysis, the questions are grouped according to the above statements.

6.5.1 The General Pattern of Pupils' Responses to All the Questions

1. Interpreting the motion of an object in terms of dot positions on a tape.

Question	1(A)	1(B)	1(C)	Total
	a	b	c	20
	b	a	c	8
	a	a	c	1
	a	b	a	1
Total				30

Table 6.5.1

Questions 1(A), 1(B) and 1(C) were used to diagnose pupils' understanding in interpreting a series of dots on a tape. Since all the questions are related, it was more practical and easier to analyse them as a group. It was interesting to note that a majority of the pupils, 20 pupils (66.7%), have a correct understanding. It was also important to note that there were 8 pupils who interpreted the motion in a reverse direction. This was later found (further analysis of pupils' responses in the next section) to be due to the ambiguity of the marking of the direction of tape movement used in the diagram. Nevertheless, all the 28 pupils were showing a consistent pattern of understanding between the positions of the dots and its relative speed. Only 2 pupils showed an inconsistent pattern of understanding.

Summary :

For this group of questions, the majority of the pupils were showing a consistent pattern of responses. This implied that the questions used are valid and capable of eliciting pupils' understanding. The marking for the direction of motion needs to be changed.

2. Comparing the motion of two identical objects in terms of the dot positions on a tape

Questions 2(A), 2(B) and 2(C) were used to diagnose pupils' understanding in interpreting the speed of two identical objects by comparing a series of dots on two tapes. As shown in **Table 6.5.2**, 15 pupils have a correct understanding in interpreting the relative speed of the objects.

Question	2(A)	2(B)	2(C)	Total
	a	c	b	15
	b	c	a	6
	a	c	a	2
	c	c	a	1
	b	c	b	1
	b	c	c	1
	c	a	b	1
	a	b	a	1
	a	b	b	1
	a	a	b	1
Total				30

Table 6.5.2

Six pupils again interpreted the motion in a reverse direction due to the ambiguity of the marking of the direction of tape movement used in the diagram. Nevertheless, all the 21 pupils are showing a consistent pattern of understanding in comparing the speed of the objects. There were 9 pupils showing an inconsistent pattern of understanding.

Summary :

For this group of questions, again a majority of the pupils were showing a consistent pattern of responses. This implied that the questions used are valid and capable of eliciting pupils' understanding in this particular area. There is no specific pattern of inconsistency detected in the pupil responses.

3. Determining whether two balls have the same speed by interpreting the dot positions on a tape

Question	Answer				Total
	a	b	c	x	
3(A)	12	18	-	-	30
3(B)	12	0	0	18	30

Table 6.5.3

Question 3(A) and 3(B) are for eliciting pupils' understanding whether the two objects have the same speed by comparing a series of dots on two different tapes. As shown in **Table 6.5.3**, 12 pupils responded that the two objects have the same speed and, as expected, this occurred when time is equal to 3 units. There were 18 pupils who correctly answered that the two objects do not have the same speed.

Summary:
The results show that these questions were capable of detecting the common form of misunderstanding as reported by Hewson (1985) in the literature.

4. Interpreting the motion of an object represented as a straight line on a distance-time graph

Question	4(A)	4(B)	4(C)	Total
	a	b	c	16
	c	c	c	9
	c	b	c	3
	a	c	c	1
	a	a	c	1
Total				30

Table 6.5.4

As shown in **Table 6.5.4**, the data showed that the system successfully detected only 9 pupils who were showing a consistent pattern of correct conception, that is the speed is constant in all the cases. There were 16 pupils who showed a consistent misunderstanding of what the slope of the graph represented. Only 5 pupils showed various forms of non-consistent understanding.

Summary:
It is interesting to note that a large number of pupils showed a form of misunderstanding by interpreting the slope of a straight line on a distance-time graph as a change of speed (Swatton and Taylor, 1994).

5. Determining whether

(a) the two objects are ever at the same place at the same time

(b) the two objects ever have the same speed

with respect of two types of motion represented by two straight lines on a distance-time graph

5(i)

Question	Answer				Total
	a	b	c	x	
5(A)	25	5	-	-	30
5(B)	0	25	0	5	30
5(C)	13	17	-	-	30
5(D)	2	8	3	17	30

Table 6.5.5

The data in **Table 6.5.5**, for the motion for two non-parallel and intercepting lines as in diagram 5(a), showed that 25 pupils believed that the two objects were at the same place at the same time at time of 5 units. Only 5 pupils did not think that to be the case. 13 pupils thought that the lines showed the same speed. There was a mixture of responses, 8 pupils believed it happens at the time of interception of the lines, 2 pupils believed it happened before the interception and 3 believed it happened after the interception. The remaining 17 pupils did not believe that the two objects ever have the same speed.

Table 6.5.6 showed the pattern of responses across all the questions 5(A) to 5(D).

Question	5(A)	5(B)	5(C)	5(D)	Total
	a	b	b	x	16
	a	b	a	b	5
	b	x	a	b	3
	a	b	a	c	2
	b	x	b	x	1
	b	x	a	c	1
	b	x	a	a	1
	a	b	a	a	1
Total					30

Table 6.5.6

The data in **Table 6.5.6** showed that :

(a) 16 pupils believed that :

- The two objects are at the same place at the same time when t = 5 units.
- The two objects are never moving at the same speed.

(b) 5 pupils believed that :

- The two objects are at the same place at the same time when t = 5 units.
- The two objects are moving at the same speed at t = 5 units.

(c) 3 pupils believed that :

- The two objects are never at the same place at the same time
- The two objects are moving at the same speed at t=5

(d) 1 pupil believed that :

- The two objects are never at the same place at the same time
- The two objects never move at the same speed.

(e) 5 pupils showed various forms of non-consistent pattern of understanding.

Summary:

The findings show various forms of understanding detected by this group of questions. As shown in **Table 6.5.6**, only 1 pupil showed a correct understanding by interpreting that the motion of objects shown by two non-parallel and intercepting lines on a distance-time graph are never at the same place at the same time and also never moving at the same speed.

5(ii)

Question	Answer				Total
	a	b	c	x	
5(E)	4	26	-	-	30
5(F)	0	3	1	26	30
5(G)	2	28	-	-	30
5(H)	1	0	1	28	30

Table 6.5.7

The data in **Table 6.5.7**, for the motion for two non-parallel and non-intercepting lines as in diagram 5(b), showed that 26 pupils believed that the two objects are never at the same place at the same time. Only 4 pupils believed that the two objects were at the same place at the same time, which was at time = 5 units. Only 2 pupils thought that the two objects ever have the same speed. One pupil believed it happened before the interception and 1 believed it happened after the interception. The remaining 28 pupils did not believe that the two objects ever have the same speed.

Table 6.5.8 showed the pattern of responses across all the questions 5(E) to 5(H).

Question	5(E)	5(F)	5(G)	5(H)	Total
	b	x	b	x	25
	a	b	b	x	2
	b	x	a	a	1
	a	b	a	c	1
	a	c	b	x	1
Total					30

Table 6.5.8

The data showed that :

(a) 25 pupils believed that :

- The two objects are never at the same place at the same time.
- The two objects never move at the same speed.

(b) 2 pupils believed that :

- The two objects are at the same place at the same time when t = 5 units.
- The two objects never move at the same speed.

(c) 3 responses each showed a non-consistent pattern of understanding.

Summary:

The findings show that a majority of the pupils believed that the two objects are never at the same place at the same time and also never moving with a same speed. Comparing with the case of the intercepting lines, therè is a vast increase in terms of the number of pupils who have a correct understanding with the case of non-intercepting lines.

5(iii).Comparing and interpreting the motion of two objects represented by two types of two straight lines on a distance-time graph

A cross reference between the responses to groups of question 5 was carried out in order to further analyse the responses.

(a) determine whether both objects ever move with the same speed

Question 5(C), 5(D), 5(G) and 5(H) were used to diagnose pupils' understanding whether the two objects are ever moving with the same speed. Questions 5(C) and 5(D) are referring to two intercepting lines whereas questions 5(G) and 5(H) are referring to two non-intercepting lines. Both cases were on a distance-time graph.

Question	5(C)	5(D)	5(G)	5(H)	Total
	b	x	b	x	17
	a	b	b	x	8
	a	c	b	x	3
	a	a	b	x	1
	a	a	a	c	1
Total					30

Table 6.5.9

Some common pattern of responses detected in **Table 6.5.9** :

(a) 17 pupils believed that:

- in both cases, the two objects are never travelling with a same speed.

(b) 8 pupils believed that:

- in the case of intercepting lines, the two objects are travelling at same speed at the point of line interception.
- in the case of non-intercepting lines, the two objects are never travelling at same speed.

Summary:

A large number of pupils have a correct understanding with regards to the two objects never travelling with a same speed. A common pattern detected is that some pupils believe that the point of interception between the two lines is the time where the two objects are moving with the same speed. Hewson (1985) referred to this as a "position-criterion" misunderstanding. The results also show that this set of questions are capable of differentiating various forms of conception.

(b) determine whether both objects are ever at the same place at the same time

Question 5(A), 5(B), 5(E) and 5(F) were used to diagnose pupils' understanding whether the two objects are ever at the same place at the same time. Questions 5(A) and 5(B) are referring to two intercepting lines whereas questions 5(E) and 5(F) are referring to two non-intercepting lines. Both cases were on a distance-time graph.

Question	5(A)	5(B)	5(E)	5(F)	Total
	a	b	b	x	22
	b	x	b	x	4
	a	b	a	b	2
	a	b	a	c	1
	b	x	a	b	1
Total					30

Table 6.5.10

Some common pattern of responses detected in **Table 6.5.10** :

(a) 22 pupils believed that:

- in the case of intercepting lines, the two objects were at the same place at the same time and it occurred at the point of line interception.
- in the case of non-intercepting lines, the two objects never were at the same place at the same time.

(b) 4 pupils believed that:

- in both cases, the two objects never were at the same place at the same time.

(c) 2 pupils believed that :

- in both cases, the two objects were at the same place at the same time and it occurred at the point of the lines interception.

Summary:

A common pattern detected is that some pupils believe that the point of interception between the two lines is the time where the two objects are at the same place at the same time. Again this concurs with the "position-criterion" misunderstanding. The results also show that this set of questions are capable of differentiating various forms of conception.

5(iv).Comparing and interpreting the motion of two objects in terms of two parallel straight lines on a distance-time graph

Question	Answer		Total
	a	b	
5(I)	26	4	30

Table 6.5.11

As shown in the **Table 6.5.11**, 26 pupils have a correct understanding that both objects were travelling at the same speed. Only 4 pupils did not believe so.

Summary:

A majority of the pupils have a correct understanding that the motion of two objects represented by two parallel lines on a distance-time graph are in fact travelling with the same speed.

6. Interpreting the changing motion of an object in terms of a distance-time graph

Question	6(A)	6(B)	Total
	c	a	10
	b	a	9
	b	b	3
	d	a	3
	a	a	2
	a	b	1
	b	c	1
	c	b	1
Total			30

Table 6.5.12

As shown in **Table 6.5.12**, there were various patterns of responses. The common pattern of responses detected were:

(a) 10 pupils believed that:

- the slowest motion occurred at the turning point of the line (point 2).
- the object is turning around at the turning point of the line (point 2).

(b) 9 pupils believed that:

- the slowest motion occurred at the portion of line below the x-axis (point 3 to point 4) "negative" part of the line
- the object is turning around at the turning point of the line (point 2)

(c) 3 pupils believed that:

- the slowest motion occurred at the portion of line below the x-axis (point 3 to point 4) "negative" part of the line
- the object is turning around at the point of the line interception with the x-axis (point 3).

(d) 8 pupils were showing various non-consistent patterns of responses.

Summary:
The finding shows various forms of pupils' consistent misunderstanding in interpreting the motion of an object, in terms of a distance-time graph, detected by the program. This again implied the suitability of the questions in diagnosing pupils' understanding in this particular area.

6.5.1.1 Conclusion

Several important points arise from these results.

(1) In general, for the majority of the cases, the results are consistent with the results of previous studies. For example, Hewson (1985) stated that many pupils used a 'position' criterion in interpreting the motion of two objects.

(2) The analysis shows that there was a reasonable distribution of answers to all the questions. So it can be implied that, in general, the questions are well understood by the pupils. In other words, the questions are suitable for the age level of pupils for the purpose of diagnosis.

(3) There is a majority of cases where the analysis showed that the pupils have a correct understanding or the various misunderstandings which have been described in the literature. So it can be inferred that the questions used in the program could be used successfully to diagnose pupil understanding.

(4) There exists a small number of cases of unexplainable responses from the pupils. It seems that some of the pupils do not have a consistent understanding or as stated by Shipstone (1984) that the pupils appeared to use more than one understanding in responding to the set of questions. For example, as described in the analysis, there are many cases in each part of section 6.4.1 where there is a non-typical pattern of responses. Since for each case, the number of pupils showing these non-typical patterns of understanding is rather small, there is no need for them to be included in the diagnosis rule at this stage.

(5) As various forms of conceptions are detected, there is a need to add new rules to the program knowledge base. The findings of the analysis show that there are a few sets of interesting patterns of responses which do not correspond exactly with any set of diagnostic rules given to the program.

For example, as discussed for the case of part 4 in section 6.5.1,

a number of pupils believed that :

> *When the slope is ascending or horizontal, the speed of the object is constant.*
> *When the slope is descending, the speed of the object is decreasing.*

This pattern of understanding had not been included in the present diagnosis rules, so the corresponding general form of new rule could be:

IF speed is constant when slope is ascending
AND speed is constant when slope is horizontal

AND speed is decreasing when slope is descending
THEN shows a description

6.5.2 Typical Sample of Individual Pupil's Responses

This section discusses the diagnosis feedback of three pupils which represented typical cases diagnosed by the program. The pupil responses to the questions were illustrated as a basis for the author to compare them with the diagnosis feedback from the program. It formed a summary of the way three typical students used the program to provide some idea of the variation found.

6.5.2.1 Pupil S8

1. Interpreting the motion of an object with respect to the dot positions on a tape

Question	Q1(A)	Q1(B)	Q1(C)
Answer	a	b	c

Pupil S8 believed that :

- as the dots become further apart, the speed of the object was increasing.
- as the dots become closer, the speed of the object was decreasing.
- for the same interval of dots, the speed of the object was constant.

2. Comparing the motion of two identical objects with respect to the dot positions on the tapes

Question	Q2(A)	Q2(B)	Q2(C)
Answer	a	c	b

Pupil S8 believed that :

- for diagram 2(a), trolley 1 is moving faster than trolley 2.
- for diagram 2(b), trolley 1 is moving at the same speed as trolley 2.
- for diagram 2(c), trolley 1 is moving slower than trolley 2.

Date: 8-June-94 9:50
Student Name: (deleted)

Refer to Diagram 1:

1. When the dots on the tape become further apart, the speed of trolley is increasing.
2. When the dots on the tape become closer, the speed of trolley is decreasing.
3. When the dots on the tape stay same distance apart, the speed of trolley is constant.

Refer to Diagram 2:

1. Trolley 1 is moving faster than trolley 2.
2. Trolley 1 is moving at same speed as trolley 2.
3. Trolley 1 is moving slower than trolley 2.

Refer to Diagram 3:

1. The two balls DO NOT have the same speed.
2. When two objects are at the same position (side-by-side), they DO NOT necessarily have the same speed.

Conclusion: No indication of using position-criterion.

Refer to Diagram 4:

1. When the slope is positive, the speed of object is increasing.
2. When the slope is negative, the speed of object is decreasing.
3. When the slope is horizontal, the speed of object is constant.

Conclusion: There is a relation between slope of graph and change of speed.

Refer to Diagram 5(a) and 5(b):
Two identical objects on a distance-time graph:

1. WILL BE at the SAME PLACE at the SAME TIME if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE at the SAME PLACE at the SAME TIME if the lines NOT meet (cross) each other.

Conclusion: Strong indication of using position-criterion.

Refer to Diagram 5(a) and 5(b):

1. The two objects will never have the SAME SPEED.

Conclusion: No indication of using position-criterion.

Refer to Diagram 5(c):

1. Two objects are moving at the SAME SPEED if the lines representing their motion are parallel to each other.

Refer to Diagram 6:

1. The motion of the object is slowest at point 2 (slope is zero).
2. The turning point is at point 2 (slope is zero).

Table 6.5.13 : Pupil S8 Diagnostic Feedback

3. Determining whether two balls ever have the same speed by interpreting the dot positions on tapes

Question	Q3(A)	Q3(B)
Answer	b	x

Pupil S8 believed that :

- the two balls never have the same speed on the tapes of diagram 3.

4. Interpreting the motion of an object in terms of a distance-time graph

Question	Q4(A)	Q4(B)	Q4(C)
Answer	a	b	c

Pupil S8 believed that :

- When the slope is ascending, the speed of the object is increasing.
- When the slope is descending, the speed of the object is decreasing.
- When the slope is horizontal, the speed of the object is constant.

5(a). Determine whether

(I) two identical objects were ever at the same place at the same time

(II) two identical objects were ever travelling with the same speed

with respect of two intercepting lines on a distance-time graph (as shown in diagram 5(a))

Question	Q5(A)	Q5(B)	Q5(C)	Q5(D)
Answer	a	b	b	x

Pupil S8 believed that :

- The two objects were at the same place at the same time.
- It occurred at time equal to 5 units.
- The two objects were never travelling at the same speed.

5(b). Determine whether

(I) two identical objects were ever at the same place at the same time

(II) two identical objects were ever travelling with the same speed

with respect of two non-parallel and non-intercepting lines on a distance-time graph (as shown in diagram 5(b))

Question	Q5(E)	Q5(F)	Q5(G)	Q5(H)
Answer	b	x	b	x

Pupil S8 believed that :

- The two objects were never at the same place at the same time.
- The two objects were never travelling at the same speed.

5(c). Determine whether two identical objects were ever travelling with the same speed with respect to two parallel lines on a distance-time graph (as shown in diagram 5(c))

Question	Q5(I)
Answer	a

Pupil S8 believed that :

- The two objects were travelling at the same speed

6. Interpreting the changing motion of an object with respect of a distance-time graph

Question	Q6(A)	Q6(B)
Answer	c	a

Pupil S8 believed that :

- The motion was slowest at point 2 (turning point of graph)
- The object was turning around at point 2 (turning point of graph)

6.5.2.1.1 Summary of Pupil S8 Responses

The program's diagnostic feedback provides full descriptive feedback to pupil S8 responses. This is due to the reason that the responses of pupil S8 were completely consistent through out all the questions. The program diagnostic feedback clearly described the understanding of this particular pupil.

6.5.2.2 Pupil S14

1. Interpreting the motion of an object with respect to the dot positions on a tape

Date: 8-June-94 15:02
Student Name: (name deleted)

Refer to Diagram 1:

1. When the dots on the tape become further apart, the speed of trolley is decreasing.
2. When the dots on the tape become closer, the speed of trolley is increasing.
3. When the dots on the tape stay same distance apart, the speed of trolley is constant.

Refer to Diagram 3:

1. The two balls have the same speed at time t = 3.
2. When two objects are at the same position (side-by-side), they have the same speed.

Conclusion: Strong indication of using position-criterion.

Refer to Diagram 5(a) and 5(b):

Two identical objects on a distance-time graph:
1. WILL BE at the SAME PLACE at the SAME TIME if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE at the SAME PLACE at the SAME TIME if the lines NOT meet (cross) each other.

Conclusion: Strong indication of using position-criterion.

Refer to Diagram 5(a) and 5(b):

Two identical objects on a distance-time graph:
1. WILL BE moving at SAME SPEED if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE moving at the SAME SPEED if the lines NOT meet (cross) each other.

Conclusion: Strong indication of using position-criterion.

Refer to Diagram 5(c):

1. Two objects are moving at the SAME SPEED if the lines representing their motion are parallel to each other.

Refer to Diagram 6:

1. The motion of the object is slowest on part 3 to 4 (negative part of graph).
2. The turning point is at point 3 (interception of time-axis).

Table 6.5.14 : Pupil S14 Diagnostic Feedback

Question	Q1(A)	Q1(B)	Q1(C)
Answer	b	a	c

Pupil S14 believed that :

- as the dots become further apart, the speed of the object was decreasing.
- as the dots become closer, the speed of the object was increasing.
- for the same interval of dots, the speed of the object was constant.

2. Comparing the motion of two identical objects with respect to the dot positions on the tapes

Question	Q2(A)	Q2(B)	Q2(C)
Answer	b	c	a

Pupil S14 believed that :

- for diagram 2(a), trolley 1 is moving slower than trolley 2.
- for diagram 2(b), trolley 1 is moving at the same speed as trolley 2
- for diagram 2(c), trolley 1 is moving faster than trolley 2.

3. Determining whether two balls ever have the same speed by interpreting the dot positions on tapes

Question	Q3(A)	Q3(B)
Answer	a	a

Pupil S14 believed that :

- the two balls have a same speed at the interval of time = 3 units.

4. Interpreting the motion of an object in terms of a distance-time graph

Question	Q4(A)	Q4(B)	Q4(C)
Answer	a	a	c

Pupil S14 believed that :

- When the slope is ascending, the speed of the object is increasing.
- When the slope is descending, the speed of the object is increasing.

- When the slope is horizontal, the speed of the object is constant.

5(a). Determine whether
(I) two identical objects were ever at the same place at the same time
(II) two identical objects were ever travelling with the same speed
with respect of two intercepting lines on a distance-time graph (as shown in diagram 5(a))

Question	Q5(A)	Q5(B)	Q5(C)	Q5(D)
Answer	a	b	a	b

Pupil S14 believed that :

- The two objects were at the same place at the same time.
- It occurred at time equal to 5 units.
- The two objects were travelling at the same speed.
- It occurred at time equal to 5 units.

5(b). Determine whether
(I) two identical objects were ever at the same place at the same time
(II) two identical objects were ever travelling with the same speed
with respect of two non-parallel and non-intercepting lines on a distance-time graph (as shown in diagram 5(b))

Question	Q5(E)	Q5(F)	Q5(G)	Q5(H)
Answer	b	x	b	x

Pupil S14 believed that :

- The two objects were never at the same place at the same time.
- The two objects never travel at the same speed.

5(c). Determine whether two identical objects were ever travelling with the same speed with respect to two parallel lines on a distance-time graph (as shown in diagram 5(c))

Question	Q5(I)
Answer	a

Pupil S14 believed that :

- The two objects were travelling at the same speed

6. *Interpreting the changing motion of an object with respect of a distance-time graph*

Question	Q6(A)	Q6(B)
Answer	b	b

Pupil S14 believed that :

- The motion was slowest on the part 3 to 4
- The object turned around at point 3 (point of interception with x-axis)

6.5.2.2.1 Summary of Pupil S14 Responses

Pupil S14 showed a reverse order but consistent idea in interpreting the object's motion with respect to dot positions on a tape. There was a misinterpretation in the direction of the tape's motion. The description in the feedback is correct, but no statement mentions about this reverse direction case.

There is a small discrepancy between the feedback result generated by the program and the result from this analysis. It seems that the description feedback for case (2) and (4) is not listed in the generated results due to the pattern of understanding not being included in the present diagnosis rule of the program. To cater for this discrepancy, a new diagnosis rule could easily be added.

For example, a new diagnosis rule for case (2) could be:

IF	in diagram 2(a), trolley 1 is moving slower than trolley 2
AND	in diagram 2(b), trolley 1 is moving at the same speed as trolley 2.
AND	in diagram 2(c), trolley 1 is moving faster than trolley 2.
THEN	shows a descriptive feedback

Apart from the above mentioned cases, there is an agreement between the pupil S14 responses with the program diagnostic feedback.

6.5.2.3 Pupil S11

1. Interpreting the motion of an object with respect to dot positions on a tape

Question	Q1(A)	Q1(B)	Q1(C)
Answer	a	b	c

Date: 8-June-94 13:18
Student Name: (name deleted)

Refer to Diagram 1:
1. When the dots on the tape become further apart, the speed of trolley is increasing.
2. When the dots on the tape become closer, the speed of trolley is decreasing.
3. When the dots on the tape stay same distance apart, the speed of trolley is constant.

Refer to Diagram 2:
1. Trolley 1 is moving faster than trolley 2.
2. Trolley 1 is moving at same speed as trolley 2.
3. Trolley 1 is moving slower than trolley 2.

Refer to Diagram 3:
1. The two balls DO NOT have the same speed.
2. When two objects are at the same position (side-by-side), they DO NOT necessarily have the same speed.

Conclusion: No indication of using position-criterion.

Refer to Diagram 4:
1. When the slope is positive, the speed of object is constant.
2. When the slope is negative, the speed of object is constant.
3. When the slope is horizontal, the speed of object is constant.

Conclusion: There is NO relation between slope of graph and change of speed.

Refer to Diagram 5(a) and 5(b):
Two identical objects on a distance-time graph:
1. WILL BE moving at SAME SPEED if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE moving at the SAME SPEED if the lines NOT meet (cross) each other.

Conclusion: Strong indication of using position-criterion.

Refer to Diagram 5(a) and 5(b):
1. The two objects will never be at the SAME PLACE at the SAME TIME.

Conclusion: No indication of using position-criterion.

Refer to Diagram 5(c):
1. Two objects are moving at the SAME SPEED if the lines representing their motion are parallel to each other.

Refer to Diagram 6:
1. The motion of the object is slowest at point 2 (slope is zero).
2. The turning point is at point 3 (interception of time-axis).

Table 6.5.15 : Pupil S11 Diagnostic Feedback

Pupil S11 believed that :

- as the dots become further apart, the speed of the object was increasing.
- as the dots become closer, the speed of the object was decreasing.
- for the same interval of dots, the speed of the object was constant.

2. Comparing the motion of two identical objects in terms of dot positions on tapes

Question	Q2(A)	Q2(B)	Q2(C)
Answer	a	c	b

Pupil S11 believed that :

- for diagram 2(a), trolley 1 is moving faster than trolley 2.
- for diagram 2(b), trolley 1 is moving at the same speed as trolley 2.
- for diagram 2(c), trolley 1 is moving slower than trolley 2.

