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An Intelligent Computer-based Tutor for  
Elementary Mechanics Problems

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by

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## Abstract

ALBERT, an intelligent problem-solving monitor and coach, has been developed to assist students solving problems in one-dimensional kinematics. Students may type in kinematics problems directly from their textbooks. ALBERT understands the problems, knows how to solve them, and can teach students how to solve them. The program is implemented in the TUTOR language and runs on the Control Data mainframe PLATO system.

A natural language interface was designed to understand kinematics problems stated in textbook English. The interface is based on a pattern recognition system which is intended to parallel a cognitive model of language processing. The natural language system has understood over 60 problems taken directly from elementary Physics textbooks.

Two problem-solving routines are included in ALBERT. One is goal-directed and solves the problems using the standard kinematic equations. The other uses the definition of acceleration and the relationship between displacement and average velocity to solve the problems. It employs a forward-directed problem-solving strategy. The natural language interface and both the problem-solvers are fast and completely adequate for the task.

The tutorial dialogue system uses a modified version of the natural language interface which operates in a two-tier fashion. First an attempt is made to understand the input with the pattern recognition system, and if that fails, a keyword matching system is invoked. The result has been a fairly robust language interface.

The tutorial is driven by a tutorial management system (embodying a tutorial model) and a context model. The context model consists of a student model, a tutorial status model and a dynamic dialogue model. ALBERT permits a mixed initiative dialogue in the discussion of a problem.

The system has been tested by Physics students in more than 80 problem-solving sessions and the results have been good. The response of the students has been very favourable.

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## Chapter 1

### Introduction

#### 1.1. Twenty-five years of CAI

Computer-assisted instruction (CAI) made its first appearance in the late 1950s, when mainframe computers made their way into Universities in the United States of America. By 1963, several big projects were under way, most notably one at the University of Illinois which led to the development of the PLATO system (Alpert & Bitzer, 1970) and one concerned with the development of drill and practice arithmetic systems at Stanford under the direction of Patric Suppes (Suppes, Jerman and Brian, 1968).

CAI learning centres were also established at Florida State University, the University of Texas and the University of Michigan, during the 1960s. Bunderson's work at the University of Texas later led to the development of the TICCIT system at Brigham Young University in cooperation with the Mitre Corporation. At the University of California, Irvine, Bork established a development centre for computer-based learning materials, which has now been operating for over 16 years (Bork, 1985).

Hawkins (1977) reviews the early development of CAI in the United States.

By 1970, interest in CAI had spread to the United Kingdom where several projects began at about this time. This work resulted in funding for the National Development Program in Computer Assisted Learning (NDPCAL) in 1973. The British viewed the American use of CAI as mostly "tutorial" in nature (Harding, 1980). The National Council for Educational Technology stated in 1969 that it could see "no real difference in kind between programmed learning and computer-based learning" (Hawkins, 1977). For this reason, the NDPCAL project set out to augment the traditional instructional process, rather than to replace it.

One arm of the NDPCAL project became known as CUSC (Computers in the Undergraduate Science Curriculum). In the CUSC project, the emphasis was on the development of interactive simulations of physical systems for

Chemistry, Physics and Biology (Laurillard, 1977).

In the 1960s and the early 1970s, computing equipment was relatively expensive, particularly terminals with adequate graphics capability. For example, the IBM 2250, a directed beam CRT, cost over 50 000 pounds sterling (Skyrme, 1981). In any case, interactive computing was not as widespread as it is today, with much of the processing then being done by means of batch job submission. Although Bork's students and others using systems such as PLATO had graphics screens, this was by no means the order of the day. Many students had to use slow and noisy teletypewriter machines or uppercase only scrolling terminals.

It is significant that CAI survived these hardships and inadequacies and a breakthrough came in the mid-70s, when low cost microcomputers became available. Many educators were ready and waiting to explore the new medium of instruction. From 1978 onwards, there has been an explosion of interest in the use of CAI, and microcomputers now proliferate our schools and universities.

This has had several positive effects. For example, many researchers with a good understanding of instructional design have become involved and have made a valuable contribution to the knowledge of how to design good educational software. Also, several excellent books have been published on how to design good CAI materials. (See for example Alessi & Trollip, 1985.) As a result, there has been a marked improvement in the quality of the courseware produced in the last five years.

Clearing houses have been set up for the review and distribution of educational software. One of the most significant of these, in the United States, is the Minnesota Educational Computing Consortium (MECC) which offers advice to schools with an interest in the use of microcomputer software. MECC has undertaken to evaluate, develop and distribute courseware for the Apple II and other microcomputers.

CONDUIT started out in 1971 as a consortium of universities developing software for colleges and universities. They have been publishing courseware for over 10 years and currently offer over 200 software packages for mini- and microcomputers (Leaven, 1985). They have also

published an author's guide (Peters and Johnson, 1978) and a BASIC programming guide (Frederick, 1979) which are aimed at assisting those producing their own courseware.

A noteworthy development in the last five years has been the growth in the number of authoring languages and authoring systems. Although authoring languages such as TUTOR for the PLATO system and the IBM Coursewriter have been available on mainframe systems for many years, lesson authors using microcomputers have had to work with conventional programming languages. Several authoring languages are now available for microcomputers. The oldest of these is PILOT which is rather limited in its capabilities.

More recently, languages such as TenCore for the IBM pc and enhancements such as EnBASIC for the Apple II have been valuable aids to persons working on those computers. CONDUIT will release a package of tools shortly which is designed to assist programmers using BASIC. It will include enhancements to the language and tools for answer judging and graphics creation (Leaven, 1985).

High level authoring systems, which can be used by persons with no knowledge of computer programming, and authoring languages, which are intended to make the programmer's task easier, can lead to a reduction in development time, although this has been the subject of some debate (Avner, Smith and Tenczar, 1985). Many would be authors are being encouraged by the ease of use of authoring systems such as PLM, Omnisym, and PCD on PLATO, WISE on the WYCATT system and the many others which are making their appearance in the market place<sup>1</sup>.

There are many vendors of microcomputer courseware now and some publishers of books are beginning to include microcomputer software in their repertoires.

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1. Some of these products and issues are reviewed in the Journal of Computer-based Instruction 11(3), a special issue on authoring tools.

## 1.2. Origins of CAI in Physics

In the 1960s, a few Physics teachers began investigating the use of computers in teaching. In many cases, the computer was used as a computational aid, as Bork (1969) did with his "Least Action" program.

This program ran on a PDP-1 computer and was designed to illustrate Hamilton's principle of least action. Students entered a displacement versus time curve via a graphics tablet and stylus. The curve was displayed on an oscilloscope screen along with the Lagrangian action for the curve as calculated by the computer. The curve of least action was always kept on the CRT screen, with the value of the action. The idea of programs such as this was to relieve students of the computational burden, thereby allowing them to concentrate on the physical principles.

Several other workers began investigating the "conversational" use of the computer. This grew out of the ideas of programmed learning