3. Determining whether two balls ever have the same speed by interpreting the dot positions on tapes

Question	Q3(A)	Q3(B)
Answer	b	x

Pupil S11 believed that :

- the two balls never have a same speed on the tapes of diagram 3.

4. Interpreting the motion of an object in terms of a distance-time graph

Question	Q4(A)	Q4(B)	Q4(C)
Answer	c	c	c

Pupil S11 believed that :

- When the slope is ascending, the speed of the object is constant.
- When the slope is descending, the speed of the object is constant.
- When the slope is horizontal, the speed of the object is constant.

5(a). Determine whether

(I) two identical objects were ever at the same place at the same time

(II) two identical objects were ever travelling with the same speed

with respect of two intercepting lines on a distance-time graph (as shown in diagram 5(a))

Question	Q5(A)	Q5(B)	Q5(C)	Q5(D)
Answer	b	x	b	x

Pupil S11 believed that :

- The two objects were never at the same place at the same time.
- The two objects were never travelling at the same speed.

5(b). Determine whether

(I) two identical objects were ever at the same place at the same time

(II) two identical objects were ever travelling with the same speed

with respect to two non-parallel and non-intercepting lines on a distance-time graph (as shown in diagram 5(b))

Question	Q5(E)	Q5(F)	Q5(G)	Q5(H)
Answer	b	x	b	x

Pupil S11 believed that :

- The two objects were never were at the same place at the same time.
- The two objects were never travelling at the same speed.

5(c). Determine whether two identical objects were ever travelling with the same speed with respect to two parallel lines on a distance-time graph (as shown in diagram 5(c))

Question	Q5(I)
Answer	a

Pupil S11 believed that :

- The two objects were travelling at the same speed

6. Interpreting the changing motion of an object with respect to a distance-time graph

Question	Q6(A)	Q6(B)
Answer	c	b

Pupil S11 believed that :

- The motion was slowest at point 2 (turning point of the graph).

- The object turning around at point 3 (point of interception on x-axis).

6.5.2.3.1 Summary of Pupil S11 Responses

The program's diagnostic feedback provided a complete descriptive feedback to pupil S11 responses. This is due to the reason that the responses of pupil S11 were completely consistent throughout all the questions, so the initial diagnosis rules pre-loaded inside the knowledge base were able to detect the form of understanding and provide a complete feedback. The program's diagnostic feedback clearly described the understanding of this particular pupil.

6.5.2.4 Conclusion

Several points arise from these results.

1. The analysis of individual pupil's responses shows that the questions are able to function as intended .

2. With respect to typical sets of understanding, the diagnosis made by the program in general matches sufficiently with the pupils' responses. This agreement with the diagnostic feedback provides sufficient evidence for the program to act as a tool for providing a useful insight into pupil understanding. In other words, it can be concluded that the program is able to diagnose effectively within the scope of the diagnosis rules supplied in the knowledge base.

3. The analysis showed that several patterns of responses have not been available in the diagnostic knowledge base. This is due to a non-typical contradictory set of responses given by the pupil, or to a set of consistent responses which do not correspond exactly with any set of diagnostic rules known by the program or shown from literature of previous research. The interesting pattern of responses could then be added easily in a form of new diagnosis rule as described for the case of pupil S14.

6. 6 Floating and Sinking

Summary of characteristics of questions on floating and sinking :

- The test consisted of 19 multiple choice questions with 2 or 3 alternative answers. The complete list of questions is shown in **Appendix E6**.

- The branching format of questioning is used in the test. Therefore some of the questions will not be answered by all pupils.
- The main objective is to diagnose the pupils into two possible groups with respect of their understanding of whether an object will float or sink in water due to the object's heaviness (or lightness) or the amount of air it contains and to explore the various forms of understanding related with this particular topic. It is possible that some pupils will not fall into either group.
- The method of reaching a conclusion in this topic is rather flexible. The decision is based on a probability criterion. In other words, the program did cater for some minor conflicting answers or ideas in the pupils responses. Refer to previous details in chapter 5.

For clarity of discussion, the questions are grouped into the following concept areas:

(1) determine whether a sealed glass bottle (full of air) will sink or float on water and to detect reason for the choice;
(2) further testing the idea with smaller glass and plastic bottle (for pupils who responded that the glass bottle will sink in section 1);
(3) determine what happens when sand is added into the glass bottle;
(4) general understanding about the effect of heaviness/lightness and amount of air on sinking and floating of an object; and
(5) general explorative questions.

6.6.1 The General Pattern of Pupils' Responses to All the Questions

1. Determine whether a sealed glass bottle (full of air) will sink or float on water and to detect the reason for the choice.

Question	Answer				Total
	a	b	c	x	
1(A)	3	26	1	-	30
1(B)	0	1	0	29	30
1(C)	2	1	0	27	30
1(F)	5	16	5	4	30

Table 6.6.1

Question 1(A) was used to test the pupils' understanding whether a sealed glass bottle which is full of air will float or sink in water. Question 1(B), 1(C), and 1(F) are related to question 1(A) in trying to probe for reasons. The data in **Table 6.6.1** showed that 3 pupils believed that the bottle will sink, 26 pupils believed that it will float and only 1 pupil is not sure whether it will sink or float. For the total of 3 pupils who believed that the bottle will sink, 2 pupils gave the reason by responding that it is heavy, while the remaining 1 pupil gave the reason that the bottle was made from glass and glass normally sinks in water. For the 26 pupils who believed that the bottle will float, 5 pupils reasoning with "it is lighter", 16 pupils reasoning with "it is full of air" and the remaining 5 pupils believed that it is caused by other reason or reasons. The pupil who is not sure whether the bottle will float or sink gave the reason that not enough information is provided in the question.

Summary:
As shown in the results, there were various forms of understanding detected which is shown by the reasonable distribution of pupils' choice of answers provided to the questions. It is interesting to note that a majority of the pupils believed that the bottle will float on the water, as the glass bottle was used in the question to link with everyday experience that glass normally sinks in water as it is made from heavy material. The notion of air inside the glass attracts a large number of pupil to believe that the bottle will float. Only one pupil is not sure of the choice.

2. Further testing the idea with a smaller glass bottle and plastic bottle (for pupils who responded that the glass bottle will sink in section 1)

Question	Answer				Total
	a	b	c	x	
1(D)	1	2	0	27	30
1(E)	2	1	0	27	30

Table 6.6.2

Question 1(D) and 1(E) were used only for the pupils who answered that the glass bottle will sink (answered "a" to question 1(A)). Question 1(D) is trying to further test the idea when the glass bottle is replaced with a much smaller glass bottle whereas in question 1(F) the glass bottle is replaced with a plastic bottle. As shown in **Table 6.6.2**, only 1 pupil believed that the smaller bottle will now float and 2 pupils still believed that the smaller bottle will sink. For the plastic bottle, 2 pupils believed it will float while the remaining pupil believed will not float.

Table 6.6.3 shows the cross-tabulation for question 1(D) and 1(E) with the answer to 1(A) = "a" (total 3 pupils)

The cross-tabulation further provides more detailed information. The data shows that:

- 1 pupil believed that both the small glass bottle and the plastic bottle will now float.
- 1 pupil believed that the small glass bottle will still sink but the plastic bottle will float.

- 1 pupil believed that in both cases, the bottle will still sink.

1(D)	a	b	c	Total
1(E)				
a	1	1	0	2
b	0	1		1
c	0	0	0	0
Total	1	2	0	3

Table 6.6.3

Summary:

Again, the results showed a variety of linkages which represented various forms of ideas or understanding. By comparing the case of the glass bottle with a smaller one and a plastic bottle provides a way to explore and challenge the pupils' understanding.

3. Determine what happens when sand is added into the glass bottle

Question	Answer				Total
	a	b	c	x	
2(A)	23	7	-	-	30
2(B)	10	10	3	7	30
2(D)	6	1	-	23	30
1(C)	20	0	-	10	30

Table 6.6.4

In this part, the pupils are presented with a new situation where a little sand is added into the glass bottle. Then the bottle's lid was replaced and put back into the water.

Question 2(A) is used to further diagnose or explore the pupils' idea with respect of the sinking or floating of the bottle when sand is added to the bottle. Question 2(B) and 2(D) are used to probe the reason for the case of floating and sinking respectively. Question 2(C) is asked if the response for question 2(B) is "a" or "b". The data in **Table 6.6.4** showed that 23 pupils answered that it still floats, but lower into the water. The remaining 7 pupils believed that it will sink. Looking into the reason given by the pupils, out of the 23 pupils who believed that it still float, the program detected that :

- 10 pupils believed that there is still enough air inside the bottle to make it float;
- 10 pupils believed that there is not enough sand being added to make it heavy enough to sink; and
- 3 pupils chose other reason or reasons.

For the case of 7 pupils who believed that the bottle still sinks (question 2(D)), 6 pupils believed that the bottle is now heavier whereas only 1 pupil believed that it is because not enough air is inside to make it float now.

All the twenty pupils who answered "a" or "b" to question 2(B), believed that if more sand is added into the bottle, the bottle will finally sink when enough sand is added.

Summary:
There were various forms of understanding detected in the findings which is shown by reasonable distribution of pupils' answer to the questions.

The following forms of cross-tabulation provide a more detailed linkage between the various understanding of the concepts.

(A) Cross tabulation for questions 1(A) and 2(A)

1(A)	a	b	c	Total
2(A)				
a	0	22	1	23
b	3	4	0	7
Total	3	26	1	30

Table 6.6.5

The cross tabulation in **Table 6.6.5** provides an interesting result. Out of 26 pupils who responded that the bottle (without sand) will float, 22 pupils still believed that the bottle (with sand added) will float, while the remaining 4 pupils now believed that it will sink. The single pupil who responded with 'not sure' in question 1(A), now believed that the bottle will float. The 3 pupils who responded that the bottle will sink in question 1(A) also consistently believed that it will again sink in the case of question 2(A).

Summary:
The finding shows some form of consistency in the pupils' answers. There is some indication that pupils will change their answer corresponding to common sense knowledge. For example, 4 pupils who believed that the bottle (without sand) will float, now believed that bottle (with sand) will sink.

(B) Cross tabulation for questions 2(A) and 2(B) with answer to question 1(A) is "b" (Total = 22 pupils)

2(B) / 2(A)	a	b	c	Total
a	10	9	3	22
Total	10	9	3	22

Table 6.6.6

The cross-tabulation in **Table 6.6.6** showed that out of the 22 pupils who responded that the bottle will float without sand or with sand (answer "b" to question 1(A) and answered "a" to question 2(A)) :

- 10 pupils believed that the reason is the bottle still has enough air inside it to make it float.
- 9 pupils believed that the reason is that the bottle is not heavy enough to make it sink.
- 3 pupils gave other reasons.

Summary:
The result shows a balanced distribution of pupils' answers to the questions.

(C) Cross tabulation for question 2(A) and 2(D) with answer to question 1(A) is "a" (Total = 3 pupils)

2(D) / 2(A)	a	b	Total
b	3	0	3
Total	3	0	3

Table 6.6.7

As shown in cross-tabulation in **Table 6.6.7**, all the pupils (total =3) who responded that the bottle will sink in both cases (with sand or without sand) believed that the heaviness of the bottle causes it to sink.

Summary:
The result indicates a consistent understanding among these pupils.

It is possible to carry out further cross-tabulations to compare the reason provided by the pupils for question 1(A) and 2(A). The important answer derived from this comparison is whether the reasons given by the pupil for the different questions is consistent.

(D) Cross tabulation for question 1(F) and 2(B)

The cross tabulation in **Table 6.6.8** compared the reason for the bottle to float given by the pupils for the cases of glass bottle with and without sand.

1(F)	a	b		Total
2(B)				
a	3	7	0	10
b	2	4	3	9
c	0	1	2	3
Total	5	12	5	22

Table 6.6.8

For pupils who believed that the bottle without sand floats (total=5 pupils) because it is lighter:

- 3 pupils now believed that the bottle (with sand) floats because it still has enough air.
- 2 pupils still believed that the bottle (with sand) floats because it is not heavy enough (lighter).

For pupils who believed that the bottle without sand floats (total=12 pupils) because it is full of air:
When sand is added to the bottle:

- 7 pupils still believed that the bottle floats because it still has enough air.
- 4 pupils now believed that the bottle floats because it is not heavy enough (lighter).
- 1 pupil gave other reason.

For pupils who believed that the bottle without sand floats (total=5 pupils) because of other reason:

- 3 pupils still believed that the bottle (with sand) floats because it is not heavy enough (lighter).
- 2 pupils still gave 'other reason' as the cause of floating.

Summary:
Although there were some cases which showed consistency in the reason given for the floating of the bottle, the data in the table show a great deal of inconsistency in the reasoning given by the pupils.

4. General understanding about the heaviness/lightness and amount of air with sinking and floating of an object

Question 2(E), 2(F) and 2(G) are used to test the general understanding about sinking or floating and its relation with heaviness/lightness and amount of air contained in an object. Only those who answer yes to 2(e) are asked question 2(f)

Question	Answer				Total
	a	b	c	x	
2(E)	14	16	-	-	30
2(F)	6	0	8	16	30
2(G)	23	7	-	-	30

Table 6.6.9

The data in **Table 6.6.9** showed that 14 pupils have a general belief that "heaviness" or "lightness" of an object causes it to sink or float. For these 14 pupils, when asked further whether "the heavier an object, the more likely it is to sink", 6 pupils agreed with the statement, while the remaining 8 pupils believed that it still depends on other factor or factors. For the next statement that is whether "the amount of air inside an object will cause it to float or sink in water", 23 out of total 30 pupils agreed with the statement, while the remaining 7 pupils did not agree.

Summary:
These general questions provide further information with regards to pupils' understanding of the topic of sinking and floating.

(A) Cross tabulation between question 2(E) and 1(F)

The cross tabulation in **Table 6.6.10** provides a way to compare the pupils' responses to the general statements with the previous responses with the case of glass bottle.

As shown in **Table 6.6.10**, for the case of floating, only 3 pupils showed a consistent belief in their answer to question 1(F) with the general statement that heaviness/lightness of an

2(E)	a	b	Total
1(F)			
a	3	2	5
b	6	10	16
c	2	3	5
x	3	1	4
Total	14	16	30

Table 6.6.10

object causes an object to float or sink. In another aspect, 10 pupils who answered that the bottle floats because it is full of air and at the same time did not believe with the general statement that heaviness/lightness of an object causes an object to float or sink. The rest of the pupils showed various forms of inconsistency.

(B) Cross tabulation between question 2(G) and 1(F)

Cross-tabulation shown in **Table 6.6.11** is for matching the pupils' response to the general statement that the amount of air inside an object will cause it to float or sink in water with their response to question 1(F). Question 1(F) inquired about the reason why the bottle floats on water.

2(G) / 1(F)	a	b	Total
a	4	1	5
b	12	3	15
c	4	2	6
x	3	1	4
Total	23	7	30

Table 6.6.11

As shown in **Table 6.6.11**, there are 12 pupils who show an exact matching. In other words, there is a wide agreement between pupils who agree with the general statement that the amount of air inside an object causes it to float or sink and the reason given in question 1(F) (by answering "b").

(C) Cross tabulation between question 2(E) and 1(C)

Cross-tabulation shown in **Table 6.6.12** is for matching the pupils response to the general statement that the heaviness/lightness of an object will cause it to float or sink in water with their response to question 1(C). Question 1(C) inquired about the reason why the bottle sinks in water.

2(E) / 1(C)	a	b	Total
a	1	1	2
b	1	0	1
c	0	0	0
x	12	15	27
Total	14	16	30

Table 6.6.12

Out of 3 pupils who gave the reason of heaviness (answering "a" or "b" in question 1(C)), 2 pupils agreed with the general statement that heaviness/lightness of an object causes an object to float or sink.

(D) Cross tabulation between question 2(G) and 1(C)

Cross-tabulation shown in **Table 6.6.13** for matching the pupils response to the general statement that the amount of air inside an object will cause it to float or sink in water to their response to question 1(C) which inquires about the reason why the bottle sinks in water.

2(G) / 1(C)	a	b	Total
a	1	1	2
b	1	0	1
c	0	0	0
x	20	7	27
Total	22	8	30

Table 6.6.13

As shown in the data in **Table 6.6.13**, only 1 pupil shows a consistent understanding by believing that the bottle sinks because it is heavy and at the same time did not believe with the general statement that the amount of air inside an object will cause it to float or sink in water.

Summary:
The various cross tabulation analysis shows that there exists a consistency in the pupils' responses. For example, there is a greater consistency in the pupil reasoning with respect of agreeing with the general statement that the amount of air inside an object to cause it to float or sink and by responding that "it is full of air" to question 1(F) which asked why the bottle floats. On the other hand, there also exist various forms of inconsistency in the answers, as shown in the various cases.

5. General explorative questions

The questions in this part are used to further explore the various pupils' understanding. These questions could provide more in-depth study of those pupils who the program diagnosed as believing that it is heaviness or lightness that determines whether an object floats or sinks in water and/or the amount of air contained in an object that determines whether an object floats or sinks in water.

From the results of the pupils trials, the program has diagnosed that :

- 6 pupils believe that heaviness or lightness determines whether an object floats or sinks in water.
- 9 pupils believe that the amount of air that is contained in an object determines whether an object floats or sinks in water.

(A) For "heaviness/lightness" reasoning

Question 3(a) to 3(d) are only asked of those pupils who the program diagnosed to believe that heaviness of an object is an important factor that determines whether an object floats or sinks in water. The findings are shown in **Table 6.6.14**.

Question	Answer				Total
	a	b	c	x	
3(A)	1	5	-	24	30
3(B)	3	2	1	24	30
3(C)	5	1	-	24	30
3(D)	3	0	3	24	30

Table 6.6.14

For the statement that "a ship is very much heavier than the glass bottle, but it floats" :

- 5 pupils thought that other reason or reasons make it float.
- Only 1 pupil answered that it is because the ship is also very large.

For the statement that "objects will float if they are light for their size" :

- 3 pupils agreed with this statement.
- 2 pupils did not agree with this statement.
- 1 pupil was not sure.

For the statement that "heavy object (large mass) can be made to float if it has a large volume" :

- 5 pupils agreed with this statement.
- 1 pupil did not agree with this statement.

For the statement that " will a tanker which is loaded with 400 000 tonnes of oil float?"

- 3 pupils responded that it will float (common sense).
- 3 pupils responded that it cannot be answered unless one knows the volume of the tanker.

Summary :
The results show the various forms of inter-related ideas with respect to these explorative questions. It is interesting to note that out of the total 6 pupils, 5 pupils believed that other reason or reasons cause the ship to float on water.

(B) For "amount of air" reasoning

Question 4(A) and 4(B) are only asked of those pupils who the program diagnosed to believe that the amount of air contained in an object is an important factor that determines whether an object floats or sinks in water. Question 4(B) are only for pupils who answered "a" to question 4(A). The finding was shown in **Table 6.6.15**.

Question	Answer			Total
	a	b	x	
4(A)	6	3	21	30
4(B)	2	4	24	30

Table 6.6.15

For the statement: "why an ice cube (which almost contains no air inside it) floats on water ?"

- 6 pupils responded because it is lighter than water.
- 3 pupils were not sure.

For the 6 pupils who believed that the ice cube floats on water because it is lighter than water, they were asked to respond to the next statement : "do you mean that the "heaviness or lightness" of an object cause it to sink or float ?" :

- 2 pupils agreed with statement.
- 4 pupils did not agree with this statement.

Summary:
It is interesting to note that out of 6 who answered that it floats because it is lighter than water in question 4(a) , only 2 agree with the statement that heaviness/lightness of an object causes an object to sink or float.

6.6.1.1 Conclusion

Several points arise from these results :

(1) In general, the main purpose of this diagnostic testing, to diagnose the pupils into 2 distinctive groups was successful, although within a constraint that it requires a greater

consistency in the pupils' responses. Out of the 30 pupils, 6 pupils were diagnosed to believe that heaviness or lightness of an object determines whether it floats or sinks in water, while 9 pupils were diagnosed to believe that the amount of air contained in the object determines whether it floats or sinks in water. At this stage, the diagnosis rule determined that the remaining 15 pupils did not reach a minimum level for inclusion into either group.

(2) As the format of this topic is rather different from the other topics, the analysis was rather limited in the sense that it was only trying to arrange pupils into 2 possible groups. Within this constraint, as shown in the results of the analysis, the program is very useful for in-depth explorative study on the pupils' basic understanding and the various inter-relation of ideas on the topic of sinking and floating.

(3) At this stage, the rules are only designed to be able to make decisions based on certain simple clear-cut basic cases only. For instance, if the overall responses of a pupil did not reach a certain probability value, then the program could not make a decision. By analysing the pupils' responses, more rules could be added to cater for the various forms of reasoning. Several forms of in-depth relationship between the pupils' responses were detected as shown in the analysis. For example, as shown in the findings of cross tabulation between answer 2(G) and 1(C), a number of pupils who were showing a conflicting belief in their responses. The conflicting cases have not been included in determining the value of the probability criteria. Some of the conflicting understandings are listed as follows :

1. There are a number of pupils who gave the reason that the bottle floats because it is lighter but at the same time did not agree with the general statement that "heaviness" or "lightness" of an object causes it to float or sink in water.

2. There are a number of pupils who gave the reason that the bottle sinks because it is heavy but at the same time did not agree with the general statement that "heaviness" or "lightness" of an object causes it to float or sink in water.

3. There are a number of pupils who gave the reason that the bottle floats because it is full of air but at the same time did not agree with the general statement that the amount of air contained inside an object will cause it to float or sink in water.

4. There are a number of pupils who gave the reason that the bottle sinks because it is heavy but at the same time agreed with the general statement that the amount of air contained inside an object will cause it to float or sink in water.

It is possible that additional rules could be added into the knowledge base to ask further questions with the intention to challenge these forms of conflicting answers. As an example, a rule for the conflicting understanding in part (I) could be:

IF answer to question 1(F) is "a"
AND answer to question 2(E) is "b"
THEN conflicting_idea is detected
ask further questions

The answers from the extra questions could then be used to change the value of the probability criteria for possible inclusion into either of the groups.

(4) The explorative part of questioning (questions 3 and 4) also provides some information for inclusion into further development of the program. For example the following rule could be added that challenges any conflicting understanding as shown in question 4(B):

IF user is diagnosed to have "amount of air" reasoning
AND user responds that heaviness/lightness of ice-cubes cause it to float on water
THEN there exists a conflicting of understanding
ask more questions

Another possible additional rule could be :

IF user is diagnosed to have "heaviness/lightness" reasoning
AND users responds that "other reasons" causes the ship to float
THEN more detailed questioning is needed.

(5) The analysis shows that there was a reasonable distribution of answers to all the questions. So, in general, it can be inferred that the questions are well understood by the pupils. In other words, the question level is suitable for the proposed age level of the pupils.

(6) In this topic, the pattern of pupils' answers is rather unpredictable. To a certain degree, this could be due to the nature of the questions used. One limiting aspect of the questions is that there is not enough provision provided for the pupils with alternatives in the multiple-choice answers especially for brighter pupils. For example, it could provide more interesting results if the concept of density could be included in the earlier part of the questioning. As this diagnosis is more toward explorative types of diagnosis, this limitation could be justified.

6.6.2 Typical Sample of Individual Pupil's Responses

The discussion is divided into two sections. In the first section, the classification performance of the program is described. Since the main criteria for classification of pupils into the three pre-defined groups as described below was based on a minimum value of a certainty index, these listings provide a way of analysing the values of the certainty indexes for "heaviness/lightness" reasoning and "amount of air" reasoning in order to check for any discrepancy in grouping the pupils into various groups. The second section discusses the diagnosis feedback of three pupils which represents typical cases diagnosed by the program.

For each individual pupil, the program would diagnose into the three categories of :

- "heaviness or lightness" reasoning
- "amount of air" reasoning
- indecisive group

6.6.2.1 Probability Indices and Classification Rule

This section analyses the whole 30 pupils' responses in order to justify the methodology proposed for the program classification rule.

Table 6.6.16 shows the relationship between the pupils' responses and the value of HI (Heaviness Index), AI (Air Index) and absolute (HI-AI).

The data in **Table 6.6.16** shows that :

1. The maximum value of |HI-AI| is 0.94
   The minimum value of |HI-AI| is 0.00

2. Example of some distinctive cases:

(a) Pupil 30 : Diagnosis result is "amount of air" reasoning, AI index = 0.88, HI index = 0.00
All the responses were directed towards an understanding that the amount of air contained inside an object causes it to float or sink in water.

(b) Pupil 14 : Diagnosis result is "heaviness/lightness" reasoning, HI index = 0.94, AI index = 0.00
All the responses were directing towards an understanding that the heaviness or lightness of an object causes it to float or sink in water.

Pupil	Heaviness causes bottle (without sand) to sink/float	Amount of air causes bottle (without sand) to sink/float	Smaller bottle will float	Plastic bottle will float	Heaviness causes bottle (with sand) to sink/float	Amount of air causes bottle (with sand) to sink/float	Agree with statement 1	Agree with statement 2	HI Index	AI Index	|HI-AI|	Diagnostic Result
1	no	no	x	x	yes	no	yes	yes	0.75	0.50	0.25	none
2	no	yes	x	x	no	yes	no	no	0.00	0.75	0.75	air
3	no	yes	x	x	no	yes	no	yes	0.00	0.88	0.88	air
4	no	yes	x	x	yes	no	no	no	0.50	0.50	0.00	none
5	no	yes	x	x	no	yes	no	yes	0.00	0.88	0.88	air
6	no	no	x	x	no	no	no	yes	0.00	0.50	0.50	air
7	no	yes	x	x	no	no	no	yes	0.00	0.75	0.75	air
8	no	no	x	x	yes	no	yes	yes	0.50	0.75	0.25	none
9	no	no	x	x	yes	no	no	no	0.50	0.00	0.50	heaviness
10	no	no	x	x	no	no	no	no	0.00	0.00	0.00	none
11	no	no	x	x	yes	no	yes	yes	0.75	0.50	0.25	none
12	no	yes	x	x	no	yes	no	yes	0.00	0.88	0.88	air
13	yes	no	x	x	yes	no	no	no	0.75	0.00	0.75	heaviness
14	yes	no	yes	yes	yes	no	no	yes	0.94	0.50	0.44	heaviness
15	yes	no	x	x	no	yes	yes	yes	0.75	0.75	0.00	none
16	yes	no	no	no	yes	no	yes	yes	0.88	0.50	0.38	heaviness
17	yes	no	no	yes	yes	no	yes	no	0.94	0.00	0.94	heaviness
18	no	yes	x	x	yes	no	no	yes	0.50	0.75	0.25	none
19	no	yes	x	x	no	yes	yes	yes	0.50	0.88	0.38	air
20	no	yes	x	x	yes	no	yes	yes	0.75	0.75	0.00	none
21	no	yes	x	x	yes	no	no	yes	0.50	0.75	0.25	none
22	yes	no	x	x	yes	no	yes	yes	0.88	0.50	0.38	heaviness
23	no	yes	x	x	yes	no	yes	no	0.75	0.50	0.25	none
24	no	yes	x	x	yes	no	yes	yes	0.75	0.75	0.00	none
25	no	yes	x	x	no	yes	no	yes	0.00	0.88	0.88	air
26	yes	no	x	x	no	yes	yes	yes	0.75	0.75	0.00	none
27	yes	no	x	x	no	yes	no	yes	0.50	0.75	0.25	none
28	no	yes	x	x	no	yes	yes	yes	0.50	0.88	0.38	air
29	no	yes	x	x	yes	no	yes	yes	0.75	0.75	0.00	none
30	no	yes	x	x	no	yes	no	yes	0.00	0.88	0.88	air

Table 6.6.16 : Relationship between pupils' responses and values of HI and AI

(c) Pupil 10 : Diagnosis result is "undecided", HI index = 0.00, AI index = 0.00
All the responses are not tending towards either type of understanding.

3. Examples of some borderline cases

(a) Pupil 11 : Diagnosis result is "undecided", HI index = 0.75, AI index = 0.50, |HI-AI| = 0.25
Only two responses are tending towards an understanding that heaviness or lightness of an object causes it to float or sink in water, but because the pupil also agreed with statement 2 (amount of air reasoning), the program could not make a distinctive decision.

(b) Pupil 21 : Diagnosis result is "Heaviness" reasoning, HI index = 0.88, AI index = 0.50, |HI-AI| = 0.38
Since all the responses are tending towards an understanding that heaviness or lightness of an object causes it to float or sink in water, although the pupil also agreed with statement 2 (amount of air reasoning), the program made a "heaviness/lightness" reasoning decision.

4. Example of contradictory cases

(a) Pupil 20 : Diagnosis result is "undecided", HI index = 0.75, AI index =0.75
Two groups of responses are tending towards an understanding that heaviness or lightness of an object causes it to float or sink in water and at the same time another two groups of responses are tending towards an understanding that the amount of air contained inside an object causes it to float or sink in water. Both the HI and AI indexes have the same value.

The same scenario occurs for the cases of pupil 15, pupil 26 and pupil 29.

(b) Pupil 4 : Diagnosis result is "undecided", HI index = 0.50, AI index =0.50
One group of responses are tending towards an understanding that heaviness or lightness of an object causes it to float or sink in water and at the same time another one group of responses are tending towards an understanding that the amount of air contained inside an object causes it to float or sink in water. Both the HI and AI indexes have a same value.

6.6.2.1.1 Summary of the Results of the Classification Rule

1. The result shows that the program works correctly in using the cut-off number as a decision factor. For all cases where |HI-AI| greater than 0.35, the program made a decision

into either group. Similarly, for all cases for |HI-AI| less than 0.35, an "undecided" case was detected.

2. Analysis of the borderline cases shows that the chosen arbitrary number is working as intended. That is when the program detected that all the responses of a specific pupil are tending towards a particular reasoning and at the same time the pupil agreed with the general statement of the opposite reasoning, then the program is still able to make a decision towards that particular reasoning. If not all of the responses are tending toward a particular reasoning, but at the same time the pupil agreed with the general statement of the opposite reasoning, then the program could not make a distinctive decision. The results of pupil 11 and pupil 21 clearly differentiate between the two cases.

This second section discusses the diagnosis feedback of three pupils which represented typical cases diagnosed by the program. The pupil responses to the questions were illustrated as a basis for the author to compare them with the diagnosis feedback from the program. It formed a summary of the way three typical students used the program to provide some idea of the variation found.

6.6.2.2 Pupil F30

Diagnostic Test: Floating and Sinking

Date:10-June-94 11:18
Student Name: (name deleted)

This program detected that you believe :

AMOUNT OF AIR CONTAINED

is the reason that causes objects to float or sink in water.

Table 6.6.17 : Pupil F30 Diagnostic Feedback

1. Determine whether a sealed glass bottle (full of air) will sink or float on water and to detect a reason for the choice

Question	Q1(A)	Q1(B)	Q1(C)	Q1(F)
Answer	b	x	x	b

Pupil F30 believed that :

- The sealed glass bottle will float on the water.
- The bottle floats on the water because it is full of air.

2. Further testing the idea with a smaller glass bottle and plastic bottle (for pupils who responded that the glass bottle will sink in section 1)

Question	Q1(D)	Q1(E)
Answer	x	x

Pupil F30 did not answer these questions as he/she answered the bottle will float in part (1).

3. Determine what happens when sand is added into the glass bottle

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	a	a	a	x

Pupil F30 believed that :

- When a little sand was added into the bottle, the bottle still floats but lower into the water.
- It still has enough air inside to make it float.
- When enough sand is added, the bottle will finally sink.

4. General understanding about the effect of heaviness/lightness and amount of air on sinking and floating of an object

Question	Q2(E)	Q2(F)	Q2(G)
Answer	b	x	a

Pupil F30 believed that :

- Heaviness or lightness of an object does not cause it to sink or float in water.
- The amount of air contained inside an object will cause it to float or sink in water.

5. General explorative questions

(a) Detected "heaviness/lightness" reasoning

Question	Q3(A)	Q3(B)	Q3(C)	Q3(D)
Answer	x	x	x	x

Pupil F30 did not answer questions 3(A) to 3(D) because the program detected him/her as believing that the amount of air causes an object to sink or float.

(a) Detected "amount of air" reasoning

Question	Q4(A)	Q4(B)
Answer	a	b

Pupil F30 believed that :

- Although an ice cube contains almost no air, it will float on water because it is lighter than water.
- Heaviness or lightness of an object does not cause it to sink or float.

6.6.2.2.1 Summary of Pupil F30 Responses

The pattern of pupil F30 responses is matching exactly with the program's feedback that the pupil believed that the amount of air contained inside an object causes it to float or sink in water. This understanding seems to be consistent throughout all of the questions.

6.6.2.3 Pupil F17

Diagnostic Test: Floating and Sinking

Date:10-June-94 9:16
Student Name: (name deleted)

This program detected that you believe :

HEAVINESS

is the reason that causes objects to float or sink in water.

Table 6.6.18 : Pupil F17 Diagnostic Feedback

1. Determine whether a sealed glass bottle (full of air) will sink or float on water and to detect a reason for the choice

Question	Q1(A)	Q1(B)	Q1(C)	Q1(F)
Answer	a	x	a	x

Pupil F17 believed that :

- The sealed glass bottle will sink in the water.
- The bottle sinks in the water because it is heavy.

2. Further testing the idea with a smaller glass bottle and plastic bottle (for pupils who responded that the glass bottle will sink in section 1)

Question	Q1(D)	Q1(E)
Answer	b	a

Pupil F17 believed that :

- When the glass bottle is replaced with a smaller glass bottle, it will still sink.
- When the glass bottle is replaced with a PLASTIC bottle, it will now float.

3. Determine what happens when sand is added into the glass bottle

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	b	x	x	a

Pupil F17 believed that :

- When a little sand was added into the bottle, the bottle will sink into the water.
- The bottle with sand sinks because now it is heavier.

4. General understanding about the effect of heaviness/lightness and amount of air on sinking and floating of an object

Question	Q2(E)	Q2(F)	Q2(G)
Answer	a	a	b

Pupil F17 believed that :

- Heaviness or lightness of an object causes it to sink or float in water.
- The heavier an object, the more likely it is to sink. It depends on other factor(s).

- Does not agree that the amount of air contained inside an object will cause it to float or sink in water.

5. General explorative questions

(a) Detected "heaviness/lightness" reasoning

Question	Q3(A)	Q3(B)	Q3(C)	Q3(D)
Answer	b	b	a	a

Pupil F17 believed that :

- There is other reason(s) that a ship floats on water
- The objects will not float if they are light for their size.
- A heavy object (large mass) can be made to float if it has a large volume.
- A tanker which is loaded with 400 000 tonnes of oil will float on water.

(b) Detected "amount of air" reasoning

Question	Q4(A)	Q4(B)
Answer	x	x

Pupil F17 did not answer questions 4(A) and 4(B) because the program detected him/her as believing that heaviness or lightness of an object causes it to sink or float.

6.6.2.3.1 Summary of Pupil F17 Responses

The pattern of pupil F17 responses is matching exactly with the program's feedback that the pupil believed that the heaviness or lightness of an object causes it to float or sink in water. This understanding seems to be consistent throughout all the questions. The responses to the explorative questions show some evidence of understanding of the effect of volume and mass of an object and its relation to sinking and floating.

6.6.2.4 Pupil F20

Diagnostic Test: Floating and Sinking ------------------------------------ Date:10-June-94 11:23 Student Name: (name deleted) This program COULD NOT detect any specific reason between : HEAVINESS AND AMOUNT OF AIR CONTAINED that you believe causes an object to float or sink in water.

Table 6.6.19 : Pupil F20 diagnostic Feedback

1. Determine whether a sealed glass bottle (full of air) will sink or float on water and to detect a reason for the choice

Question	Q1(A)	Q1(B)	Q1(C)	Q1(F)
Answer	b	x	x	b

Pupil F20 believed that :

- The sealed glass bottle will float on the water.
- The bottle floats on the water because it is full of air.

2. Further testing the idea with a smaller glass bottle and plastic bottle (for pupils who responded that the glass bottle will sink in section 1)

Question	Q1(D)	Q1(E)
Answer	x	x

Pupil F20 did not answer these questions as he/she answered the bottle will float in part (1)

3. Determine what happens when sand is added into the glass bottle

Question	Q2(A)	Q2(B)	Q2(C)	Q2(D)
Answer	b	x	x	a

Pupil F20 believed that :

- When a little sand was added into the bottle, the bottle will sink into the water.
- The bottle with sand sinks because now it is heavier.

4. General understanding about the effect of heaviness/lightness and amount of air on sinking and floating of an object

Question	Q2(E)	Q2(F)	Q2(G)
Answer	a	a	a

Pupil F20 believed that :

- Heaviness or lightness of an object causes it to sink or float in water.
- The heavier an object, the more likely it is to sink. It depends on other factor(s).
- Agree that the amount of air contained inside an object will cause it to float or sink in water.

5. General explorative questions

(a) Detected "heaviness/lightness" reasoning

Question	Q3(A)	Q3(B)	Q3(C)	Q3(D)
Answer	x	x	x	x

Pupil F20 did not answer questions 3(A) to 3(D) because the program could not detect any specific category for this pupil.

(b) Detected "amount of air" reasoning

Question	Q4(A)	Q4(B)
Answer	x	x

Pupil F20 did not answer questions 4(A) and 4(B) because the program could not detect any specific category for this pupil.

6.6.2.4.1 Summary of Pupil F20 Responses

The responses to all the questions show that pupil F20 seems to believe that both the object's heaviness/lightness and the amount of air it contains causes it to float/sink in water, so the program could not make a decision in this case. There is a complete agreement between pupil F20 responses with the program's diagnostic feedback.

6.6.2.5 Conclusion

Several points arise from this analysis of a sample of individual pupil's responses.

(1) Within the competence of the pre-planned classification rule and the limitation of the questions used, the ability of the program to make a correct decision in placing the pupil into the specific group is clearly justified as described in the discussion of section 6.6.2.1.

(2) In general, there is good agreement between the diagnosis made by the program and the pupils' responses. This agreement provides sufficient evidence for the program to be used as a tool for providing a useful insight into pupil understanding in this topic.

(3) There exist a number of cases where the program could not identify the pupils into either of the groups. This is due to the contradictory understanding as shown in the pupils' responses. For example, in some of the cases, although the general pattern of responses is showing that a pupil has an understanding that the bottle sinks because it is heavy, at the same time part of the responses also show the pupil did not believe with the general statement in question 2(G) that heaviness/lightness of an object causes it to float or sink.

CHAPTER 7

TEACHER EVALUATION

7.1 Overview

The overall objective of the evaluation was to elicit teacher reaction to the prototype diagnostic testing system. The second form of program evaluation involved getting several volunteer teachers to participate in the validation of the prototype expert system program. If teacher judgements are to be used as the standard for adequate performance, the opinions of the teacher must be gathered for the cases used in the evaluation study. In this study, the teacher acted as an expert in order to compare the pupils' responses to the diagnostic questions with the diagnostic feedback generated by the prototype program. At the same time, the teacher was also requested to examine important aspects of the program, for example the quality of the system-user interface. This evaluation is considered as one of the most important steps for this diagnostic program, since it gives the expert a way of evaluating system-generated results in the real educational setting. The specific objective is to evaluate several important aspects of the program based on a five-point scale ranging from "strongly agree" to "strongly disagree" and also to provide teachers with the facility to note down any remarks they want to make regarding the program.

The evaluation methods used in this study were:

- running the program on a selection of test cases for diagnostic feedback comparison;
- examining the specific important attributes of the program; and
- asking teachers to complete a questionnaire concerning the overall usability of the system.

7.2 Evaluation Procedure

An invitation letter was sent to twenty science teachers in the area, selected on a basis of the schools and science teachers known to the institution through initial teacher training. The response was low (with one return) so departmental and personal contact was used to secure fourteen teachers in all. This difficulty was not unforeseen due to the pressures on science teachers at the time due the National Curriculum implementation.

A questionnaire was designed to focus on key issues to keep teachers' time to a minimum. It was also important to note that since the expert system was still a new technology in education and as a large number of teachers have never been exposed to expert system technology, the evaluation process was more inclined toward evaluation of the system interface, the diagnosis results and the diagnostic questions used in the program.

All the teachers were given the same tasks. First of all, the evaluators were given some background information about the project and what they had to do. In order to provide a complete and fair evaluation, teachers were encouraged to:

- work through all the topics available in the program, if possible;
- work through the program as many times as required; and
- ask any questions at any time during the evaluation session.

For the evaluation purposes, the teachers were specifically asked to :

1. assess the quality of the program's attributes;
2. compare the diagnostic results as generated by the program with their own judgement; and
3. assess the suitability of the questions used in the program.

At the end of the evaluation session, the evaluator was asked to complete a questionnaire designed to assess several characteristics of the prototype system.

7.2.1 Assessing the Quality of the Program's Attributes

At the beginning of the evaluation session, the teachers were shown the running of the system by choosing an option in a specially created batch file in order to familiarise themselves with the system. They were required to examine the program's attributes, namely, the on-screen information, the input and output operation of the program, the error messages and the overall running of the program. This process was repeated until the teachers were really familiar with the program.

7.2.2 Comparing the Diagnostic Results as Generated by the Program with Teacher Estimated Judgement

For the sole purpose of comparing the diagnostic results, it was decided that it was reasonable to simplify the evaluation task by using the special replay function of the expert system shell. The replay function allows the program to be rerun by using the previous answers which were kept in a special file. Then the teachers would be able to look through the pupil's answer during the rerun and then make comparison of their own judgement with the diagnostic results as provided by the program. For this purpose, a detailed text file comprising the set of answers for a specific pupil on each topic was compiled. These special text files were used to run the program as a demonstration or feedback session with the teacher. Only the information contained in the file was used as an input to the program, and no modifications were made to the program.

For each topic available in the program, five distinctive cases from the pupil trial were selected to be replayed by the program. The teachers were asked to chose at random from the menu one case of the pupil's sample answers to a specific topic. When a topic had been selected, a sample testing program would use a set of real answers from a pupil in the school based trial. The teachers were then required to compare their judgement of the pupil's answers with the diagnostic feedback given by the program at the end of each topic session.

7.2.3 Assessing the Suitability of the Questions Used in the Program

For the purpose of assessing the suitability of the questions used in the program, the teachers were provided with a copy of the complete printed set of the questions for each topic. They could then write down any remark or comment regarding the questions used. A flowchart showing the sequencing of the questions was also made available for easy reference.

7.3 Batch file

A simple batch file was created to provide a quick and easy menu style interface for the teacher to select the required set of questions. The structure of the batch file is shown in **Figure 7.1**. Options 1, 2, and 3 reroute to the actual diagnostic program for the topics of Electricity, Floating and Sinking, and Speed and Graphs respectively. These options allowed the teachers to actually work through the program in order to familiarise themselves. Options 5, 6 and 7 provide a choice to make a sample run for the topics of Electricity, Floating and Sinking and Speed and Graphs respectively with pupils' responses. These options provided a convenient method for the teacher to run the sample cases for judgement comparison. **Figure 7.2** shows the next stage of the batch file when the user selected option 5, where 5 sample cases of pupils' answers were available.

```
*******************
Topic  Available :
*******************
1.        Electricity

2.        Floating and Sinking

3.        Speed and Graph

4.        Return to DOS

=================================
5.        Sample  :  Electricity

6.        Sample  :  Floating/Sinking

7.        Sample  :  Speed and Graph

=================================

Type the number you want and press ENTER  :
```

Figure 7.1 Structure of the batch file

```
********************************
          Sample  :  Electricity

1.        Student  A

2.        Student  B

3.        Student  C

4.        Student  D

5.        Student  E

0.        Finish

********************************
To choose  :  type  e [space] number
********************************

Your  Choice ?  :
```

Figure 7.2 Structure of the batch file : sample run for the topics of Electricity

7. 4 Questionnaire

In the questionnaire, the following criteria were assessed:

(a) On-screen Information :

Clear and easy to view screen layout

Display of relevant messages

Use of colour to separate different sections on screen

Graphic on the screen

(b) User-system Interaction :

prompting for user reaction

(c) System Diagnosis Feedback :

results of diagnosis

format of diagnosis

(d) Suitability of Questions :

The complete questionnaire is listed in **Appendix G1**. The questionnaire was adapted from one proposed by Morris (1993).

Each criterion is assessed by a number of questions in which the teacher is asked to tick one of the five alternative options. There is also a space provided for additional comments at the side of each question. The teacher was also asked to give a general assessment of each criterion using a five-point scale ranging from "strongly agree" to " strongly disagree". Finally, the teachers were asked some "open" questions which allowed them to express their opinions concerning the best and worst aspects of the system, those aspects which caused most difficulty, and suggested improvements.

7. 5 Result of Teacher Evaluation

The results discussed in this section are based on the questionnaire responses given by the teachers who took part in the study. In order for comparisons to be made between different aspects of the program a rating system was devised. Scores were allocated for each response as follows:

Score	Rating
5	strongly agree
4	agree
3	neutral
2	disagree
1	strongly disagree

A total score for each question was obtained and the average was calculated to give results between 1 and 5. High scores represented the most favourable responses. The small sample of teachers does not provide data which lends itself to any particular statistical analysis, so the data is analysed for any particular trends and extremes.

For the purpose of discussion and as a simple guide, the following criteria of user acceptance are suggested:

- An average rating of 4 and above could be considered as a good characteristic of the program;
- An average rating between 3 and 4 could be considered as an acceptable characteristic of the program; and
- An average rating of below 3 could be considered as a need-to-revise characteristic of the program.

7.5.1 On-Screen Information

Statement/Question	Rating
3. The use of colour helps to make the display clearer.	4.4
7. The graphic helps to make the questions more understandable.	4.3
1. The separation of text, input and graphic area helps make the screen display clear.	4.2
8. The graphic is well illustrated on the screen.	4.1
2. The information on the screen is easy to see and read.	4.0
4. The prompts or message clearly indicate what to do next.	3.9
5. The messages displayed by the system are relevant.	3.9
6. The important parts of questions are properly highlighted.	3.9
Overall, how would you rate the system in terms of on-screen information ?	4.2

Table 7.1 On-Screen Information

Table 7.1 presents the findings for on-screen information. The results show that in general teachers were largely satisfied with the way text and graphics were displayed on the screen. The results show that the teachers gave a high rating to the use of colour to help make the text and graphic display clearer, the presence of graphics helps make the questions more understandable, and the separation of areas for text, graphic and input helps make the screen display clearer.

The teachers were relatively less happy with the messages or prompting attributes of the program. Since at this stage, the program only provides a basic system of message display or prompting, this rating is still acceptable.
The teachers were less happy with the way that important parts of the questions are being properly highlighted; this needs to be carefully examined. Some other form of highlighting the important parts of questions could be considered, for example blinking, underline or using different colours.

Overall, the teachers rated the system in term of on-screen information quite favourably.

7.5.2 User-System Interaction

Statement/Question	Rating
5. The method of entering answers is consistent throughout the system.	4.4
4. The user could easily key in the answer to the question	4.3
6. The movement from one part to another part is clear	4.1
7. The action that the user needs to take at any stage is clear	4.1
3. The user could easily change the input (answer).	3.8
1. The system clearly informs the user when it detects an input error.	3.7
2. The user could easily correct the input errors.	3.7
Overall, how would you rate the system in term of user-system interaction ?	4.2

Table 7.2 User-System Interaction

Table 7.2 shows the findings for user-system interaction. The teachers were satisfied with :

- easy and consistent method of entering the answer to the question
- clarity of movement from one part of the program to another part
- clarity of action that needs to be taken by the user during the testing

The teachers in general were less happy with the way the system notified the user of input error, correcting any wrong input and the changing of input. Nevertheless, the average points are still within an acceptable range.

The other alternative form of user-system interaction is through a menu system. Unfortunately, although menu selection is one of the features of Leonardo, the requirement of the program is that the diagram or graphics have to be displayed together with the question text. This makes it necessary to convert the screen from normal text to graphic screen and the production of a simple menu form of interaction becomes more complicated.

In general, it can be concluded that teachers were happy with the user-system interface of the program as shown by the average point of 4.2 given to this criteria.

7.5.3 System Diagnostic Feedback

Statement/Question	Rating
1. The results of diagnosis are clearly and concisely displayed.	4.0
3. The diagnosis results are consistent.	3.9
4. The diagnosis results are accurate.	3.8
2. The format of diagnosis results is informative to user.	3.4
Overall, how would you rate the system in term of system diagnostic feedback ?	3.9

Table 7.3 : System Diagnostic Feedback

Table 7.3 presents the findings for system diagnostic feedback. The results showed that generally the teachers were satisfied with the clarity and conciseness of the results of the diagnosis. They also accepted that the diagnosis results are consistent and accurate. Although the rankings were not very high, they were still within the acceptable range. The teachers were less satisfied with the format of the diagnostic results to the user. The user in this context is a pupil. They thought that the format is more suitable for a discussion between teacher and pupil. For example, one of the teachers commented that "Diagnosis is correct, but it does not inform the student of any misconception, or what to do about them."

The overall rating for the program in terms of diagnostic feedback is acceptable but provides an indication of possible future development.

7.5.4 Suitability of Questions

Statement/Question	Rating
3. The sequence of questions is appropriate.	4.1
4. It is possible to diagnose pupil understanding by using the questions.	3.7
1. The wording of questions suitable to the pupils level of understanding.	3.6
2. The alternative answers given are adequate.	3.6

Table 7.4 Suitability of Questions

Table 7.4 presents the findings for suitability of questions. Since this part of evaluation is very subjective, the average point scored for all aspects, except for the sequencing part, were relatively lower than other section. It seemed that overall teachers were satisfied with the suitability of the questions for diagnostic purposes. They were specifically satisfied with the level of wording used in the questions and adequacy of the alternative answers provided in the questions. Particularly high ratings were given to the appropriateness of the sequencing of the questions. Some of the teachers responded very positively to the way the questions sequence depended on previous response.

The greatest problem identified is in the area of the questions for the sinking/floating topic. Since this particular topic did not conform to the traditional form of testing, where there is a clear correct answer, several teachers have some reservation about this form of diagnostic process. The teachers seemed to be more comfortable with the traditional form of questioning.

7.5.5 "Open" Question

The "open" question part of the questionnaire was an attempt to elicit some further comments from the teachers regarding several general aspects of the program.

Comments were generally encouraging/positive and some constructive suggestions were made. Nevertheless, some parts of the open question were left blank by the teachers. Most of the comments were individualised in nature and concentrated on a variety of specific aspects of the program. Responses to these open-questions are summarised in the following section.

7.5.5.1 Best Aspect of the Program

The majority of the teachers considered that the best aspect of the system was that it is easy to use and provided a clear screen layout. Two of them also considered that the sequencing of the questions was the best aspect of the system. Some teachers also believed that overall, the system could provide an alternative to help identifying pupils' misunderstanding in science.

Several specific comments about the best aspects of the system :

- quick, clear, and easy to use;
- clear questions, good graphics;
- easy to use, clear screen layout;
- logical structure in questioning, that is using the pupil answers to select/display next question; and
- helps identifying problems in understanding.

7.5.5.2 Worst Aspect of the Program

Eight teachers chose not to write any comment for this part. For the remaining teachers, several specific comments about the worst aspects of the system :

- program's display needs to be more exciting;
- need to provide more responses with listed option;
- format of feedback provided by the program; and
- input section of the system.

7.5.5.3 Common Mistakes

Only 2 teachers responded in this part. One of them complained about not reading everything on the screen and the other about pressing a wrong key

7.5.5.4 Improvement of the Program

A few suggestions were made on how to improve the program. These include:

- much more depth in the diagnosis knowledge base is needed as at the present stage it appears to be no immediate advantage over a conventional test, except on teacher time;

- there is a need to add some aspect of instant correction to pupils' misunderstanding. Some teachers suggested that the program could become part of an integrated computerised learning system ; and
- the screen display needs to be more exciting. In this case, using a graphic user interface (GUI) could provide a more professional screen display.

7.6 Conclusion

The findings from this evaluation provided valuable insight into how the program functioned. In general the teachers' reactions were positive and indicated that the prototype program was effective and would be appropriate for classroom use. However, many of their comments require careful consideration for future projects incorporating the use of expert system technology in diagnostic testing.

As a summary, a brief discussion of several important aspects of these findings are listed below.

- In general, teachers were quite satisfied with the program. Almost all the ratings could be rounded off to a scale of 4 which represents the key "Agree". Most teachers commented on the quickness of the diagnosis and the usefulness of the program in testing understanding in science. Only one teacher complained about the slowness of the program.

- When comparing the program-generated diagnosis results and the diagnosis results estimated by the teachers, the diagnosis accuracy of the program is high. This agreement with the program diagnosis showed the correctness of the reasoning techniques used in the program and suggests that it is possible to use 'expert knowledge' in this way.

- Several aspects of the user-system interface need to be upgraded as commented on by some of the teachers. A more exciting interface could employ a menu system where selection of the option is by using a mouse. There is a possibility to develop a system which operates under a more user-friendly graphical user interface environment where the quality of graphics and text display and user-system interaction could be enhanced.

- Several teachers commented on the format of feedback provided by the program. At the current development stage, the program only provides a form of feedback that needs teacher involvement in interpreting the results of diagnosis with the pupil. It is anticipated that a more informative form of feedback needs to be provided.

- The branched sequencing of questions which related to previous responses was recognised as beneficial by some teachers.

- Some teachers thought that the system seemed to be over simplistic, especially for experienced teachers. This was expected as the rules contained in the knowledge base are still at an initial stage. As more rules are added as a result of further analysis of pupils' responses, the performance of the system can be upgraded.

- There is a need to add some aspect of instant correction of pupils' misunderstanding during the diagnosis. For example, a separate teaching module can be added to the program to provide a form of tutorial to teach about any particular misconception detected. (This could be a very big extension in the role of the program.)

CHAPTER 8

DISCUSSION AND CONCLUSION

8.1 Overview

This chapter presents a discussion of the key findings of this research, a description of the limitations of the research and recommendations for future work.

Section 8.2 presents the three research questions from chapter 1 together with a summary of the findings regarding these questions. Section 8.3 contains a description of the limitations of the research and the final section, 8.4 presents recommendations for future work.

8.2 Summary of key findings

The discussion of key findings follows the pattern of the objectives as stated in chapter 1.

8.2.1 Research Question 1

How can expert systems technology be used as a science misconception diagnostic testing program ?

1. Identifying and organising, into a suitable form, a sample of pupils' misconceptions in selected Physics topics by analysing previous research in science misconception.

The research finds that the enormous literature source on science misconceptions for various topics provides a readily-tapped resource for identifying and organising pupils' misconceptions. The various reported common misconceptions formed a basis to build the parameters (facts) and logical relationships between them. A parameter is a domain fact (conception) and the various logical relationships between the parameters represents a 'pattern-case' condition.

2. Developing and maintaining a diagnostic question database in Physics at GCSE level.

Based on the identified misconception domains , a set of diagnostic questions was developed and maintained at GCSE level. The research finds that, as suggested by Tamir (1985), multiple-choice questions that used distractors based on pupils' conceptions and misconceptions could be used as a basis for diagnosing. The use of appropriate language in forming the question was identified as of considerable importance. Sentence structure, syntax, vocabulary, and the overall shape of the sentence were all issues which needed to be addressed.

3. Writing down the structure of science misconception knowledge into a production rule format suitable for expert system implementation.

- Since the study is exploratory and without pre-existence of a strong domain model, the author cannot begin to write large sets of complex diagnosis knowledge representation. The rule-based formalism was chosen because it is thought to provide a more flexible modular representation which simplifies the task of updating the knowledge base. Individual rules can be added, deleted or modified without affecting the overall performance or structure of the system.

- When writing rules, the first action is to break down the logic being represented into a series of discrete steps, each step corresponding to a different stage of the decision making process, the purpose being to modularise the building of the knowledge base. The logic in each step of the decision making process will translate into a set of related rules. These rules represent some kind of pre-planned routines stating what to do in a number of well-defined situations.

- A tabular matrix forms an effective way of representing the various conceptions and their relationships. Organising and developing this matrix representational scheme is a lengthy and tedious process, but this matrix helps to make sure that the diagnosis rule-base is consistent and 'complete' during the development stage. Once the science misconception knowledge has been structured into a matrix form, the process of encoding the knowledge into a rule-base becomes relatively easier and routine.

4. Organising the diagnosis expertise and knowledge into a format suitable for expert system implementation.

The diagnosis expertise and knowledge is designed to consist of two distinct but related sets of diagnosis and questioning rules. The diagnosis rule contains the 'expert knowledge' in the form of 'pattern-case' rules. The questioning rule determines the sequence of questions being displayed which is based on a branching strategy. The question displayed by the program is based on the answer to the previous question.

The research finds that :

- The questioning rule eliminates the unnecessary waste of time in answering more questions and also reduces the possibility of confusion among the pupils.

- Separating the two forms of rules enables any modification to a specific rule to be carried out easily without affecting the other rule.

5. Developing and implementing a prototype expert system diagnosing program which incorporates the above format by using a personal computer based shell.

- Prototyping methodologies, which permit addressing incompletely defined problems having unclear requirements, were a valuable part of the development process. Given the difficulty of analysing the structure and details of certification decision processes, it proved critical to use prototyping methodologies rather than traditional system development life cycle techniques. The latter require far more complete understanding of the problem before an application may be developed than was possible in this instance.

- The prototype program was implemented with a commercial expert system development tool or shell, Leonardo. The mixture of the rule-based and frame-based formalism of knowledge representation provided a basis for encoding the diagnosis knowledge. Expert systems development tools are well-suited to prototyping since the rules added to a knowledge-base may be readily redefined, restructured and refined. As understanding of a problem improves, it is possible to add new rules and new complexities with minimal effort. Application development systems, which lack the inference engine of an expert system, seldom permit this type of flexibility.

- In encoding the rules into a shell, there is a need to describe accurately and completely the situation where the knowledge applies. In the research, a tabular matrix and a flowchart is used to make sure that the diagnosing rule and the questioning rule is consistent and complete. The built-in Leonardo editor was used to check for syntax errors upon rule entry. The editor syntactically checked both parameter constraints and rule clauses.

- The user interface of the shell needs to be modified to accommodate a situation that suits a normal classroom testing environment. An expert system shell which only allows a simple text output as a way to prompt for user answers is not adequate for this application; it is important for the system to be able to display graphical data as a way to foster the understanding of the question. In the prototype system, a modified version of the user interface has been implemented. The procedure language provided with the shell has been extensively used in the research in order to provide the required user interface design.

8.2.2 Research Question 2

Can the methodology discussed above be extended into other topics ?

The key findings of the research with regard to question 2 are :

- In the research, two further topics were developed by following the methodology listed in research question 1. The research finds that the developmental methodology discussed in research question 1 is easily repeatable for organising and developing the diagnosis knowledge of other science topics. The design structure of the prototype program is also rather flexible to allow easy extension of the program into other topics in science. Specifically the design which allows the questions to be kept outside of the main program module in the form of normal text files has proved to be a time saving factor during the developmental stage. By modifying a simple rule in the knowledge base to read the new text file, a different set of questions could be displayed.

- For the new topics, the overall structure of the prototype program is kept intact. In addition to ensuring consistency of the user interface, it shows that only the diagnosis rule base, feedback descriptive texts, and the questioning rule are changed to represent the diagnosis knowledge for a new topic. This greatly reduces the development time. This seems to prove the advantages of expert system development strategy as compared to traditional programming strategy as stated in the literature.

- The topic of Speed and Motion Graphs employs the graphical capability of the Leonardo shell. The research finds that, although the graphics capability of the Leonardo shell is rather limited, the facility seems to be adequate for the requirement of the research. All of the graphics drawing is carried out by using the procedure programming language of the shell.

- The topic of Sinking and Floating employs the 'certainty factors' feature of the Leonardo shell. The 'certainty factor' is a method for assigning probability value to a conception or object. The research finds that this feature adequately suits the requirement to cater for the 'incomplete reasoning knowledge' strategy implemented for this particular topic.

- In the topic of electricity, most of the questions are developed with a simple form of "yes or no" or simple one-word answers. This choice was influenced by the reported works of earlier researchers (for example, Trollip et al., 1992) and basic introductory books on expert systems. For the extended two topics, more standard multiple-choice stems are used where several alternatives were carefully provided for selection. Although no formal study was carried out in this research to compare the effectiveness of each of the forms, informal observation shows that pupils and teachers are more comfortable with the standard multiple-choice format.

8.2.3 Research Question 3

What can be learned from the evaluation of the prototype expert system diagnostic program ?

Both teachers and pupils have evaluated the prototype program.

1. Analysing pupils' responses to the questions in order to confirm and then enhance further the diagnostic capability of the program.

For all the three exploratory topics, a similar mode of inferences can be made regarding the pattern of pupils' responses to the questions. The key findings of the research are as follows:

- In a majority of cases, a reasonable number of pupils are detected as having a correct understanding of the various types of potential misunderstanding which have been described in the literature.

- The questions are well organised and understood by the pupils as indicated by the reasonable distribution of answers to all the questions.

- There is some consistent pattern of responses which do not correspond directly with any of the pre-defined rules in the diagnostic knowledge base. The modularity of the rule-based formalism allows these detected patterns of responses to be included to further enhance the diagnostic capability of the program. Nevertheless, there exists limited cases where there is an unexplainable and disarray pattern of responses which are not considered for addition into the rule-base.

2. Analysing teachers' comments on the effectiveness of the program and the correctness of the program's feedback by running sample cases of the pupils' responses.

The research finds that :

- In general, the teachers commented highly on the accuracy and consistency of the results of the program diagnosis.

- The overall user-interface structure of the prototype program is acceptable, although a more user-friendly graphical user interface environment where the quality of graphics and text display and user-system interaction could be enhanced.

- A more informative form of diagnostic feedback needs to be provided especially for the pupil's own interpretation as the present form of feedback still needs a teacher involvement.

- The teachers were satisfied with the suitability of the questions used for the diagnostic purposes. This includes the level of wording and adequacy of the alternative answers provided in the questions.

- The branched sequencing of questions which related to previous responses was recognised as beneficial by some teachers.

8.3 Limitations of the Study

1. The prototype program is designed to have competence with a limited area of science misconceptions and as soon as it encounters a pattern outside the scope of its competency, the program could not make any diagnosis. Continuous analysis of pupils' patterns of responses needs to be carried out manually in order to further enhance the diagnostic capability of the program.

2. The number of questions used for all of the selected topics of interest is rather limited. If more questions are developed and used, it is anticipated that there would be much more richness in the pupil's pattern of responses.

3. With respect to program evaluation, other forms of research methodologies are possible. For example :
    - interviewing the pupils in order to detect and compare their conceptions with the answers provided through the program
    - comparing the results of program feedback with teacher feedback by manually checking the answers to the questions

   Due to time constraint and the limited number of teachers willing to give up time while already under great pressure, these alternative methodological techniques have not been carried out in this research. It is suggested that the techniques should be utilised in further development of the program.

8.4 Suggestions for Further Research

Further work could be focused to the following points:

1. An expansion of the prototype components to produce a complete package suitable for a computer aided testing and learning system. For example, in addition to diagnosing, a specialist tutoring module could be added to provide lessons for the detected misconception. This idea will coincide with the notion of Integrated Learning Systems (ILS) as proposed by the National Council of Educational Technology (1994).

2. The augmentation and better organisation of the diagnosis knowledge base in a future study could examine the use of neural network technology together with the production rule-base formalism in representing the knowledge base. The capability of neural networks to 'learn' from the past examples of the decision-making could be used as a basis for further expansion of the program. For example, a neural network can be trained to predict an intermediate variable which is used for the expert system to reason about a problem. Alternatively, an expert system can be used to infer the value of a certain variable which can be treated as an input to a neural network.

3. The full and longer implementation of the program in the classroom is worthy of separate study. A future study could compare the advantages and disadvantages of technological-based diagnostic testing with the traditional paper and pencil test.

4. At the time of writing up of the thesis, Leonardo for Windows is just about to be released. It is anticipated that the Windows version could provide a better developmental

strategy in terms of graphical user interface and graphics capability to further enhance the user-interface component of the program.

8.5 Conclusions

This thesis and its prototype program investigate one aspect of expert systems application in diagnosing pupils' science misconception. It shows how a basic expert system can be used as a supportive tool for teachers in a normal daily classroom activity. With respect to the conceptual framework, it has been more concerned with the bringing together of computer technology, expert systems and research in diagnosing science misconceptions rather than breaking new ground in each separately. Without a strong pre-defined domain model, the research cannot involve a large set of complex knowledge representation. In terms of practicality, this research should be viewed as an explorative study to provide a more structured approached in developing a science diagnostic knowledge representation suitable for inclusion into the expert system.

This report has described in detail the development of the prototype program which includes the development and representation of the diagnosis 'expert knowledge', the structure and operation of the prototype program, and the verification and validation of the prototype program. These strategies have been presented which can be employed by other researchers to enable them to be more readily understand and then further enhance the use of expert systems technology in the school-based environment.

The results from the school-based evaluation suggested this program has a basic and sufficient structure, expertise and background knowledge to function well as a diagnostic tool. Some enhancements and improvements can be made in the full implementation of the prototype. Such a diagnostic tool could be used for conducting a more systematic and reliable school based testing especially in developing countries where the expertise is still very much lacking. It also freeing up much of teachers' time to devote to other tasks.

Finally, this expert system diagnostic program is not to be viewed as a replacement for human decision makers, but as aids or tools for such persons. Expert systems obviously cannot perform in areas not covered by the knowledge base. Furthermore, decisions reached by expert systems can be no better than the accuracy of the knowledge or rules that comprises the knowledge base.

REFERENCES

Anderson, J.R., Boyle C.F. and Reiser, B.J. (1985). Intelligent tutoring system. **Science, 228**(4698), 456-462.

Attisha, M. and Yazdani M. (1984). An expert system for diagnosing children's multiplication errors. **Instructional Science, 13,** 79-92.

Beaumont, J.G. (1989). Expert systems support for diagnostic assessment of arithmetic skills. **National Foundation for Educational Research Abstract**.

Ben_Davies, A. and Ben-Shalom, U. (1994). An expert system for evaluating exams : a case study. **Journal of Research on Computing in Education, 26**(2), 143-153.

Berry D..C. and Hart, A. E. (1990). Evaluating expert systems. **Expert Systems,** 7(4), 199-207.

Beynon-Davies, P. (1993). **Knowledge Engineering for Information Systems**. McGraw-Hill Company, London.

Bielawski, L. and Lewand, R. (1991). **Intelligent System Design: Integrating Expert Systems, Hypermedia and Databases Technologies**. John Wiley and Sons, New York.

Bodkin, T. and Ian, G. (1989). Case studies of expert system development using microcomputer software packages. **Expert Systems, 6**(1), 12-16.

Boohan, R. (1992). DIAG: a program to diagnose students' conceptual models in science. **Journal of Computer Assisted Learning, 8,** 206-220.

Buchanan, B.G. and Shortliffe, E.H. (1985). **Rule-Based Expert Systems**. Addison-Wesley, Massachusetts.

Budde, R., Kautz, K., Kuhlenkamp, K and Zullighoven, H. (1991). **Prototyping : An Approach to Evolutionary System Development**. Springer-Verlag, Berlin.

Chadha, S.R., Mazlack, L.J. and Pick, R.A. (1991). Using existing knowledge sources (cases) to build an expert system. **Expert Systems, 8**(1), 3-6.

Children's Learning in Science Research Group (1990). **Research on Students' Conceptions in Science : a Bibliography**. Centre for Studies in Science and Mathematics Education, University of Leeds.

Drenth, H. and Morris, A. (1992). Prototyping expert solutions: an evaluation of Crystal, Leonardo, GURU and ART-IM. **Expert Systems, 9**(1), 35-45.

Driver, R. , Guesne, E. and Tiberghien, A. (Eds.) (1985) . **Children's Ideas in Science**. Open University Press, Milton Keynes.

Fensham, P.J., Gerrard, J. and West, L.W. (1981). The use of cognitive mapping in teaching and learning strategies. **Research in Science Education, 11**, 121-129.

Forcheri, P and Molfino, M.T. (1995). Knowledge based systems for teaching and learning maths. **British Journal of Educational Technology, 26**(1), 42-54.

Frederiksen, J.R. and White, B.Y. (1990). Intelligent tutors as intelligent testers. In Frederiksen, N., Glaser,R., Lesgold, A., and Shafto, M.G. (Eds.), **Diagnostic Monitoring of Skills and Knowledge Acquisition**. LEA, Hilldale, N.J.

Fredette, N. and Lockheed, J. (1980). Student conceptions of simple circuit. **Physics Teachers, 18**, 194-198.

Freedle, R (Ed.) (1990). **Artificial Intelligence and the Future of Testing**. Lawrence Erlbaum Associates, Hilldale, New Jersey.

Gallant, S.I. (1993). **Neural Network Learning and Expert Systems**. MIT Press, London.

Galpin, B. (1989). **Expert Systems in Primary Schools**. British Library Research Paper 73, The British Library.

Gisolfi, A. and Moccaldi, G. (1990). A student model for an algebraic tutor. In Estes, N., Heene, J., and Leclercq, D. (Eds.), **The Proceeding of The Seventh International Conference on Technology and Education**, Volume 2, CEP Consultants Ltd, Edinburgh.

Glaser, J. (1963). Instructional technology and the measurement of learning outcomes. **American Psychologist, 18**, 510-1055.

Goodall, A (1985). **The Guide to Expert Systems**. Learned Information, Oxford.

Gott, R. (1984). Predicting and explaining the operation of simple DC circuits. In Duit R., Jung, W., and Rhoneck C.V. (Eds.), **Aspects of Understanding Electricity**. IPN-Arbeitsberichte.

Halloun, I.A. and Hestenes, D. (1985). The initial knowledge state of college physics students. **American Journal of Physics, 53**(11), 1043-1055.

Harmon, P. and Sawyer, B. (1990). **Creating Expert Systems For Business and Industry**. John Wiley and Sons, New York.

Haslam, F. and Treagust, D.F. (1987). Diagnosing secondary students: misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. **Journal of Biological Education, 21**(3), 203-211.

Helm, H. (1980). Misconceptions in physics amongst South African students. **Physics Education, 15**, 92-105.

Hewson, P.W. (1985). Diagnosis and remediation of an alternative conception of velocity using a microcomputer program. **American Journal of Physics, 53**(7), 684-690.

Hewson, P.W. and Hewson, M.G. (1988). An appropriate conception of teaching science: a view from studies of science learning, **Science Education, 72**(5), 597-614

Hicks R.B. and Laue H. (1989). A computer-assisted approach to learning physics concepts. **American Journal of Physics, 57**(9), 807-811.

Johnson, L. and Keravnou, E.T. (1988). **Expert Systems Architectures**. Kogan Page, London.

Jonassen, D.H. and Grabinger, R.S. (1992). Levels of processing in building expert systems. In Kommers, P.A.M., Jonassen, D.H. and Mayes, J.T. (Eds.), **Cognitive Tools For Learning**. Springer-Verlag, Heidelberg, FRG.

Jonassen, D.H., Wilson, B.G., Wang, S. and Grabinger, R.G. (1993). Constructivist uses of expert systems to support learning. **Journal of Computer-Based Instruction, 20**(3), 86-94.

Karrqvist, C. (1984). The development of concepts by means of dialogues centred on experiments. In Duit R., Jung, W., and Rhoneck C.V. (Eds.), **Aspects of Understanding Electricity**. IPN-Arbeitsberichte.

Marshall, G. (1990). **Students' Guide to Expert Systems**. Heinemann Newnes, Oxford.

McDermott, L.C. (1990). Research and computer-based instruction: opportunity for interaction. **American Journal of Physics, 58**(5), 452-462.

McDermott, L.C. and Shaffer, P.S. (1992). Research as a guide for curriculum development: an example from introductory electricity. **American Journal of Physics, 60**(11), 994-1003.

McDermott, L.C. and Zee, E.H.V. (1984). Identifying and addressing student difficulties with electric circuits. In Duit, R., Jung, W. and Rhoneck, C. V. (Eds.), **Aspects of Understanding Electricity**. IPN-Arbeitsberichte.

McFarland T.D. and Parker R. (1990). **Expert Systems in Education and Training**. Educational Technology Publications, Englewood Cliffs, New Jersey.

Mestre, J. and Touger, J. (1989). Cognition Research - What's in it for physics teachers? **The Physics Teacher, Sept**, 447-456

Michaelsen, R.H. (1985). The technology of expert systems. **Byte, 10**(4), 303-312.

Morris, A.(1990). **The Application of Expert System in Libraries and Information Centres**. Bowker-Sour, London.

Morris, A. (1993). **Expert Systems and Their Use in Information Science**. PhD Thesis. Loughborough University of Technology.

Nachmias, R., Stavy, R. and Avrams, R. (1990). A microcomputer-based diagnostic system for identifying students' conception of heat and temperature. **International Journal of Science Education, 12**(2), 123-132.

National Council for Educational Technology (1994). **Integrated Learning Systems : A Report of the Pilot Evaluation of ILS in the UK**. NCET, Coventry.

Niedderer, H., Schecker, H. and Bethge, T. (1991). The role of computer-aided modelling in learning physics. **Journal of Computer Assisted Learning**, 7, 84-95.

Occena, L.G. and Miller, S.L. (1993). IEADVISE : an undergraduate course advising expert system in industrial engineering. **Expert Systems, 10**(3), 139-148.

Olsen, J.B. (1990). The four generations of computerised testing: toward increase use of AI and expert systems. **Educational Technology, 30**(3), 36-41.

O'Keefe R., Balci, O. and Smith, E. P. (1987). Validating expert system performance. **IEEE Expert, Winter**, 81-89.

Okey, J.R. and McGarity, J. (1982). Classroom diagnostic testing with microcomputer. **Science Education, 66**(4), 571-579.

Osborne, R.J. (1983). Towards modifying children's ideas about electric current. **Journal of Research in Science and Technological Education, 1**, 73-82.

Osborne, R.J. and Gilbert, J.K. (1980). A technique for exploring the students' view of the world. **Physics Education, 15**, 376-379.

Padilla, M.J., McKenzie, D.L. and Shaw, E.L. (1986). An examination of the line graphing ability of students in grades seven through twelve, **School Science and Mathematics, 86**(1), 20-26.

Park, O.C. and Seidel, R.J. (1987). Conventional CBI versus intelligent CAI. **Educational Technology, May**, 15-21.

Park, O.C. and Tennyson, R.D. (1983). Computer-based instructional systems for adaptive education: A review. **Contemporary Educational Review, 2**, 121-135.

Preece, A.D. (1990). Towards a methodology for evaluating expert systems. **Expert Systems,** 7(4), 215-223.

Raglan, S.W. and McFarland, T.D. (1987). Application of expert system in education: a technology for decision-making. **Education Technology, 27**(5), 33-36.

Selley, N. (1993). Why do things floats ? A study of the place for alternative models in school science. **School Science Review, 74**(269), 55-61.

Settle, F.A. (1987). The application of expert systems in the general chemistry laboratory. **Journal of Chemical Education, 64**(4), 341-345.

Shariffadeen, T.M.A. (1991). Information technology in education - the emerging Malaysian scenario. **Proceeding of the National Symposium on Educational Computing**, 19-21 November 1991, Kuala Lumpur, 2-19.

Shipstone, D. M. (1984). On children's use of conceptual models in reasoning about current electricity. In Duit, R., Jung, W. and Rhoneck, C. V. (Eds.), **Aspects of Understanding Electricity**. IPN-Arbeitsberichte.

Shipstone, D. M. (1985). Electricity in simple circuit. In Driver, R., Guesne, E., and Tiberghien, A. (Eds.), **Children's Ideas in Science**, Open University Press, Milton Keynes.

Shipstone, D. M. (1988). Pupil understanding of simple electrical circuit : some implication for instruction. **Physics Education, 23**(2), 92-96.

Software Directions (1992). **Leonardo Tutorial**.

Software Directions (1992). **Leonardo User's Guide**.

Software Directions (1992). **Leonardo Reference Manual**.

Steinberg, E.R. (1991). **Computer Assisted Instruction : A Synthesis of Theory, Practice, and Technology**. Lawrence Erlbaum Associates, Hilldale, N.J.

Swatton, P. and Taylor, R.M. (1994). Pupil performance in graphical tasks and its relationship to the ability to handle variables. **British Educational Research Journal, 20**(2), 227-243.

Tamir, P. (1989). Some issues related to the use of justification to multiple-choice answers. **Journal of Biological Education, 23**(4), 285-292.

Tamir, P. (1990). Justifying the selection of answers in multiple choice items. **International Journal of Science Education, 12**(5), 563-573.

Treagust, D.F. (1988). Development and use of diagnostic tests to evaluate students' misconception in science. **International Journal of Science Education, 10**(2), 159-169.

Treagust, D.F. and Smith, C.L. (1989). Secondary students' understanding of gravity and the motion of planets. **School Science and Mathematics, 89**, 380-391.

Trollip, S.H., Lippert, R.C., Starfield, A.M. and Smith, K.A. (1992). Building knowledge bases : an environment for making cognitive connections. In Kommers, P.A.M., Jonassen, D.H. and Mayes, J.T. (Eds.), **Cognitive Tools For Learning**. Springer-Verlag, Heidelberg, FRG.

White G.J. (1993). Using expert systems in schools. **Computer Education, June**, 16-18.

Wolfgram, D.D., Dear, T.J. and Galbraith, C.S. (1987). **Expert Systems for the Technical Professional**. John Wiley & Sons, New York.

APPENDIX B1

OBJECT FRAMES

Example of Text, List or Real Object Default Frame

1 :	Name	:
2 :	LongName	:
3 :	Type	:
4 :	Value	:
5 :	Certainty	:
6 :	DerivedFrom	:
7 :	DefaultValue	:
8 :	FixedValue	:
9 :	AllowedValue	:
10 :	ComputeValue	:
11 :	OnError	:
12 :	QueryPrompt	:
13 :	QueryPreface	:
14 :	Expansion	:
15 :	Commentary	:
16 :	Introduction	:
17 :	Conclusion	:
18 :	Ruleset	:

Example of Procedural Object Default Frame:

1 :	Name	:
2 :	LongName	:
3 :	Type	:
4 :	AcceptsReal	:
5 :	AcceptsText	:
6 :	AcceptsList	:
7 :	ReturnsReal	:
8 :	ReturnsText	:
9 :	ReturnsList	:
10 :	LocalReal	:
11 :	LocalText	:
12 :	LocalList	:
13 :	Externals	:
14 :	Body	:

APPENDIX D1

ELECTRICITY QUESTIONS

	Questions	Comments
1	Please refer to the diagram I. The bulb L1 is connected to the battery with wire. It is found that the bulb L1 lights up. Scientists believe that the bulb L1 lights up because ELECTRIC CURRENT or CURRENT from the battery flows through it. Now please answer a few questions regarding the electric current in the circuit.	
A	Do you think that the current in the circuit is stored in the battery ? A. yes B. no	
B	Is the CURRENT stored in the battery the same as the ENERGY stored in the battery ? A. yes B. no	
C	If the current is NOT stored in the battery, what do you think makes the current flow through the bulb L1 ? A. potential difference (Voltage) in the battery. B. energy in the battery.	
D	Do you think the current leaves the battery at BOTH ends (terminals) of the battery and then meets in the bulb L1 (causing it to light up) ? A. yes B. no	
E	As the current flows through the bulb, did the bulb use up the current ? A. yes B. no	
F	Do you mean that more current is leaving one end of the battery than returns to the other end ? A. yes B. no	

ELECTRICITY QUESTIONS (Continued)

	Questions	Comments
G	You have said that the bulb uses up the current. Has the bulb used up ... A. all the current. B. only part of the current.	
H	When you said that ALL the current is used up by the bulb, does it mean that the wire to the other end has no current passing through it ? A. yes B. no	
I	You have answered that the bulb DID NOT use up the current. Does this mean that the amount of current entering the bulb is the SAME as the amount of current leaving the bulb ? A. yes B. no C. I am not sure	
J	You have said that the current DID NOT leave both ends of the battery. Is it leaving one end of the battery and then returning to the other end ? A. yes B. no	
K	Is the current leaving the ... A. positive terminal and back to the negative terminal. B. negative terminal and back to the positive terminal.	

ELECTRICITY QUESTIONS (Continued)

	Questions	Comments
2	Now, another bulb L2 is added to the circuit in SERIES with L1. Both bulbs are of the same kind. Refer to diagram II. Both bulbs light up.	
A	Compared to the previous circuit (diagram I), L1 in diagram II is ________ L1 in diagram I. A. brighter than B. dimmer than C. the same brightness as	
B	You have answered that L1 in diagram II is dimmer than L1 in diagram I. Is it because current is shared between L1 and L2 in diagram II ? A. yes B. no C. I am not sure	
C	Do you think that the amount of current flowing through diagram I is the same as the amount of current flowing through diagram II ? A. yes B. no C. I am not sure	
D	You have answered that L1 in diagram I and L1 in diagram II is the same brightness. Is it because the battery still provides the same amount of current in both diagrams ? A. yes B. no C. I am not sure	
E	Which of these do you think is true ? A. L1 is brighter than L2. B. L1 is dimmer than L2. C. L1 and L2 are the same brightness.	

ELECTRICITY QUESTIONS (Continued)

	Questions	Comments
F	You have said that L1 and L2 have the same brightness. Is this because the current has to be shared out equally by both bulbs L1 and L2 ? A. yes B. no C. I am not sure	
G	You have said that L1 is brighter than L2. Is this because the current gets used up as it moves from battery to L1 and then to L2 ? A. yes B. no C. I am not sure	
3	Now, please refer to diagram III. In this circuit the bulb L is between two VARIABLE RESISTORS, R1 and R2. The resistors are initially set to a certain values and the bulb light up.	
A	If resistor R1 is increased, the bulb L ... A. becomes brighter. B. becomes dimmer. C. stays the same brightness.	
B	If resistor R2 is increased, the bulb L ... A. becomes brighter. B. becomes dimmer. C. stays the same brightness.	

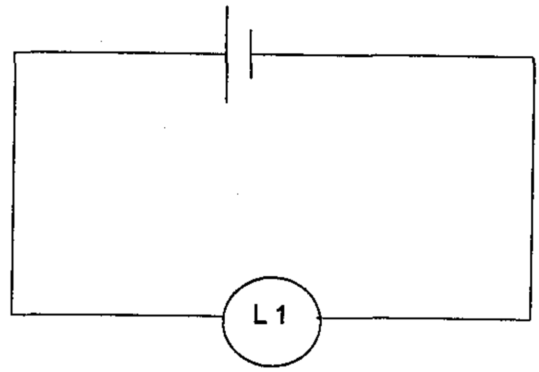


Diagram I

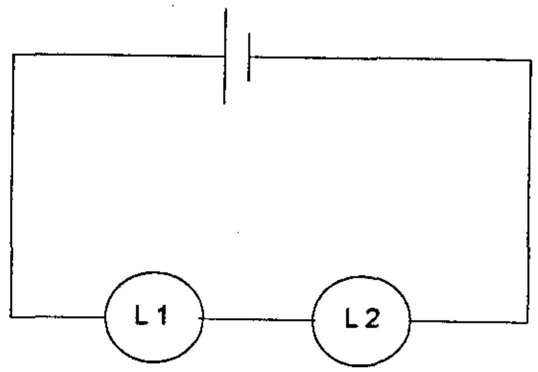


Diagram II

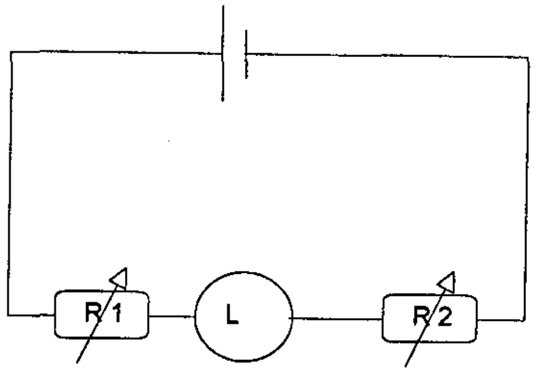


Diagram III

APPENDIX D2

LIST OF TABULAR MATRICES : ELECTRICITY

Question Area 1 :

Rule	Parameters			
	Current is stored in the battery	Current as energy	What makes current flows ?	
Rule 1	yes	yes	-	Descriptive 1(A)
Rule 2	yes	no	-	Descriptive 1(B)
Rule 3	no	-	potential difference	Descriptive 1(C)

Question Area 2 :

Rule	Parameters			
	Current leaves both battery terminals ?	Current leaves one end and return to the other end ?	Current leaving	
Rule 2(a):	yes	-	-	Descriptive 2(A)
Rule 2(b):	no	yes	positive to negative end	Descriptive 2(B)
Rule 2(c):	no	yes	negative to positive end	Descriptive 2(C)

LIST OF TABULAR MATRICES : ELECTRICITY (Continued)

Question Area 3 :

Rule	Parameters					
	Bulb used current ?	Bulb used ALL current ?	More current leaving one end than returning to other end ?	Wire to other end has no current flow through it ?	Same amount of current entering and leaving the bulb ?	
Rule 1	yes	yes	-	yes		Descriptive 3(A)
Rule 2	yes	no	yes	-	-	Descriptive 3(B)
Rule 3	no	-	-	-	yes	Descriptive 3(C)

Question Area 4 :

Rule	Parameters				
	Bulb L1 in diagram II is ______ bulb L1 in diagram I	Current is shared between L1 and L2 in diagram II	Amount of current flowing through both diagrams is the same	Battery provides the same amount of current in both diagrams	
Rule 1	dimmer than	yes	yes	-	Descriptive 4(A)
Rule 2	same brightness as	-	-	yes	Descriptive 4(A)

LIST OF TABULAR MATRICES : ELECTRICITY (Continued)

Question Area 5 :

Rule	Parameters			
	Bulb L1 is ______ bulb L2	Current is shared out equally by both *bulbs L1 and L2*	Current is used as it moves from battery to L1 and then L2	
Rule 1	same brightness as	yes	-	Descriptive A
Rule 2	brighter than	-	yes	Descriptive B

Question Area 6 :

Rule	Parameters		
	R1 increases, bulb L becomes....	R2 increases, bulb L becomes	
Rule 1	dimmer	brighter	Descriptive A
Rule 2	dimmer	dimmer	Descriptive B

APPENDIX D3

ANALYSIS OF RESPONSES RULES :ELECTRICITY

Name: check_ans1

if ans1 is "a"
then battery_stored_current is present;
check_ans1 is finish

if ans1 is "b" or ans1 is "x"
then check_ans1 is finish

Name: check_ans2

if ans2 is "a"
then current_as_energy is present;
check_ans2 is finish

if ans2 is "b" or ans2 is "x"
then check_ans2 is finish

Name: check_ans3

if ans3 is "a"
then current_from_pd is present;
check_ans3 is finish

if ans3 is "b"
then current_from_energy is present;
check_ans3 is finish

if ans3 is "x"
then check_ans3 is finish

Name: check_ans4

if ans4 is "a"
then current_both_terminal is present;
check_ans4 is finish

if ans4 is "b" or ans4 is "x"
then check_ans4 is finish

Name: check_ans5

if ans5 is "a"
then bulb_used_current is present;
check_ans5 is finish

if ans5 is "b" or ans5 is "x"
then check_ans5 is finish

ANALYSIS OF RESPONSES RULES :ELECTRICITY (Continued)

Name: check_ans6

if ans6 is "a"
then term1_more_current_term2 is present;
check_ans6 is finish

if ans6 is "b" or ans6 is "x"
then check_ans6 is finish

Name: check_ans7

if ans7 is "a"
then bulb_used_all_current is present;
check_ans7 is finish

if ans7 is "b"
then bulb_used_part_current is present;
check_ans7 is finish

if ans7 is "x"
then check_ans7 is finish

Name: check_ans8

if ans8 is "a"
then other_term_passive is present;
check_ans8 is finish

if ans8 is "b" or ans8 is "x"
then check_ans8 is finish

Name: check_ans9

if ans9 is "a"
then current_is_conserve is present;
check_ans9 is finish

if ans9 is "c"
then current_is_conserve is notsure;
check_ans9 is finish

if ans9 is "b" or ans9 is "x"
then check_ans9 is finish

Name: check_ans10

if ans10 is "a"
then current_is_unidirection is present;
check_ans10 is finish

if ans10 is "b" or ans10 is "x"
then check_ans10 is finish

Name: check_ans11

if ans11 is "a"
then current_pos_neg is present;
check_ans11 is finish

if ans11 is "b"
then current_neg_pos is present;
check_ans11 is finish

if ans11 is "x"
then check_ans11 is finish

Name: check_ans12

if ans12 is "a"
then 2bulb_bright_than_1bulb is present;
check_ans12 is finish

if ans12 is "b"
then 2bulb_dimmer_than_1bulb is present;
check_ans12 is finish

if ans12 is "c"
then 2bulb_same_bright_1bulb is present;
check_ans12 is finish

Name: check_ans13

if ans13 is "a"
then 2bulb_share_current is present;
check_ans13 is finish

if ans13 is "c"
then 2bulb_share_current is notsure;
check_ans13 is finish

if ans13 is "b" or ans13 is "x"
then check_ans13 is finish

Name: check_ans14

if ans14 is "a"
then current_same_amt_d1d2 is present;
check_ans14 is finish

if ans14 is "c"
then current_same_amt_d1d2 is notsure;
check_ans14 is finish

if ans14 is "b" or ans14 is "x"
then check_ans14 is finish

Name: check_ans15

if ans15 is "a"
then constant_current_source is present;
check_ans15 is finish

if ans15 is "c"
then constant_current_source is notsure;
check_ans15 is finish

if ans15 is "b" or ans15 is "x"
then check_ans15 is finish

Name: check_ans16

if ans16 is "a"
then bulb1_bright_than_bulb2 is present;
check_ans16 is finish

if ans16 is "b"
then bulb1_dimmer_than_bulb2 is present;
check_ans16 is finish

if ans16 is "c"
then bulb1_same_bright_bulb2 is present;
check_ans16 is finish

Name: check_ans17

if ans17 is "a"
then bulb12_share_current is present;
check_ans17 is finish

if ans17 is "c"
then bulb12_share_current is notsure;
check_ans17 is finish

if ans17 is "b" or ans17 is "x"
then check_ans17 is finish

Name: check_ans18

if ans18 is "a"
then bulb12_used_current is present;
check_ans18 is finish

if ans18 is "c"
then bulb12_used_current is notsure;
check_ans18 is finish

if ans18 is "b" or ans18 is "x"
then check_ans18 is finish

Name: check_ans19

if ans19 is "a"
then r1_inc_bulb_brighter is present;
check_ans19 is finish

if ans19 is "b"
then r1_inc_bulb_dimmer is present;
check_ans19 is finish

if ans19 is "c"
then r1_inc_bulb_same_bright is present;
check_ans19 is finish

Name: check_ans20

if ans20 is "a"
then r2_inc_bulb_brighter is present;
check_ans20 is finish

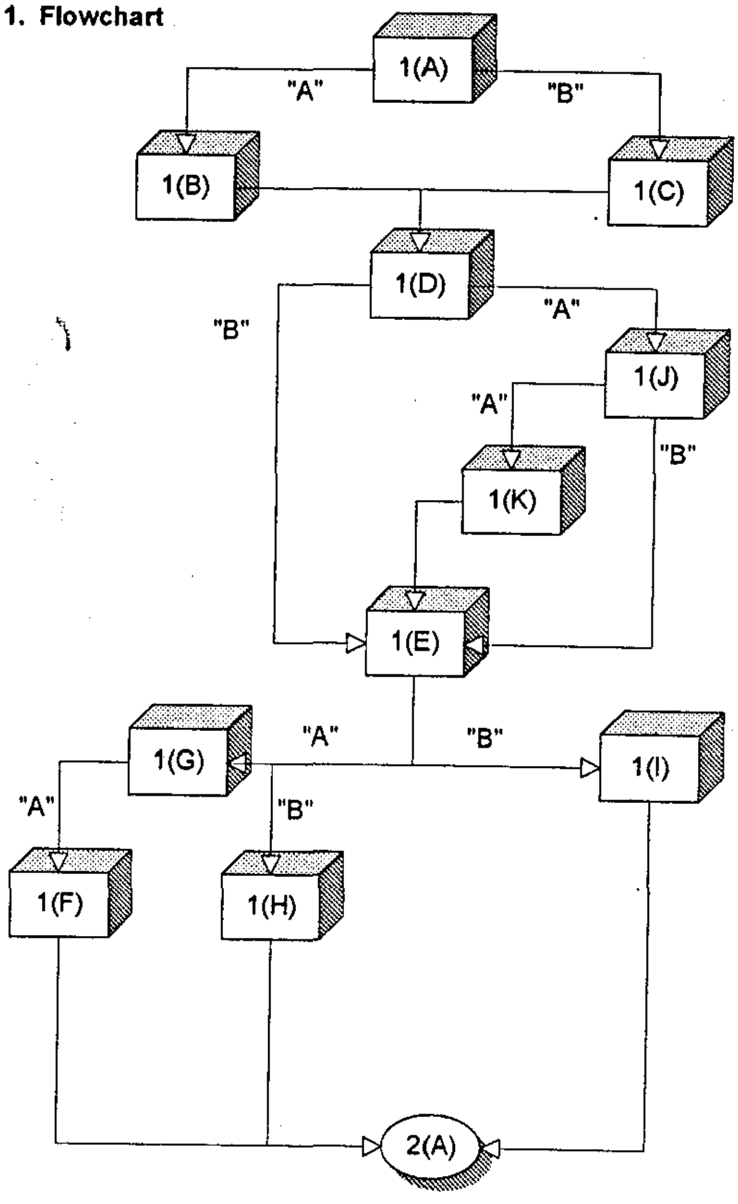
if ans20 is "b"
then r2_inc_bulb_dimmer is present;
check_ans20 is finish

if ans20 is "c"
then r2_inc_bulb_same_bright is present;
check_ans20 is finish

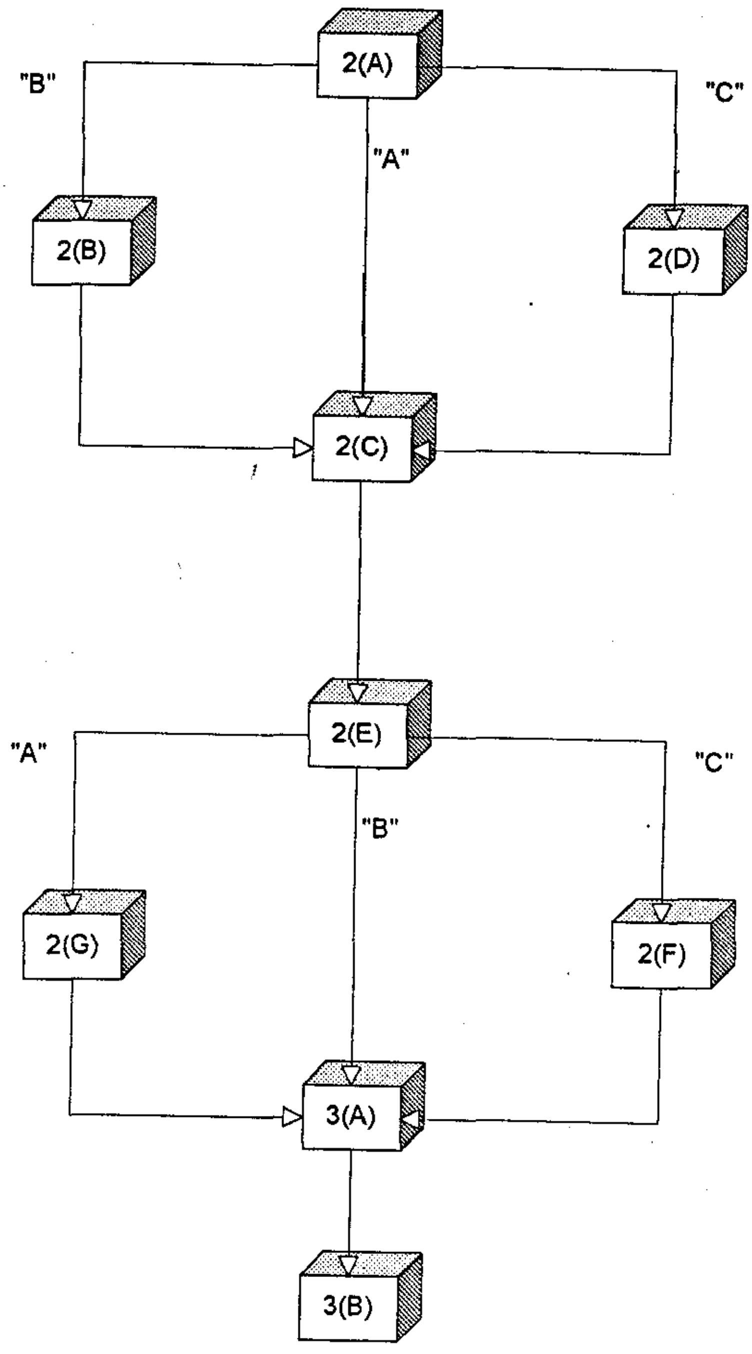
APPENDIX D4

QUESTION SEQUENCING RULES : ELECTRICITY

1. **Flowchart**



Question Flow Chart for Electricity



Question Flow Chart for Electricity (Continued)

QUESTION SEQUENCING RULES : ELECTRICITY (Continued)

2. Rules

Name: display_S1
if initialise is yes
then run file_1(retest);
display_S1 is yes

Name: display_Q1
if display_S1 is yes
then run file_2(txt1,retest,ans1);
run accept_2ans(ans1);
display_Q1 is yes

Name: display_Q2
if display_Q1 is yes
and ans1 is "a"
then run file_2(txt2,retest,ans2);
run accept_2ans(ans2);
display_Q2 is yes

if display_Q1 is yes
and ans1 is "b"
then run file_2(txt3,retest,ans3);
run accept_2ans(ans3);
display_Q2 is yes

Name: display_Q3
if display_Q2 is yes
then run file_2(txt4,retest,ans4);
run accept_2ans(ans4);
display_Q3 is yes

Name: display_Q4
if display_Q3 is yes
and ans4 is "b"
then run file_2(txt10,retest,ans10);
run accept_2ans(ans10);
display_Q4 is yes

if display_Q3 is yes
and ans4 is "a"
then display_Q4 is yes

Name: display_Q5
if display_Q4 is yes
and ans10 is "a"
then run file_2(txt11,retest,ans11);
run accept_2ans(ans11);
display_Q5 is yes

QUESTION SEQUENCING RULES : ELECTRICITY (Continued)

if display_Q4 is yes
and ans10 is "b"
then display_Q5 is yes

if display_Q4 is yes
and ans10 is "x"
then display_Q5 is yes

Name: display_Q6
if display_Q5 is yes
then run file_2(txt5,retest,ans5);
run accept_2ans(ans5);
display_Q6 is yes

Name: display_Q7
if display_Q6 is yes
and ans5 is "a"
then run file_2(txt7,retest,ans7);
run accept_2ans(ans7);
display_Q7 is yes

if display_Q6 is yes
and ans5 is "b"
then run file_2(txt9,retest,ans9);
run accept_3ans(ans9);
display_Q7 is yes

Name: display_Q8
if display_Q7 is yes
and ans7 is "b"
then run file_2(txt6,retest,ans6);
run accept_2ans(ans6);
display_Q8 is yes

if display_Q7 is yes
and ans7 is "a"
then run file_2(txt8,retest,ans8);
run accept_2ans(ans8);
display_Q8 is yes

if display_Q7 is yes
and ans7 is "x"
then display_Q8 is yes

Name: display_S2
if display_Q8 is yes
then run file_21(retest);
display_S2 is yes

QUESTION SEQUENCING RULES : ELECTRICITY (Continued)

Name: display_Q12
if display_S2 is yes
then run file_2(txt12,retest,ans12);
run special_3ans(ans12);
display_Q12 is yes

Name: display_Q13
if display_Q12 is yes
and ans12 is "b"
then run file_2(txt13,retest,ans13);
run special_3ans(ans13);
display_Q13 is yes

if display_Q12 is yes
and ans12 is "c"
then run file_2(txt15,retest,ans15);
run special_3ans(ans15);
display_Q13 is yes

if display_Q12 is yes
and ans12 is "a"
then display_Q13 is yes

Name: display_Q14
if display_Q13 is yes
then run file_2(txt14,retest,ans14);
run special_3ans(ans14);
display_Q14 is yes

Name: display_Q15
if display_Q14 is yes
then run file_2(txt16,retest,ans16);
run accept_3ans(ans16);
display_Q15 is yes

Name: display_Q16
if display_Q15 is yes
and ans16 is "c"
then run file_2(txt17,retest,ans17);
run accept_3ans(ans17);
display_Q16 is yes

if display_Q15 is yes
and ans16 is "a"
then run file_2(txt18,retest,ans18);
run accept_3ans(ans18);
display_Q16 is yes

if display_Q15 is yes
and ans16 is "b"
then display_Q16 is yes

QUESTION SEQUENCING RULES : ELECTRICITY (Continued)

Name: display_S3
if display_Q16 is yes
then run file_31(retest);
display_S3 is yes

Name: display_Q19
if display_S3 is yes
then run file_2(txt19,retest,ans19);
run accept_3ans(ans19);
display_Q19 is yes

Name: display_Q20
if display_Q19 is yes
then run file_2(txt20,retest,ans20);
run accept_3ans(ans20);
run close_graphic;
display_Q20 is yes

APPENDIX D5

MAIN RULESET :ELECTRICITY

Main Rule :

rule: set_the_goal
seek diagnosis

rule: initialisation
if start is yes
and initialise is yes
then start_up is finish

rule: display_question
if start_up is finish
and Display_Question is finish
then test is done

rule: check_answer
if test_2 is done
and check_answer is finish
then answer_analysis is done

rule: analyse_models
if answer_analysis is done
and model is finish
then run convert_model(model,model_list);
post_analysis is done

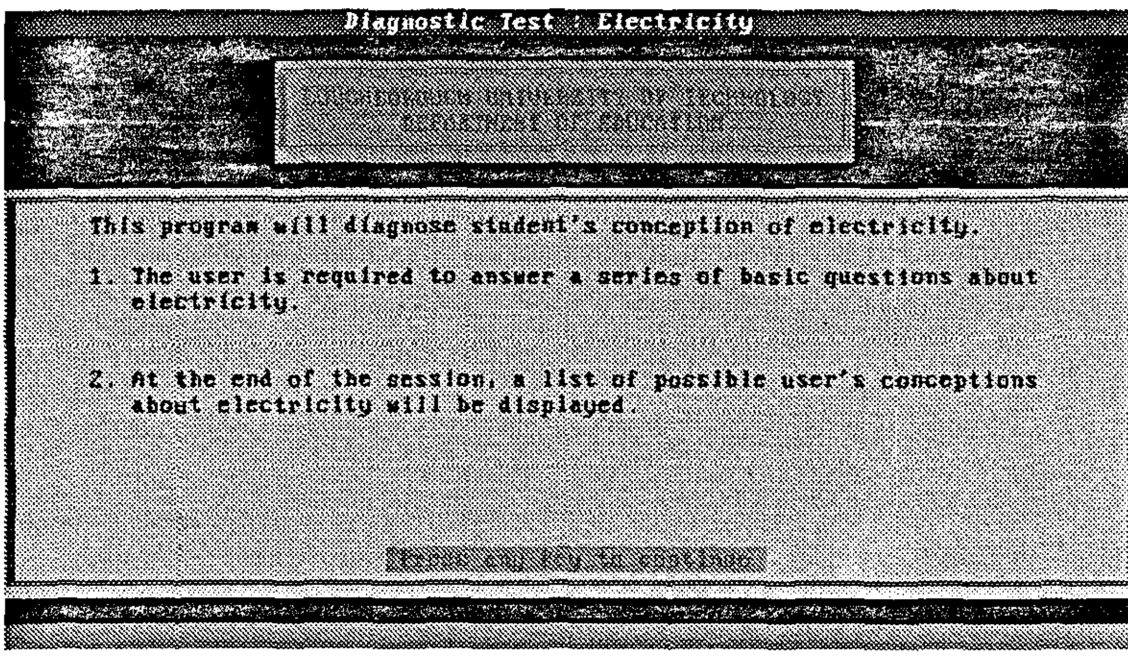
rule: report_results and store_responses
if post_analysis is done
and disp_results is finish
then run research_report(user_name,research_data,research_data2);
report_display is done

rule: check_for_printing
if report_display is done
and ask_print is finish
then askprint is check

rule: check_retest
if askprint is check
and recycle is check
then diagnosis is done

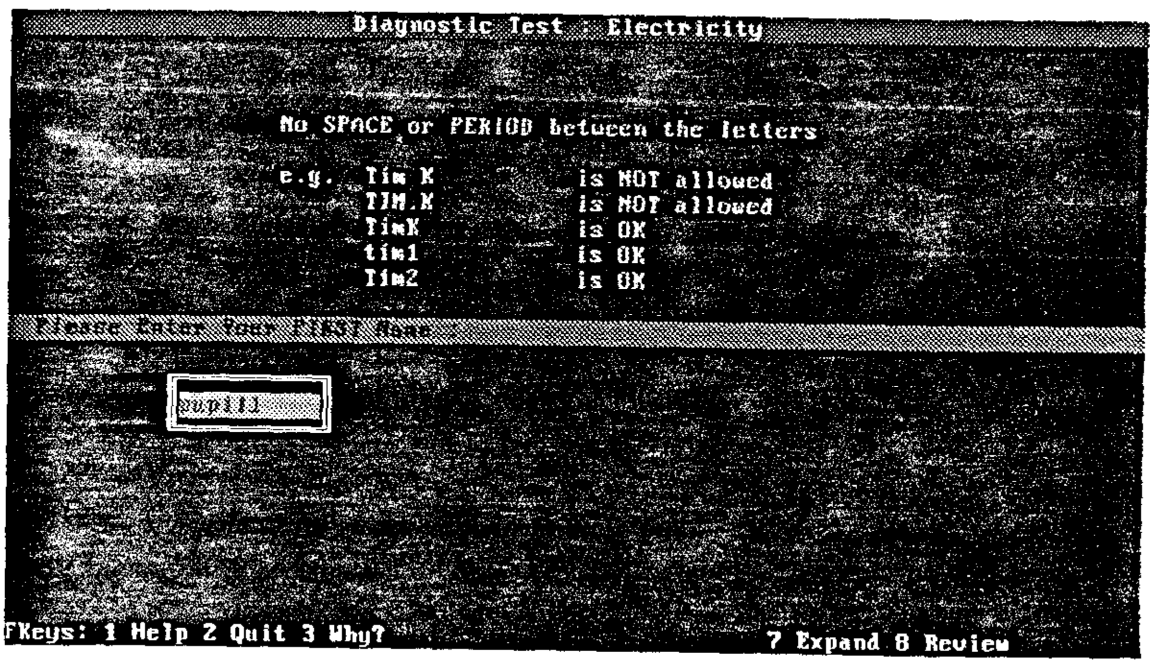
APPENDIX D6

SNAPSHOT OF PROGRAM SCREENS



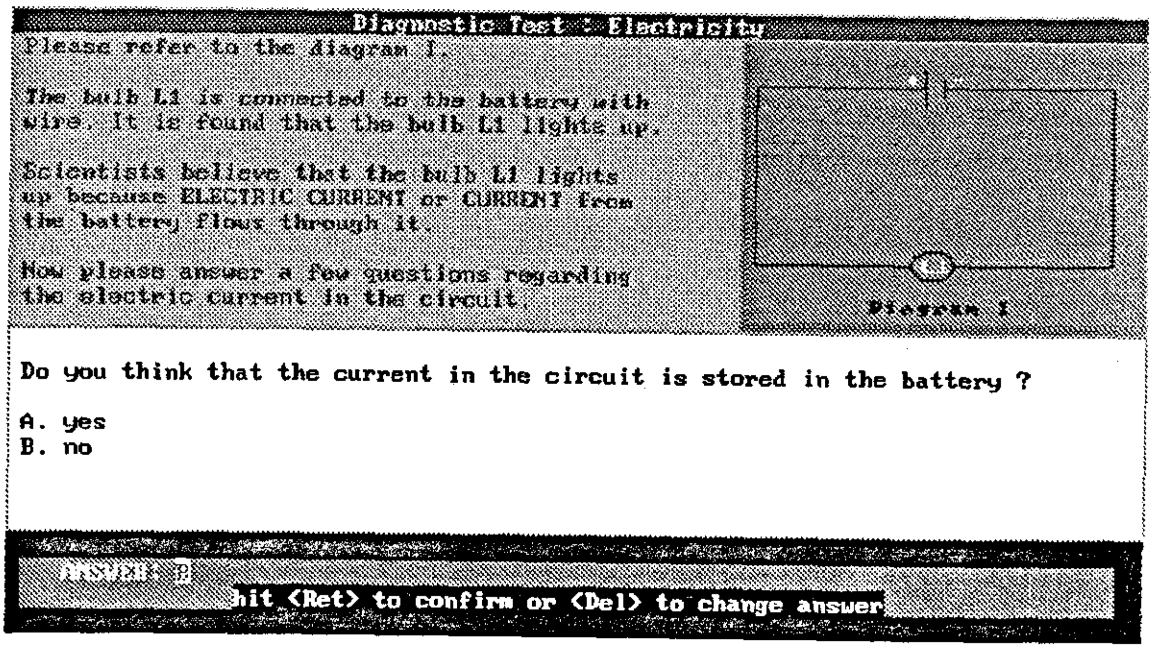
Introductory Screen

SNAPSHOT OF PROGRAM SCREENS (Continued)



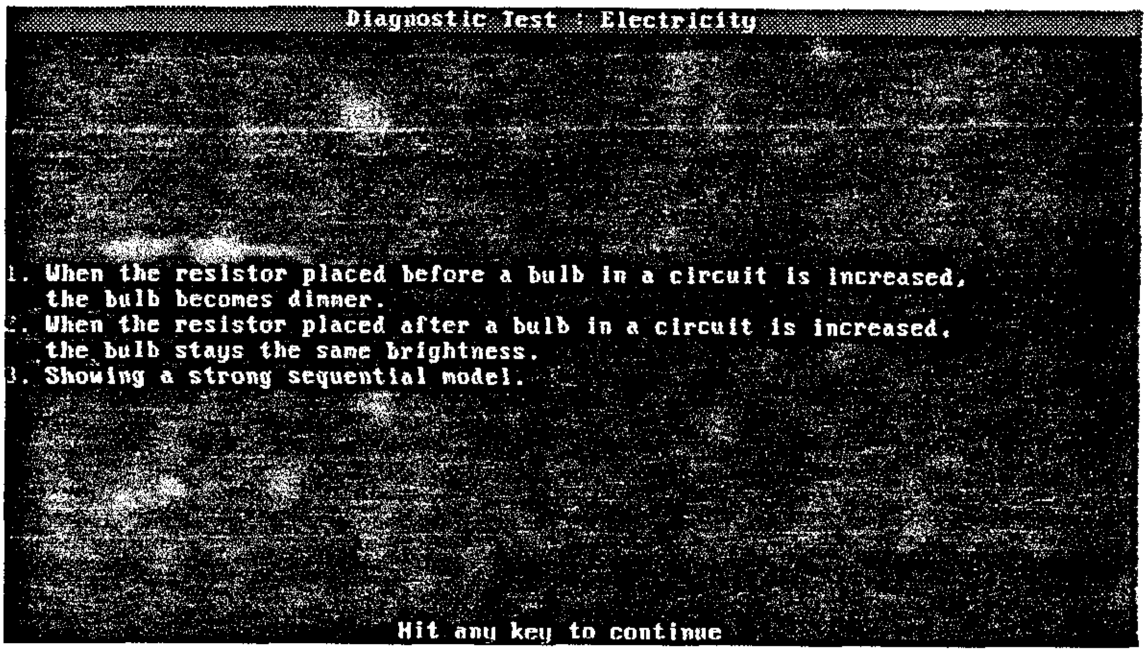
'Asking For User Name' Screen

SNAPSHOT OF PROGRAM SCREENS (Continued)



'Question' Screen

SNAPSHOT OF PROGRAM SCREENS (Continued)



'Descriptive Feedback' Screen

APPENDIX D7

DESCRIPTIVE FEEDBACK : ELECTRICITY

1. Rules

Name: Description

if battery_stored_current is present
and current_as_energy is present
then description is 'c1'

if battery_stored_current is absent
and current_from_pd is present
then description is 'c2'

if battery_stored_current is present
and current_as_energy is absent
then description is 'c3'

if current_both_terminal is present
then description is 'c4'

if current_both_terminal is absent
and current_is_unidirection is present
and current_pos_neg is present
then description is 'c5'

if current_both_terminal is absent
and current_is_unidirection is present
and current_neg_pos is present
then description is 'c6'

if bulb_used_current is present
and bulb_used_all_current is present
and other_term_passive is present
then description is 'c7'

if bulb_used_current is present
and term1_more_current_term2 is present
and bulb_used_part_current is present
then description is 'c8'

if bulb_used_current is absent
and current_is_conserve is present
then description is 'c9'

if bulb1_same_bright_bulb2 is present
and bulb12_share_current is present
then description is 'c10'

if bulb1_bright_than_bulb2 is present
and bulb12_used_current is present
then description is 'c11'

DESCRIPTIVE FEEDBACK : ELECTRICITY (Continued)

if 2bulb_dimmer_than_1bulb is present
and 2bulb_share_current is present
and current_same_amt_d1d2 is present
then description is 'c12'

if 2bulb_same_bright_1bulb is absent
and constant_current_source is present
then description is 'c13'

if r1_inc_bulb_dimmer is present
and r2_inc_bulb_same_bright is present
then description is 'c14'

if r1_inc_bulb_dimmer is present
and r2_inc_bulb_dimmer is present
then description is 'c15'

2. List of Descriptions

Descriptive C1 :

1. Current is stored in the battery.
2. There is a relation between current and energy(current is a energy).

Descriptive C2 :

1. Current is NOT stored in the battery.
2. Current is produced by the Potential Difference in the battery.

Descriptive C3 :

1. Current is stored in the battery.
2. There is NO relation between current and energy.

Descriptive C4 :

1. Current flows from both terminals of battery and then meets in the bulb to cause it to light up.

Descriptive C5 :

1. Current flows in one direction.
2. Current flows from positive to negative terminal of the battery.

Descriptive C6 :

1. Current flows in one direction.
2. Current flows from negative to positive terminal of the battery.

DESCRIPTIVE FEEDBACK : ELECTRICITY (Continued)

Descriptive C7 :

1. Current is consumed as it flows through the bulb.
2. Bulb consumed ALL the current.

Descriptive C8 :

1. Current is consumed as it flows through the bulb.
2. Bulb consumed only part of the current.

Descriptive C9 :

1. Current is conserved as it flows through the bulbs.

Descriptive C10 :

1. Two bulbs in a series circuit have the same brightness.
2. The two bulbs SHARED the amount of current.

Descriptive C11 :

1. Two bulbs in a series circuit do NOT have the same brightness.
2. The first bulb is brighter than the second bulb.
3. Current is consumed as it moves from one bulb to the another.

Descriptive C12 :

1. Battery giving out a constant current, independent of the circuit.
2. Circuit with two bulbs in series is dimmer than circuit with one bulb as the current now is shared.

Descriptive C13 :

1. Battery giving out a constant current, independent of the circuit.
2. Circuit with two bulbs is same brightness with circuit of one bulb.

Descriptive C14 :

1. When the resistor placed before a bulb in a circuit is increased, the bulb becomes dimmer.
2. When the resistor placed after a bulb in a circuit is increased, the bulb stays the same brightness.
3. Showing a strong sequential model.

Descriptive C15 :

1. When the resistor placed before a bulb in a circuit is increased, the bulb becomes dimmer.
2. When the resistor placed after a bulb in a circuit is increased, the bulb becomes dimmer.

APPENDIX D8

PROCEDURE PROGRAMMING FOR DIAGRAM I

Object Name: pic1

```
Name          : pic1
LongName      :
Type          : Procedure
AcceptsReal   :
AcceptsText   :
AcceptsList   :
ReturnsReal   :
ReturnsText   :
ReturnsList   :
LocalReal     :
LocalText     :
LocalList     :
Externals     :
Body          :
                grexecute('boxo',412,15,639,178,13)
                grexecute('boxf',412,15,639,178,51)
                grexecute('line',420,40,620,40,16)
                grexecute('line',420,140,620,140,16)
                grexecute('line',420,40,420,140,16)
                grexecute('line',620,40,620,140,16)
                grexecute('line',515,30,515,50,16)
                grexecute('line',525,35,525,45,16)
                grexecute('line',516,40,524,40,51)
                grexecute('circle',520,140,12,16)
                grexecute('line',509,140,531,140,51)
                grmessage('L1',15,514,137,1,1)
                grmessage('Diagram I',16,485,160,1,1)
                return
```

APPENDIX E1

SPEED AND GRAPHS QUESTIONS

	Questions	Comments
1	A pupil carried out a simple experiment by using ticker-timer, tape and a trolley. The tape is pulled through the ticker_timer by the trolley. A series of dots is marked on the tape. Please answer the following questions.	
A	Refer to tape 1(a), the position of the dots showed that the speed of the trolley is A. increasing B. decreasing C. constant	
B	Refer to tape 1(b), the position of the dots showed that the speed of the trolley is A. increasing B. decreasing C. constant	
C	Refer to tape 1(c), the position of the dots showed that the speed of the trolley is A. increasing B. decreasing C. constant	

SPEED AND GRAPHS QUESTIONS (Continued)

	Questions	Comments
2	Now, two trolleys are released side-by-side. The position of the dots on the tapes after a certain time is shown in diagrams.	
A	In diagram 2(a), trolley 1 is moving ________ trolley 2. A. faster than B. slower than C. same speed as	
B	In diagram 2(b), trolley 1 is moving ________ trolley 2. A. faster than B. slower than C. same speed as	
C	In diagram 2(c), trolley 1 is moving ________ trolley 2. A. faster than B. slower than C. same speed as	
3	Two balls A and B move at CONSTANT speeds on separate tracks. The position occupied by the two balls at the SAME TIME are shown in the DIAGRAM 3 by identical number.	
A	Do the two balls ever have the same speed on the tapes shown ? A. yes B. no	

SPEED AND GRAPHS QUESTIONS (Continued)

	Questions	Comments
B	When do the two balls have the same speed ? A. when t = 3 B. when t = 4 C. when t = 5	
4	The motion of an object is shown as a distance-time graph as in the diagram.	
A	In diagram 4(a), the graph shows that the speed of the object is A. increasing B. decreasing C. constant	
B	In diagram 4(b), the graph shows that the speed of the object is A. increasing B. decreasing C. constant	
C	In diagram 4(c), the graph shows that the speed of the object is A. increasing B. decreasing C. constant	

SPEED AND GRAPHS QUESTIONS (Continued)

	Questions	Comments
5	The motion of two identical objects is shown as a distance-time graph as in the diagram.	
A	*Refer to diagram 5(a).* At any stage of the motion, are the objects at the SAME PLACE at the SAME TIME ? A. yes B. no	
B	When are the objects at the SAME PLACE at the SAME TIME ? A. t less than 5s B. t = 5s C. t more than 5s	
C	Refer to diagram 5(a). At any stage of the motion, are they moving at the SAME SPEED ? A. yes B. no	
D	When are the objects move at the SAME SPEED ? A. t less than 5s B. t = 5s C. t more than 5s	
E	Refer to diagram 5(b). At any stage of the motion, are the objects at the SAME PLACE at the SAME TIME ? A. yes B. no	
F	When are the objects at the SAME PLACE at the SAME TIME ? A. t less than 5s B. t = 5s C. t more than 5s	

SPEED AND GRAPHS QUESTIONS (Continued)

	Questions	Comments
G	Refer to diagram 5(b). At any stage of the motion, are they moving at the SAME SPEED ? A. yes B. no	
H	When are the objects move at the SAME SPEED ? A. t less than 5s B. t = 5s C. t more than 5s	
I	Refer to diagram 5(c). Are the two objects moving at the SAME SPEED ? A. yes B. no	
6	Diagram 6 shows the motion of an object as a distance-time graph.	
A	Which part or point of the graph is the motion slowest ? A. 1 to 2 B. 3 to 4 C. 2 D. 3	
B	Which point on the graph is the object turning around ? A. 2 B. 3 C. 4 D. 5	

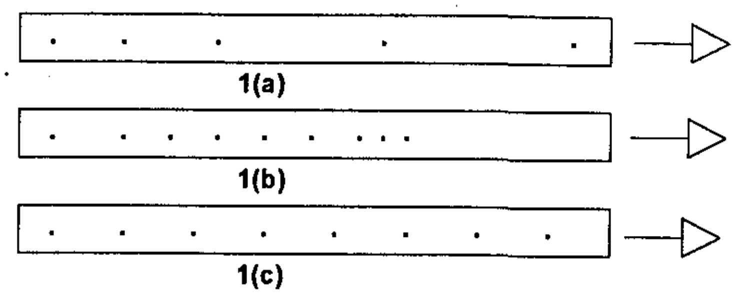


Diagram 1

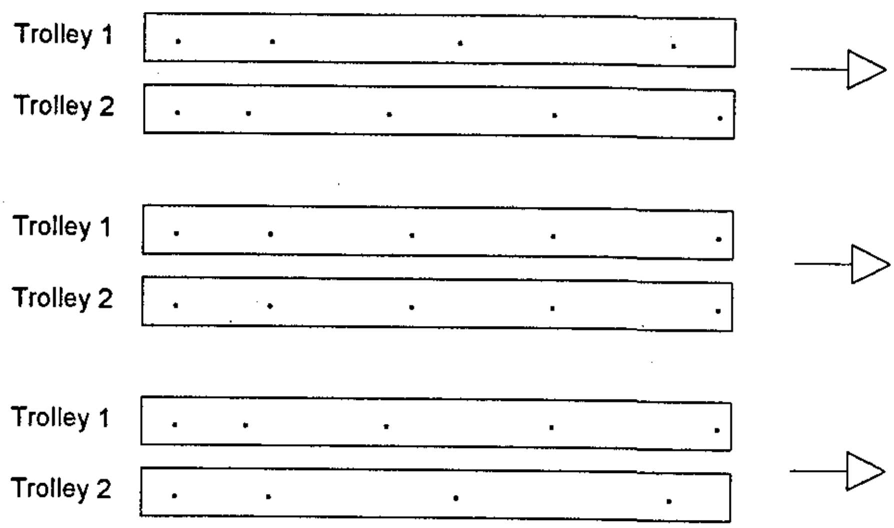
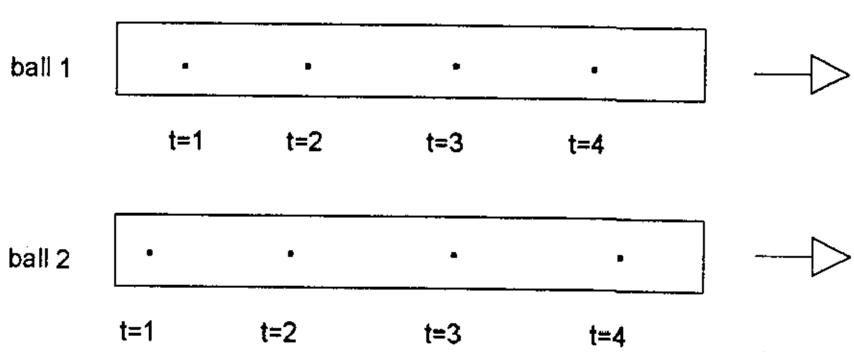


Diagram 2



[starting point is NOT shown]

Diagram 3

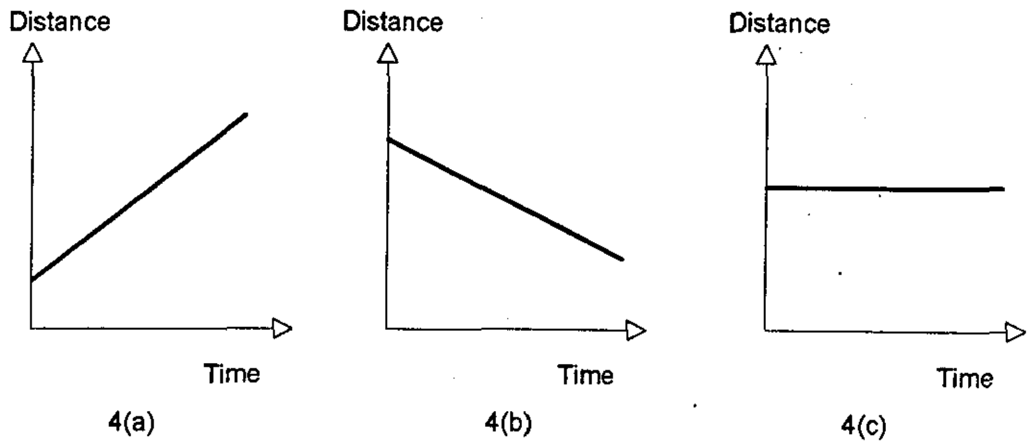


Diagram 4

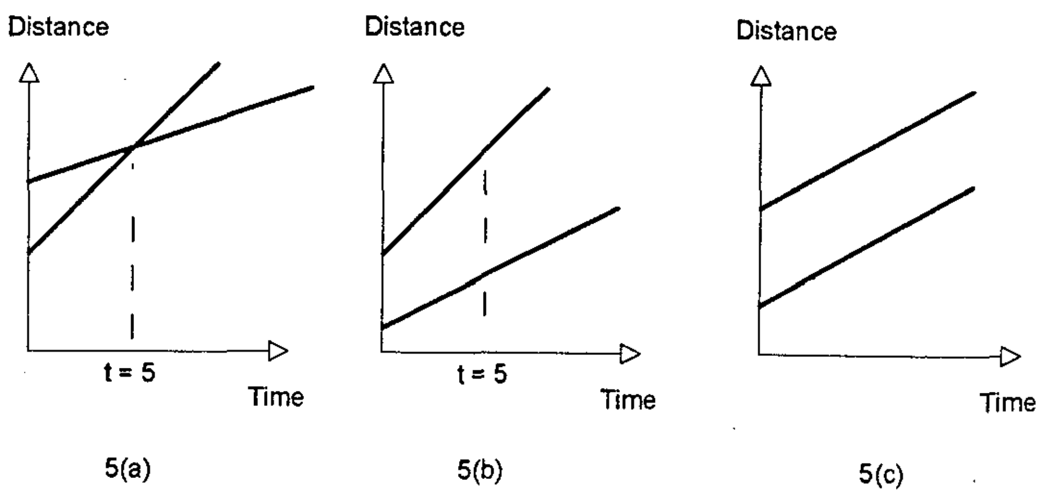


Diagram 5

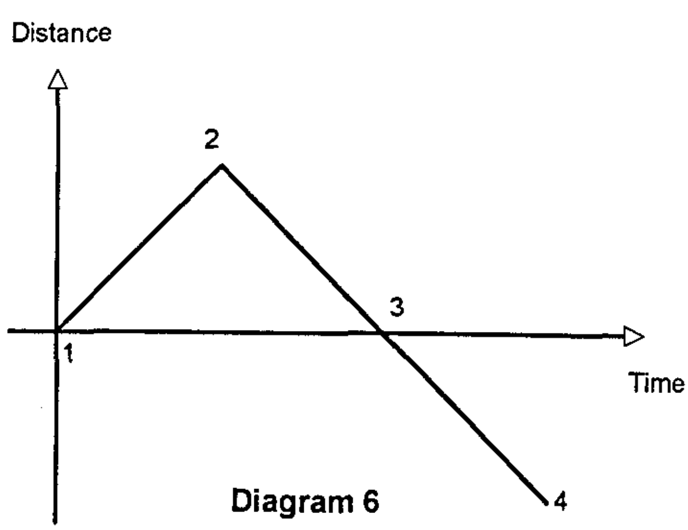
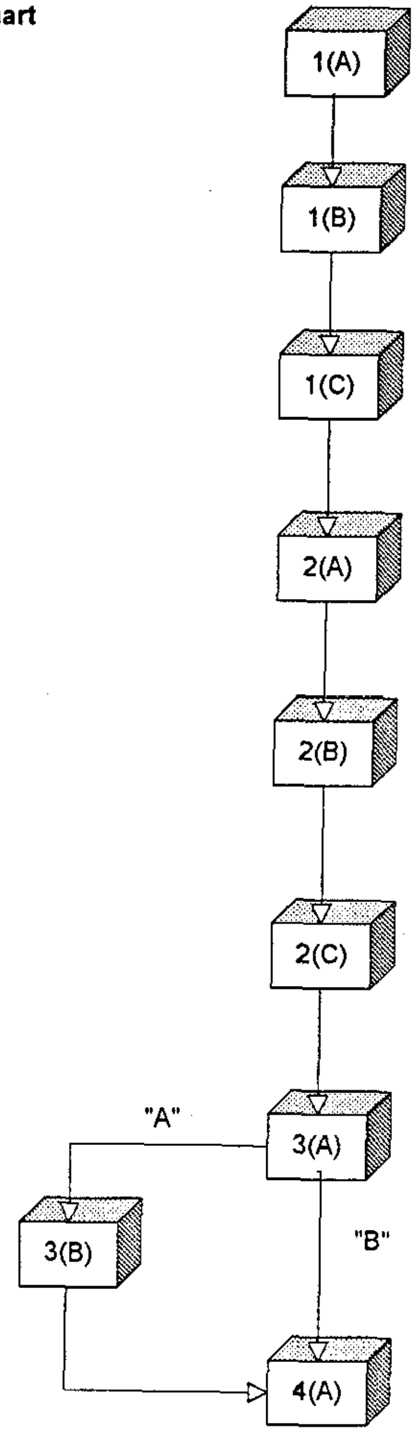


Diagram 6

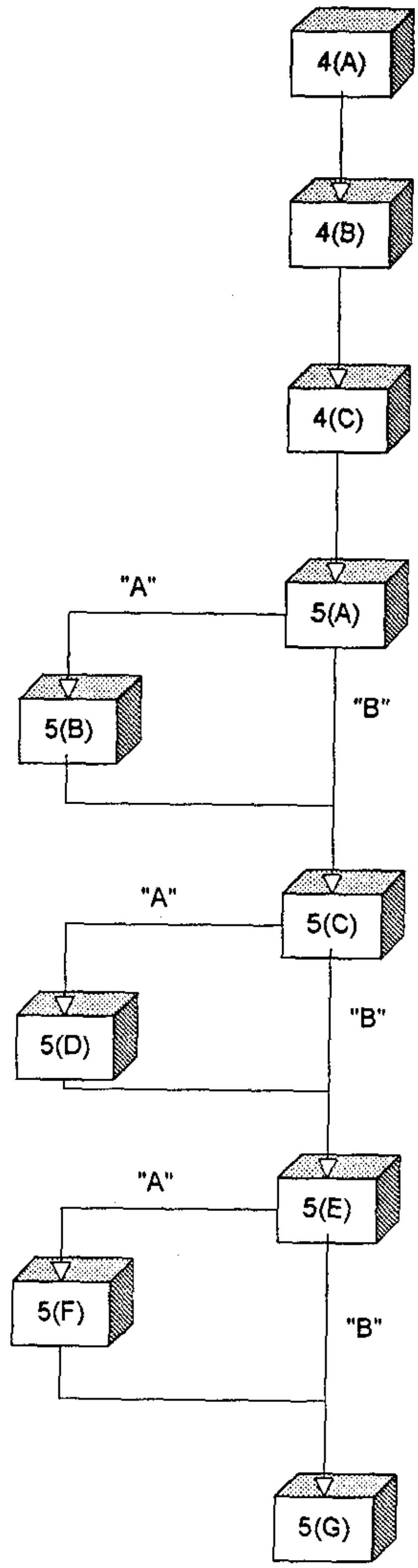
APPENDIX E2

QUESTION SEQUENCING RULES : SPEED AND GRAPHS

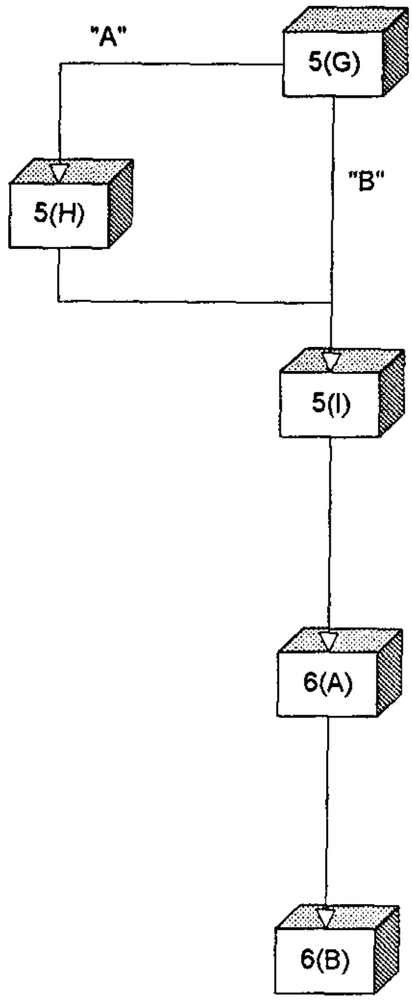
1. Flowchart



Question Flow Chart for Speed and Motion



Question Flow Chart for Speed and Motion (Continued)



Question Flow Chart for Speed and Motion (Continued)

QUESTION SEQUENCING RULES : SPEED AND GRAPHS (Continued)

2. Rules

Name: disp_ques
if display_S1 is yes
and display_Q1 is yes
and display_Q2 is yes
and display_Q3 is yes
and display_S21 is yes
and display_Q4 is yes
and display_S22 is yes
and display_Q5 is yes
and display_S23 is yes
and display_Q6 is yes
and display_S3 is yes
and display_Q7 is yes
and display_Q8 is yes
and display_S4 is yes
and display_Q9 is yes
and display_S41 is yes
and display_Q10 is yes
and display_S42 is yes
and display_Q11 is yes
and display_S5 is yes
and display_Q12 is yes
and display_Q13 is yes
and display_Q14 is yes
and display_Q15 is yes
and display_S51 is yes
and display_Q16 is yes
and display_Q17 is yes
and display_Q18 is yes
and display_Q19 is yes
and display_S52 is yes
and display_Q20 is yes
and display_S6 is yes
and display_Q21 is yes
and display_Q22 is yes
then disp_ques is finish

if initialise is yes
then run file_1(retest);
display_S1 is yes

if display_S1 is yes
then run file_2(txt1,retest,ans1);
run accept_3ans(ans1);
display_Q1 is yes

QUESTION SEQUENCING RULES : SPEED AND GRAPHS (Continued)

```
if display_Q1 is yes
then run file_2(txt2,retest,ans2);
run accept_3ans(ans2);
display_Q2 is yes

if display_Q2 is yes
then run file_2(txt3,retest,ans3);
run accept_3ans(ans3);
display_Q3 is yes

if display_Q3 is yes
then run file_21(retest);
display_S21 is yes

if display_S21 is yes
then run file_2(txt4,retest,ans4);
run accept_3ans(ans4);
display_Q4 is yes

if display_Q4 is yes
then run file_22(retest);
display_S22 is yes

if display_S22 is yes
then run file_2(txt5,retest,ans5);
run accept_3ans(ans5);
display_Q5 is yes

if display_Q5 is yes
then run file_23(retest);
display_S23 is yes

if display_S23 is yes
then run file_2(txt6,retest,ans6);
run accept_3ans(ans6);
display_Q6 is yes

if display_Q6 is yes
then run file_3(retest);
display_S3 is yes

if display_S3 is yes
then run file_2(txt7,retest,ans7);
run accept_2ans(ans7);
display_Q7 is yes

if display_Q7 is yes
and ans7 is "a"
then run file_2(txt8,retest,ans8);
run accept_3ans(ans8);
display_Q8 is yes
```

QUESTION SEQUENCING RULES : SPEED AND GRAPHS (Continued)

```
if display_Q7 is yes
and ans7 is "b"
then display_Q8 is yes

if display_Q8 is yes
then run file_4(retest);
display_S4 is yes

if display_S4 is yes
then run file_2(txt9,retest,ans9);
run accept_3ans(ans9);
display_Q9 is yes

if display_Q9 is yes
then run file_41(retest);
display_S41 is yes

if display_S41 is yes
then run file_2(txt10,retest,ans10);
run accept_3ans(ans10);
display_Q10 is yes

if display_Q10 is yes
then run file_42(retest);
display_S42 is yes

if display_S42 is yes
then run file_2(txt11,retest,ans11);
run accept_3ans(ans11);
display_Q11 is yes

if display_Q11 is yes
then run file_5(retest);
display_S5 is yes

if display_S5 is yes
then run file_2(txt12,retest,ans12);
run accept_2ans(ans12);
display_Q12 is yes

if display_Q12 is yes
and ans12 is "a"
then run file_2(txt13,retest,ans13);
run accept_3ans(ans13);
display_Q13 is yes

if display_Q12 is yes
and ans12 is "b"
then display_Q13 is yes
```

QUESTION SEQUENCING RULES : SPEED AND GRAPHS (Continued)

```
if display_Q13 is yes
then run file_2(txt14,retest,ans14);
run accept_2ans(ans14);
display_Q14 is yes

if display_Q14 is yes
and ans14 is "a"
then run file_2(txt15,retest,ans15);
run accept_3ans(ans15);
display_Q15 is yes

if display_Q14 is yes
and ans14 is "b"
then display_Q15 is yes

if display_Q15 is yes
then run file_51(retest);
display_S51 is yes

if display_S51 is yes
then run file_2(txt16,retest,ans16);
run accept_2ans(ans16);
display_Q16 is yes

if display_Q16 is yes
and ans16 is "a"
then run file_2(txt17,retest,ans17);
run accept_3ans(ans17);
display_Q17 is yes

if display_Q16 is yes
and ans16 is "b"
then display_Q17 is yes

if display_Q17 is yes
then run file_2(txt18,retest,ans18);
run accept_2ans(ans18);
display_Q18 is yes

if display_Q18 is yes
and ans18 is "a"
then run file_2(txt19,retest,ans19);
run accept_3ans(ans19);
display_Q19 is yes

if display_Q18 is yes
and ans18 is "b"
then display_Q19 is yes
```

QUESTION SEQUENCING RULES : SPEED AND GRAPHS (Continued)

```
if display_Q19 is yes
then run file_52(retest);
display_S52 is yes

if display_S52 is yes
then run file_2(txt20,retest,ans20);
run accept_2ans(ans20);
display_Q20 is yes

if display_Q20 is yes
then run file_6(retest);
display_S6 is yes

if display_S6 is yes
then run file_2(txt21,retest,ans21);
run accept_4ans(ans21);
display_Q21 is yes

if display_Q21 is yes
then run file_2(txt22,retest,ans22);
run accept_4ans(ans22);
run close_graphic;
display_Q22 is yes
```

APPENDIX E3

LIST OF TABULAR MATRICES : SPEED AND GRAPHS

Question Area 1 :

Rule	Parameters			
	Dots Position increasing [Diagram 1(a)]	Dots Position Decreasing [Diagram 1(b)]	Dots Position Constant [Diagram 1(c)]	
Rule 1 Speed :	increasing	decreasing	constant	Descriptive 1(A)
Rule 2 Speed :	constant	constant	constant	Descriptive 1(B)
Rule 3 Speed :	decreasing	increasing	constant	Descriptive 1(C)

Question Area 2 :

Rule	Parameters			
	Dots on tape 1 are moving at faster rate than dots on tape 2 [Diagram 2(a)]	Dots on tape 1 and 2 are moving at same rate [Diagram 2(b)]	Dots on tape 1 are moving at slower rate than dots on tape 2 [Diagram 2(c)]	
Rule 2(a): trolley 1 is moving ______ trolley 2	faster than	faster than	faster than	Descriptive 2(A)
Rule 2(b): trolley 1 is moving ______ trolley 2	slower than	slower than	slower than	Descriptive 2(B)
Rule 2(c): trolley 1 is moving ______ trolley 2:	same speed as	same speed as	same speed as	Descriptive 2(C)

LIST OF TABULAR MATRICES : SPEED AND GRAPHS (Continued)

Question Area 3 :

Rule	Parameters		
	Objects move at same speed ?	When is it ?	
Rule 1	yes	t = 3 units	Descriptive 3(A)
Rule 2	yes	t other than 3 units	Descriptive 3(B)
Rule 3	no	-	Descriptive 3(C)

Question Area 4 :

Rule	Parameters			
	Slope Ascending	Slope Descending	Horizontal	
Rule 1 Speed :	increasing	decreasing	constant	Descriptive 4(A)
Rule 2 Speed :	constant	constant	constant	Descriptive 4(B)
Rule 3 Speed :	decreasing	increasing	constant	Descriptive 4(C)

LIST OF TABULAR MATRICES : SPEED AND GRAPHS (Continued)

Question Area 5 :

Rule	Parameters			
	Two intercepting straight lines	Two non-parallel and non-intercepting starights lines	Two parallel straight lines	
Rule 5(a):	(a) Objects are at the same place at same time (b) It happens at the point of interception	(a) Objects never at the same place at the same time	-	Descriptive 5(A)
Rule 5(b):	(a) Objects move at the same speed (b) It happens at the point of interception	(a) Objects never move at the same speed.	-	Descriptive 5(B)
Rule 5(c)	Objects never move at the same speed	Objects never move at the same speed	-	Descriptive 5(C)
Rule 5(d)	Objects never at the same place at the same time	Objects never at the same place at the same time	-	Descriptive 5(D)
Rule 5(e):	-	-	Objects move at the same speed	Descriptive 5(E)

Question Area 6 :

Rule	Parameters		
	Motion slowest at point/part	Object turning around at point/part	
Rule 1	3 to 4	3	Descriptive 6(A)
Rule 2	3 to 4	2	Descriptive 6(B)
Rule 3	2	2	Descriptive 6(C)
Rule 4	3	3	Descriptive 6(D)
Rule 4	2	3	Descriptive 6(E)

APPENDIX E4

DIAGNOSTIC RULES : SPEED AND GRAPHS

1. Main RuleSet

Main Rule

rule: set_the_goal
seek diagnosis

rule: initialisation
if start is yes
and initialise is yes
then start_up is finish

rule: display_question
if start_up is finish
and disp_question is finish
then test is done

rule: check_answer
if test is done
and chk_answer is finish
then answer_analysis is done

rule: analyse_models and store_responses
if answer_analysis is done
and model is finish
then run convert_model(model,model_list);
post_analysis is done

if post_analysis is done
and disp_results is finish
then run research_report(user_name,research_data,research_data2);
report_display is done

rule: check_for_printing
if report_display is done
and ask_print is finish
then askprint is check

rule: check_recycle
if askprint is check
and recycle is check
then diagnosis is done

DIAGNOSTIC RULES : SPEED AND GRAPHS (Continued)

2. Analysis of Responses Rules

Name: chk_ans

```
if check_ans1 is finish
and check_ans2 is finish
and check_ans3 is finish
and check_ans4 is finish
and check_ans5 is finish
and check_ans6 is finish
and check_ans7 is finish
and check_ans8 is finish
and check_ans9 is finish
and check_ans10 is finish
and check_ans11 is finish
and check_ans12 is finish
and check_ans13 is finish
and check_ans14 is finish
and check_ans15 is finish
and check_ans16 is finish
and check_ans17 is finish
and check_ans18 is finish
and check_ans19 is finish
and check_ans20 is finish
and check_ans21 is finish
and check_ans22 is finish
then chk_ans is finish

if ans1 is "a"
then dist_inc_speed_inc is present;
check_ans1 is finish

if ans1 is "b"
then dist_inc_speed_dec is present;
check_ans1 is finish

if ans1 is "c"
then dist_inc_speed_con is present;
check_ans1 is finish

if ans2 is "a"
then dist_dec_speed_inc is present;
check_ans2 is finish

if ans2 is "b"
then dist_dec_speed_dec is present;
check_ans2 is finish
```

DIAGNOSTIC RULES : SPEED AND GRAPHS (Continued)

if ans2 is "c"
then dist_dec_speed_con is present;
check_ans2 is finish

if ans3 is "a"
then dist_con_speed_inc is present;
check_ans3 is finish

if ans3 is "b"
then dist_con_speed_dec is present;
check_ans3 is finish

if ans3 is "c"
then dist_con_speed_con is present;
check_ans3 is finish

if ans4 is "a"
then 2a_tro1_fast_tro2 is present;
check_ans4 is finish

if ans4 is "b"
then 2a_tro1_slow_tro2 is present;
check_ans4 is finish

if ans4 is "c"
then 2a_tro1_same_tro2 is present;
check_ans4 is finish

if ans5 is "a"
then 2b_tro1_fast_tro2 is present;
check_ans5 is finish

if ans5 is "b"
then 2b_tro1_slow_tro2 is present;
check_ans5 is finish

if ans5 is "c"
then 2b_tro1_same_tro2 is present;
check_ans5 is finish

if ans6 is "a"
then 2c_tro1_fast_tro2 is present;
check_ans6 is finish

if ans6 is "b"
then 2c_tro1_slow_tro2 is present;
check_ans6 is finish

if ans6 is "c"
then 2c_tro1_same_tro2 is present;
check_ans6 is finish

DIAGNOSTIC RULES : SPEED AND GRAPHS (Continued)

if ans7 is "a"
then 2ball_has_same_speed is present;
check_ans7 is finish

if ans7 is "b"
then check_ans7 is finish

if ans8 is "b" or ans8 is "c" or ans8 is "x"
then check_ans8 is finish

if ans8 is "a"
then 2ball_position_crit is present;
check_ans8 is finish

if ans9 is "a"
then grad_pos_speed_inc is present;
check_ans9 is finish

if ans9 is "b"
then grad_pos_speed_dec is present;
check_ans9 is finish

if ans9 is "c"
then grad_pos_speed_con is present;
check_ans9 is finish

if ans10 is "a"
then grad_neg_speed_inc is present;
check_ans10 is finish

if ans10 is "b"
then grad_neg_speed_dec is present;
check_ans10 is finish

if ans10 is "c"
then grad_neg_speed_con is present;
check_ans10 is finish

if ans11 is "a"
then grad_con_speed_inc is present;
check_ans11 is finish

if ans11 is "b"
then grad_con_speed_dec is present;
check_ans11 is finish

if ans11 is "c"
then grad_con_speed_con is present;
check_ans11 is finish

DIAGNOSTIC RULES : SPEED AND GRAPHS (Continued)

if ans12 is "a"
then 5a_same_place_time is present;
check_ans12 is finish

if ans12 is "b"
then check_ans12 is finish

if ans13 is "a" or ans13 is "c" or ans13 is "x"
then check_ans13 is finish

if ans13 is "b"
then 5a_position_crit is present;
check_ans13 is finish

if ans14 is "a"
then 5a_same_speed is present;
check_ans14 is finish

if ans14 is "b"
then check_ans14 is finish

if ans15 is "a" or ans15 is "c" or ans15 is "x"
then check_ans15 is finish

if ans15 is "b"
then 5a_position_speed is present;
check_ans15 is finish

if ans16 is "a"
then 5b_same_place_time is present;
check_ans16 is finish

if ans16 is "b"
then check_ans16 is finish

if ans17 is "a" or ans17 is "c" or ans17 is "x"
then check_ans17 is finish

if ans17 is "b"
then 5b_position_crit is present;
check_ans17 is finish

if ans18 is "a"
then 5b_same_speed is present;
check_ans18 is finish

if ans18 is "b"
then check_ans18 is finish

if ans19 is "a" or ans19 is "c" or ans19 is "x"
then check_ans19 is finish

DIAGNOSTIC RULES : SPEED AND GRAPHS (Continued)

if ans19 is "b"
then 5b_position_speed is present;
check_ans19 is finish

if ans20 is "a"
then 5c_same_speed is present;
check_ans20 is finish

if ans20 is "b"
then check_ans20 is finish

if ans21 is "a"
then motion_slow_12 is present;
check_ans21 is finish

if ans21 is "b"
then motion_slow_34 is present;
check_ans21 is finish

if ans21 is "c"
then motion_slow_2 is present;
check_ans21 is finish

if ans21 is "d"
then motion_slow_3 is present;
check_ans21 is finish

if ans22 is "a"
then motion_turn_2 is present;
check_ans22 is finish

if ans22 is "b"
then motion_turn_3 is present;
check_ans22 is finish

if ans22 is "c"
then motion_turn_4 is present;
check_ans22 is finish

if ans22 is "d"
then motion_turn_5 is present;
check_ans22 is finish

APPENDIX E5

DESCRIPTIVE FEEDBACK : SPEED AND GRAPHS

1. Rules

Name: description

if dist_inc_speed_inc is present
and dist_dec_speed_dec is present
and dist_con_speed_con is present
then description is 'm1'

if dist_inc_speed_dec is present
and dist_dec_speed_inc is present
and dist_con_speed_con is present
then description is 'm1a'

if 2a_tro1_fast_tro2 is present
and 2b_tro1_same_tro2 is present
and 2c_tro1_slow_tro2 is present
then description is 'm2'

if 2ball_has_same_speed is present
and 2ball_position_crit is present
then description is 'm3'

if 2ball_has_same_speed is absent
then description is 'm3a'

if grad_pos_speed_inc is present
and grad_con_speed_con is present
and grad_neg_speed_dec is present
then description is 'm4'

if grad_pos_speed_con is present
and grad_con_speed_con is present
and grad_neg_speed_con is present
then description is 'm4a'

if 5a_same_place_time is present
and 5a_position_crit is present
and 5b_same_place_time is absent
then description is 'm5'

if 5a_same_speed is present
and 5a_position_speed is present
and 5b_same_speed is absent
then description is 'm5a'

if 5a_same_speed is absent
and 5b_same_speed is absent
then description is 'm5b'

if 5a_same_place_time is absent
and 5b_same_place_time is absent
then description is 'm5c'

if 5c_same_speed is present
then description is 'm5d'

if motion_slow_34 is present
and motion_turn_3 is present
then description is 'm6'

if motion_slow_34 is present
and motion_turn_2 is present
then description is 'm6a'

if motion_slow_2 is present
and motion_turn_2 is present
then description is 'm6b'

if motion_slow_3 is present
and motion_turn_3 is present
then description is 'm6c'

if motion_slow_2 is present
and motion_turn_3 is present
then description is 'm6d'

2. List of Descriptions

Description m1 :

Refer to Diagram 1:

1. When the dots on the tape become further apart, the speed of trolley is increasing.
2. When the dots on the tape become closer, the speed of trolley is decreasing.
3. When the dots on the tape stay same distance apart, the speed of trolley is constant.

Description m1a :

Refer to Diagram 1:

1. When the dots on the tape become further apart, the speed of trolley is decreasing.
2. When the dots on the tape become closer, the speed of trolley is increasing.
3. When the dots on the tape stay same distance apart, the speed of trolley is constant.

DESCRIPTIVE FEEDBACK : SPEED AND GRAPHS (Continued)

Description m2 :

Refer to Diagram 2:

1. Trolley 1 is moving faster than trolley 2.
2. Trolley 1 is moving at same speed as trolley 2.
3. Trolley 1 is moving slower than trolley 2.

Description m3 :

Refer to Diagram 3:

1. The two balls have the same speed at time t = 3.
2. When two objects are at the same position (side-by-side), they have same speed.

Conclusion: Strong indication of using position-criterion.

Description m3a :

Refer to Diagram 3:

1. The two balls DO NOT have the same speed.
2. When two objects are at the same position (side-by-side), they DO NOT necessarily have the same speed.

Conclusion: No indication of using position-criterion.

Description m4 :

Refer to Diagram 4:

1. When the slope is positive, the speed of object is increasing.
2. When the slope is negative, the speed of object is decreasing.
3. When the slope is horizontal, the speed of object is constant.

Conclusion: There is a relation between slope of graph and change of speed.

Description m4a :

Refer to Diagram 4:

1. When the slope is positive, the speed of object is constant.
2. When the slope is negative, the speed of object is constant.
3. When the slope is horizontal, the speed of object is constant.

Conclusion: There is NO relation between slope of graph and change of speed.

DESCRIPTIVE FEEDBACK : SPEED AND GRAPHS (Continued)

Description m5 :

Refer to Diagram 5(a) and 5(b):

Two identical objects on a distance-time graph:
1. WILL BE at the SAME PLACE at the SAME TIME if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE at the SAME PLACE at the SAME TIME if the lines NOT meet (cross) each other.

Conclusion: Strong indication of using position-criterion.

Description m5a :

Refer to Diagram 5(a) and 5(b):

Two identical objects on a distance-time graph:
1. WILL BE moving at SAME SPEED if the lines representing the motion of the objects meet (cross) each other.
2. WILL NOT BE moving at the SAME SPEED if the lines NOT meet (cross) each other.

Conclusion: *Strong indication of using position-criterion.*

Description m5b :

Refer to Diagram 5(a) and 5(b):

1. The two objects will never have the SAME SPEED.

Conclusion: No indication of using position-criterion.

Description m5c :

Refer to Diagram 5(a) and 5(b):

1. The two objects will never be at the SAME PLACE at the SAME TIME.

Conclusion: No indication of using position-criterion.

Description m5d :

Refer to Diagram 5(c):

1. Two objects are moving at the SAME SPEED if the lines representing their motion are parallel to each other.

DESCRIPTIVE FEEDBACK : SPEED AND GRAPHS (Continued)

Description m6 :

Refer to Diagram 6:

1. The motion of the object is slowest on part 3 to 4 (negative part of graph).
2. The turning point is at point 3 (interception of time-axis).

Description m6a :

Refer to Diagram 6:

1. The motion of the object is slowest on part 3 to 4 (negative part of graph).
2. The turning point is at point 2 (slope is zero).

Description m6b :

Refer to Diagram 6:

1. The motion of the object is slowest at point 2 (slope is zero).
2. The turning point is at point 2 (slope is zero).

Description m6c :

Refer to Diagram 6:

1. The motion of the object is slowest at point 3 (interception of time-axis).
2. The turning point is at point 3 (interception of time-axis).

Description m6d :

Refer to Diagram 6:

1. The motion of the object is slowest at point 2 (slope is zero).
2. The turning point is at point 3 (interception of time-axis).

APPENDIX E6

FLOATING AND SINKING QUESTIONS

	Questions	Comments
1	A pupil carried out a simple experiment in order to study whether an object will float or sink in water. He put a sealed bottle full of air into a tank of water.	
A	What do you think will happen to the bottle ? A. It will sink B. It will float C. I am not sure	
B	Why you are not sure ? A. It depends on other factor(s) B. Not enough information provided	
C	Why do you think that the bottle will sink ? A. It is heavy B. It is made of glass and glass sinks in water C. Other reason(s)	
D	If the pupil replaces the glass bottle with a SMALLER glass bottle (still with lid on), do you think it will float now ? A. Yes B. No C. I am not sure	
E	If he again replaces the glass bottle with a PLASTIC bottle, do you think it will float now ? A. Yes B. No C. I am not sure	
F	Why do you think that the bottle will float ? A. It is lighter B. It is full of air C. Other reason (s)	

FLOATING AND SINKING QUESTIONS (Continued)

	Questions	Comments
2	Now the pupil adds a little sand into the bottle. He replaced the lid and put the bottle into the water.	
A	What do you think will happen now ? A. It still floats, but lower into the water B. *It will sink*	
B	Why do you think the bottle still float ? A. It still has enough air inside to make it float B. Not enough sand added to make it heavy enough to sink C. Other reason (s)	
C	If more sand is added into the bottle, do you agree that it will sink when enough sand is added ? A. Yes B. No	
D	Why do you think that the bottle will sink ? A. the bottle is heavier B. Not enough air inside it to make it float	
E	Do you think that the "heaviness" or "lightness" of an object causes it to sink or float ? A. Yes B. No	
F	Do you agree with the following statement: "The heavier an object, the more likely it is to sink." A. Yes B. No C. It depends on other factor(s)	
G	Do you think that the amount of air contained inside an object will cause it to float or sink in water ? A. Yes B. No	

FLOATING AND SINKING QUESTIONS (Continued)

	Questions	Comments
3	It seems that from your previous answers the important factor that determines whether an object floats or sinks is its HEAVINESS. Let us proceed with further questions.	
A	Compared with a ship which is very much heavier than the glass bottle, the ship floats on water. Why do you think this is so ? A. The ship is also very large B. Other reason(s)	
B	Do you mean that objects will float if they are LIGHT *for their size* ? A. Yes B. No C. I am not sure	
C	The object's size can be determined by its VOLUME. Do you agree that heavy object (large mass) can be made to float if it has a large volume ? A. Yes B. No	
D	A tanker is loaded with 400 000 tonnes of oil. Will it float ? A. Yes B. No C. Cannot be answered unless one knows the volume of the tanker	

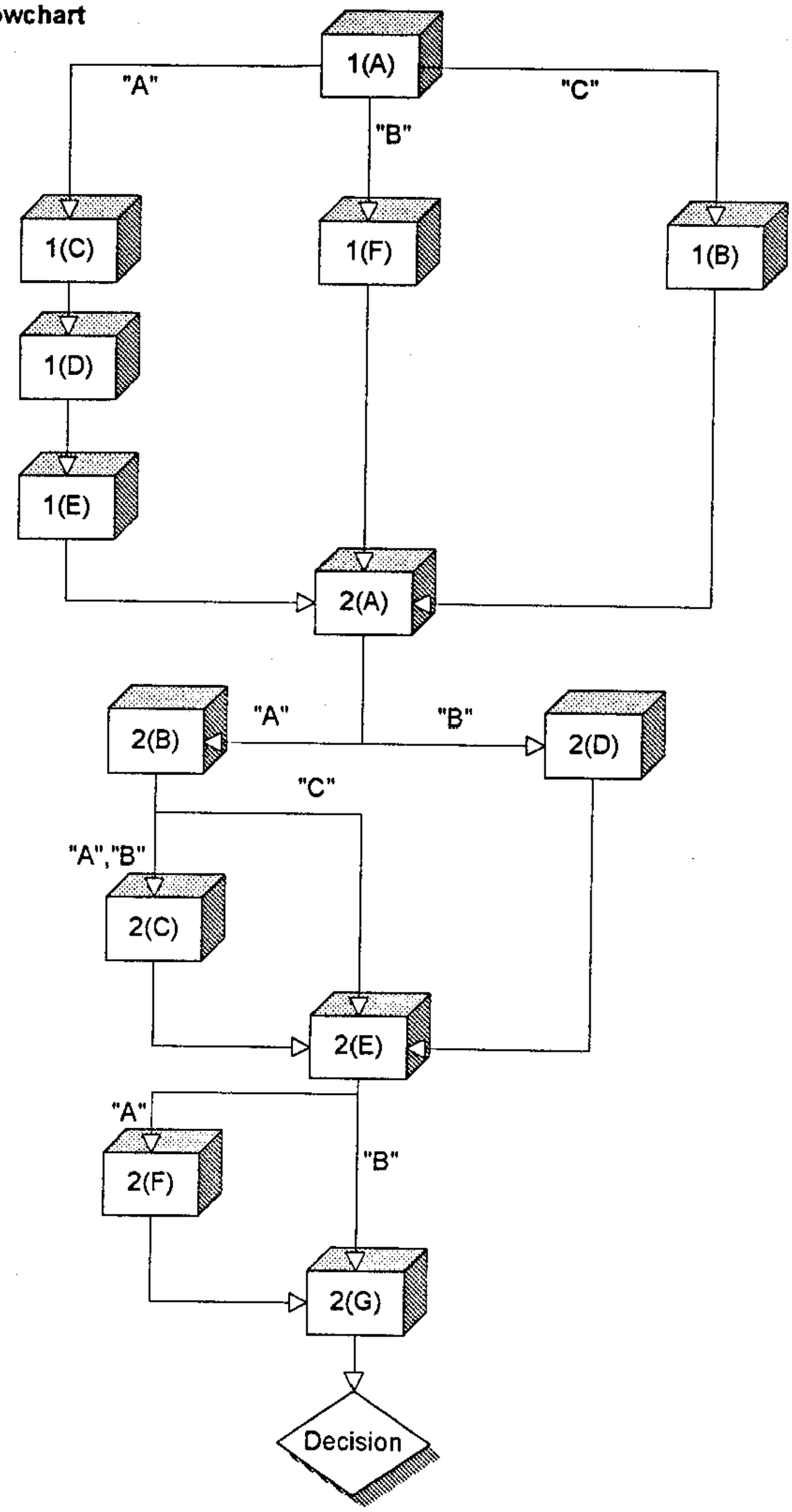
FLOATING AND SINKING QUESTIONS (Continued)

	Questions	Comments
4	It seems that from your previous answers the important factor that determines whether an object floats or sinks is the AMOUNT OF AIR it contains. Let us proceed with further questions.	
A	It is a well known fact that an ice cube always floats on water. Since there is almost no air inside the ice cube, why do you think it floats ? A. It is lighter than water B. I am not sure	
B	You said that the ice cube floats because it is lighter than water. Do you mean that "heaviness" or "lightness" of an object causes it to sink or float ? A. Yes B. No	

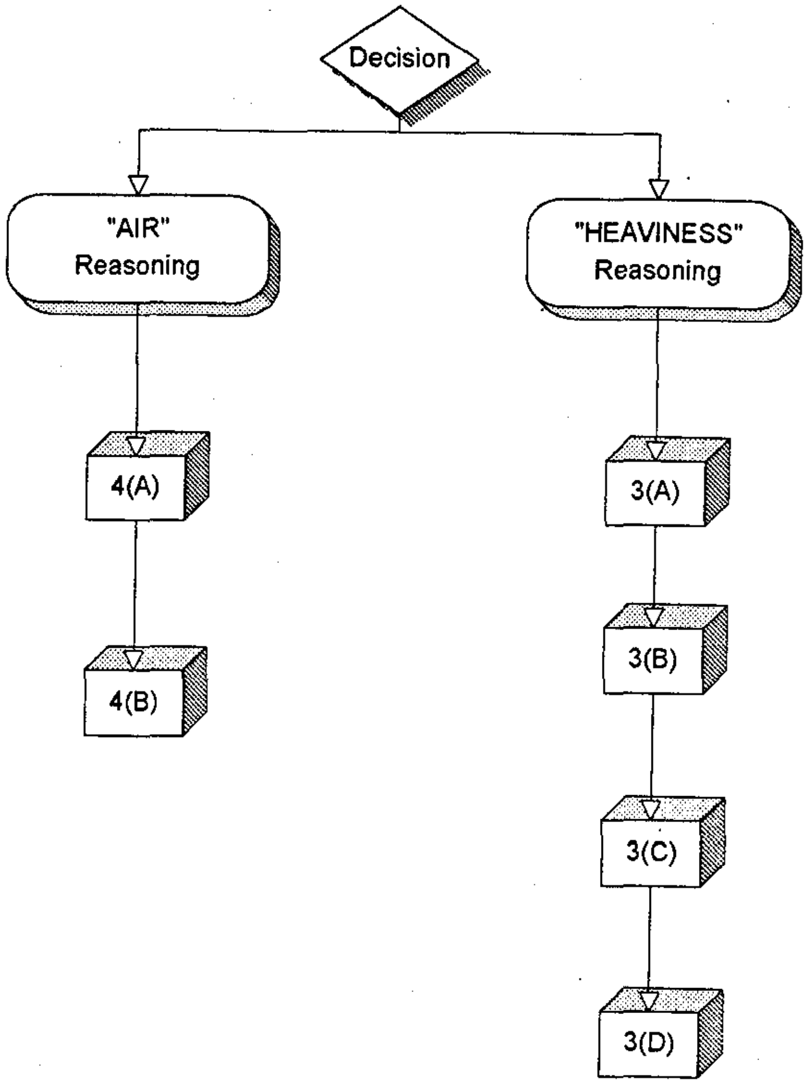
APPENDIX E7

QUESTION SEQUENCING RULES : FLOATING AND SINKING

1. **Flowchart**



Question Flow Chart For Floating/Sinking



Question Flow Chart For Floating/Sinking (Continued)

QUESTION SEQUENCING RULES : FLOATING AND SINKING (Continued)

2. Rules

Name: disp_ques

```
if display_S1 is yes
and display_Q1 is yes
and display_Q2 is yes
and display_S2 is yes
and display_Q5 is yes
and display_Q6 is yes
and display_Q7 is yes
and display_Q8 is yes
and display_Q9 is yes
and display_Q10 is yes
then disp_ques is finish

if initialise is yes
then run file_1(retest);
display_S1 is yes

if display_S1 is yes
then run file_2(txt1,retest,ans1);
run accept_3ans(ans1);
display_Q1 is yes

if display_Q1 is yes
and ans1 is "c"
then run file_2(txt2,retest,ans2);
run accept_2ans(ans2);
display_Q2 is yes

if display_Q1 is yes
and ans1 is "b"
then run file_2(txt6,retest,ans6);
run accept_3ans(ans6);
display_Q2 is yes

if display_Q1 is yes
and ans1 is "a"
then run file_2(txt3,retest,ans3);
run accept_3ans(ans3);
display_Q3 is yes

if display_Q3 is yes
then run file_2(txt4,retest,ans4);
run accept_3ans(ans4);
display_Q4 is yes
```

QUESTION SEQUENCING RULES : FLOATING AND SINKING (Continued)

```
if display_Q4 is yes
then run file_2(txt5,retest,ans5);
run accept_3ans(ans5);
display_Q2 is yes

if display_Q2 is yes
then run file_21(retest);
display_S2 is yes

if display_S2 is yes
then run file_2(txt7,retest,ans7);
run accept_2ans(ans7);
display_Q5 is yes

if display_Q5 is yes
and ans7 is "a"
then run file_2(txt8,retest,ans8);
run accept_3ans(ans8);
display_Q6 is yes

if display_Q5 is yes
and ans7 is "b"
then run file_2(txt10,retest,ans10);
run accept_2ans(ans10);
display_Q6 is yes

if display_Q6 is yes
and ans10 is "a"
then display_Q7 is yes

if display_Q6 is yes
and ans10 is "b"
then display_Q7 is yes

if display_Q6 is yes
and ans8 is "c"
then display_Q7 is yes

if display_Q6 is yes
and ans8 is "a"
then run file_2(txt9,retest,ans9);
run accept_2ans(ans9);
display_Q7 is yes

if display_Q6 is yes
and ans8 is "b"
then run file_2(txt9,retest,ans9);
run accept_2ans(ans9);
display_Q7 is yes
```

QUESTION SEQUENCING RULES : FLOATING AND SINKING (Continued)

```
if display_Q7 is yes
then run file_2(txt11,retest,ans11);
run accept_2ans(ans11);
display_Q8 is yes

if display_Q8 is yes
and ans11 is "a"
then run file_2(txt15,retest,ans15);
run accept_3ans(ans15);
display_Q9 is yes

if display_Q8 is yes
and ans11 is "b"
then display_Q9 is yes

if display_Q9 is yes
then run file_2(txt20,retest,ans20);
run accept_2ans(ans20);
display_Q10 is yes


Name: disp_ques2
if selection is "none"
then run close_graphic;
disp_ques2 is finish

if selection is "heaviness"
then run file_41(retest);
display_S3 is yes

if display_S3 is yes
then run file_2(txt12,retest,ans12);
run accept_2ans(ans12);
display_Q15 is yes

if display_Q15 is yes
then run file_2(txt13,retest,ans13);
run accept_3ans(ans13);
display_Q16 is yes

if display_Q16 is yes
then run file_2(txt14,retest,ans14);
run accept_2ans(ans14);
display_Q17 is yes


if display_Q17 is yes
then run file_2(txt16,retest,ans16);
run accept_3ans(ans16);
run close_graphic;
disp_ques2 is finish
```

```
if selection is "air"
then run file_31(retest);
display_S31 is yes

if display_S31 is yes
then run file_2(txt17,retest,ans17);
run accept_2ans(ans17);
display_Q18 is yes

if display_Q18 is yes
and ans17 is "a"
then run file_2(txt18,retest,ans18);
run accept_2ans(ans18);
run close_graphic;
disp_ques2 is finish

if display_Q18 is yes
and ans17 is "b"
then run close_graphic;
disp_ques2 is finish
```

APPENDIX E8

DIAGNOSTIC RULES : FLOATING AND SINKING

1. *Main RuleSet*

Main Rule

rule: set_the_goal
seek diagnosis

rule: initialisation
if start is yes
and initialise is yes
then start_up is finish

rule: display_question
if start_up is finish
and disp_question is finish
then test is done

rule: check_answer
if test is done
and chk_answer is finish
then run decide_case(condition,cval1,cval2);
run decide_case1(cval1,cval2,*condition,selection)*;
answer_analysis is done

if answer_analysis is done
and disp_ques2 is finish
then post_analysis is done

rule: report_results and stored_responses
if post_analysis is done
and disp_results is *finish*
then run research_report(user_name,research_data,research_data2);
report_display is done

rule: check_for_printing
if report_display is done
and ask_print is finish
then askprint is check

rule: check_retest
if askprint is check
and recycle is check
then diagnosis is done

DIAGNOSTIC RULES : FLOATING AND SINKING (Continued)

2. Analysis of Responses Rule

```
Name: chk_ans
if check_ans2 is finish
and check_ans3 is finish
and check_ans4 is finish
and check_ans5 is finish
and check_ans6 is finish
and check_ans8 is finish
and check_ans10 is finish
and check_ans11 is finish
and check_ans15 is finish
and check_ans20 is finish
then chk_ans is finish

if ans2 is "a"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
other_factors is present;
check_ans2 is finish

if ans2 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
Not_enough_info is present;
check_ans2 is finish

if ans2 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans2 is finish

if ans3 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
heavy_cause_sink is present;
check_ans3 is finish

if ans3 is "b"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
heavy_cause_sink is present;
check_ans3 is finish

if ans3 is "c"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
other_cause_sink is present;
check_ans3 is finish
```

DIAGNOSTIC RULES : FLOATING AND SINKING (Continued)

if ans3 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans3 is finish

if ans4 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
smaller_cause_float is present;
check_ans4 is finish

if ans4 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans4 is finish

if ans4 is "c" or ans4 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans4 is finish

if ans5 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
plastic_cause_float is present;
check_ans5 is finish

if ans5 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans5 is finish

if ans5 is "c" or ans5 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans5 is finish

if ans6 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
light_cause_float is present;
check_ans6 is finish

if ans6 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .5};
air_cause_float is present;
check_ans6 is finish

DIAGNOSTIC RULES : FLOATING AND SINKING (Continued)

```
if ans6 is "c"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
other_cause_float is present;
check_ans6 is finish

if ans6 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans6 is finish

if ans8 is "b"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
Not_enough_sand_to_sink is present;
check_ans8 is finish

if ans8 is "a"
then condition is "heaviness" {cf .0};
condition is "air" {cf .5};
Enough_air_to_float is present;
check_ans8 is finish

if ans8 is "c" or ans8 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans8 is finish

if ans10 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
heavier_cause_sink is present;
check_ans10 is finish

if ans10 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .5};
Not_enough_air_to_float is present;
check_ans10 is finish

if ans10 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans10 is finish

if ans11 is "a"
then condition is "heaviness" {cf .5};
condition is "air" {cf .0};
heaviness_cause_sink is present;
check_ans11 is finish
```

DIAGNOSTIC RULES : FLOATING AND SINKING (Continued)

```
if ans11 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans11 is finish

if ans11 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans11 is finish

if ans15 is "a"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
heavier_likely_sink is present;
check_ans15 is finish

if ans15 is "b"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans15 is finish

if ans15 is "c" or ans15 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans15 is finish

if ans20 is "a"
then condition is "heaviness" {cf .0};
condition is "air" {cf .5};
air_contain_float is present;
check_ans20 is finish

if ans20 is "b" or ans20 is "x"
then condition is "heaviness" {cf .0};
condition is "air" {cf .0};
check_ans20 is finish
```

APPENDIX E9

CLASSIFICATION RULE : FLOATING AND SINKING

Object Name: decide_case1

```
         Name: decide_case1
     LongName:
         Type: Procedure
  AcceptsReal: HI,AI
  AcceptsText: condition
  AcceptsList:
  ReturnsReal:
  ReturnsText: selection
  ReturnsList:
    LocalReal:
    LocalText:
    LocalList:
    Externals:
         Body:
/*          Classification Rule :
                  if abs(HI - AI) gt 0.35 then
                  selection=member(condition,1)
                  else
                  selection="undecided"
                  endif
                  return
```

APPENDIX F1

LIST OF PUPILS RESPONSES

Coding :

StudentID : 1-2
Year : 3-4
School : 5 (School 1=1, School 2=2)
Sex : 6 (M=1, F=2)

Electricity

011221bxababbxaxxbaxbcaxbb
021222bxabababxbxcxaacaxbb
031221bxabababxaxbaxabxxcb
041221bxabaabxaxxbbxbcbxbb
051021abxbaabxbxxbaxacbxbc
061021aaxbaabxaxxbaxacaxba
071221bxabaaabxbxbaxacaxbb
081221bxababbxaxxbbxacaxbb
091221bxabaabxaxxbbxacbxbb
101221bxababaaxxbbaxbcaxbb
111221bxabaabxaxxbaxacaxbc
121221abxbaabxaxxbbxbbxxbb
131021abxbaaabxaxbaxacaxbb
141022aaxaxxaaxxbcxaacaxba
151021aaxbaaaaxxbcxcacaxbb
161021aaxbaabxaxxbbxacaxbb
171022bxaaxxabxbxcxcbcaxab
181021aaxbaaabxaxbaxacaxbc
191021abxaxxbxcxxbaxacaxab
201022aaxbaaabxaxbcxbcaxaa
211021abxbaabxaxxcxaacaxbc
221021aaxbaabxcxxbaxccaxbc
231022bxbbaaabxbxbaxacaxbc
241012aaxbaaabxaxbaxacaxcb
251011bxabaabxbxxcxaccbxbc
261011abxbababxaxaxxabxxbc
271011abxbaaabxaxbaxacaxbb
281011abxbaaabxaxbaxaaxaba
291012bxabaabxaxxbaxaaxabc
301011bxabaabxbxxbaxacaxcb

LIST OF PUPILS RESPONSES (Continued)

Floating and Sinking

011221bxxxxcabaxacaxxxxxx
021222bxxxxbaaaxbxbxxxxab
031221bxxxxbaaaxbxaxxxxbx
041221bxxxxbabaxbxbxxxxxx
051021bxxxxbaaaxbxaxxxxaa
061021bxxxxcacxxbxaxxxxbx
071221bxxxxbacxxbxaxxxxbx
081221cbxxxxabaxaaaxxxxxx
091221bxxxxcabaxbxbbbbaxx
101221bxxxxcacxxbxbxxxxxx
111221bxxxxcabaxacaxxxxxx
121221bxxxxbaaaxbxaxxxxab
131021bxxxxaabaxbxbbaaaxx
141022axaaaxbxxabxaaaacxx
151021bxxxxaaaaxacaxxxxxx
161021axbbbxbxxaacabcacxx
171022axabaxbxxaaabbbaaxx
181021bxxxxbabaxbxaxxxxxx
191021bxxxxbaaaxacaxxxxaa
201022bxxxxbbxxaaaaxxxxxx
211021bxxxxbbxxabxaxxxxxx
221021bxxxxaabaxacabaacxx
231022bxxxxbabaxaabxxxxxx
241012bxxxxbbxxaacaxxxxxx
251011bxxxxbbxxbbxaxxxxab
261011bxxxxaaaaxacaxxxxxx
271011bxxxxaaaaxbxaxxxxxx
281011bxxxxbaaaxaaaxxxxxx
291012bxxxxbabaxaaaxxxxxx
301011bxxxxbaaaxbxaxxxxab

LIST OF PUPILS RESPONSES (Continued)

Speed and Graphs

011221abcbcabxcccabbxbxbxaca
021222abcccabxabcabacbxbxaca
031221abcacbbxcccabbxbxbxaaa
041221abcacbbxcccabbxbxbxaca
051021bacacabxcccbxabbxaaada
061021bacbcaaaabcabbxbxbxaba
071221abcbcbbxcccababbxbxbda
081221abcacbbxabcabbxbxbxaca
091221abcacbaacccabbxbxbxaca
101221abcacbbxaccbxacbxbxaca
111221abcacbbxcccbxabbxbxacb
121221abcacbbxcccabbxbxbxaca
131021aacbccaaabcabbxabbxabc
141022bacbcaaaaacababbxbxabb
151021bacbcaaaabcababbxbxaba
161021abcacbbxabcabbxbxbxaba
171022baccabbxabcbxaaabacbab
181021ababcaaaabcbxabbxbxbba
191021bacbcaaaabcabaaabbxbba
201022abcacbaaabcababbxbxaaa
211021abcacbbxabcabbxbxbxaba
221021abcabaaacbcabbxbxbxaba
231022abcacbbxabcabbxbxbxaca
241012bacacaaaabcabacbxbxaca
251011abcacbbxcccabbxbxbxaca
261011abcacbaacbcabbxbxbxaba
271011abcabbaaabcababacbxabb
281011abcaabbxcbcabbxbxbxabb
291012abcacbbxabcabbxbxbxaba
301011bacacbbxabcabbxbxbxada

APPENDIX G1

QUESTIONNAIRE

Evaluation of System

The system that you are about to evaluate was developed as a post-graduate research project at Loughborough University's Department of Education. This system is an expert system program that will help to diagnose pupils' understanding in science. It will ask a series of questions related to a specific science topic and, based on the answers provided, will suggest a feedback about the users' understanding of that specific topic. It is not designed to replace the teacher but to serve only as an additional support in a teacher's daily work.

What you have to do:

1. Work through the system. There are three different topics (electricity, floating and sinking, and speed and graph) in this system. You are requested to work through all the topics.

2. Fill in this questionnaire. It is designed to find out your views about this system. Please answer ALL the questions as honestly as you can. You are free to work through the system again in order to answer the questions.

Keys:

SA	Strongly Agree
A	Agree
N	Neutral
D	Disagree
SD	Strongly Disagree

Thank you very much for your effort and co-operation.

Personal Details
1. Names :
2. Class :
3. School :

Please answer all the questions by putting a tick (/) in the box which most closely matches your personal view and also by writing in the space provided.

On-screen Information

	SA	**A**	**N**	**D**	**SD**	**Comments**
1. The separation of text, input and graphic area helps make the screen display clear						
2. The information on the screen is easy to see and read.						
3. The use of colour helps to make the display clearer.						
4. The prompts or messages clearly indicate what to do next.						
5. The messages displayed by the system are relevant						
6. The important parts of questions are properly highlighted.						
7. The graphic helps to make the questions more understandable						
8. The graphic is well illustrated on the screen.						

Other comments (good or bad) you wish to add regarding on-screen information ?

Overall, how would you rate the system in term of on-screen information ?
(Please tick the appropriate box below)

Very Satisfactory	Moderately satisfactory	Neutral	Moderately unsatisfactory	Very unsatisfactory

User-System Interaction

	SA	A	N	DA	SD	Comments
1. The system clearly informs the user when it detects an input error.						
2. The user could easily correct the input errors.						
3. The user could easily change the input (answer)						
4. The user could easily key in the answer to the question.						
5. The method of entering answers is consistent throughout the system.						
6. The movement from one part to another part is clear.						
7. The action that the user needs to take at any stage is clear						

Other comments (good or bad) you wish to add regarding user-system interaction ?

Overall, how would you rate the system in term of user-system interaction ?
(Please tick the appropriate box below)

Very Satisfactory	Moderately satisfactory	Neutral	Moderately unsatisfactory	Very unsatisfactory

System Diagnosis Feedback

	SA	A	N	D	SD	Comments
1. The results of diagnosis are clearly and concisely displayed.						
2. The format of diagnosis results is informative to user.						
3 The diagnosis results are consistent.						
4. The diagnosis results are accurate.						

Other comments (good or bad) you wish to add regarding system feedback ?

Overall, how would you rate the system in term of system feedback ?
(Please tick the appropriate box below)

Very Satisfactory	Moderately satisfactory	Neutral	Moderately unsatisfactory	Very unsatisfactory

Questions

	SA	A	N	DA	SD	Comments
1. The wording of questions suitable to the pupils level of understanding						
2. The alternative answers given is adequate						
3. The sequence of the questions is appropriate.						
4. It is possible to diagnose pupil understanding by using the questions						

Other comments (good or bad) you wish to add regarding the question used ?

Open Questions:

Please give your opinions on the usability of this system. **Note**: there are no right or wrong answers.

1. What are the best aspects of the system for the user ?

2. What are the worst aspects of the system for the user ?

3. Are any of the questions ambiguous ?
   If yes, please list (refer to the question list provided)

4. What were the most common mistakes you made when using the system ?

5. Did you find any part of the system confusing to fully understand ?
   If yes, which part ?

6. Is there anything else about the system you would like to add ?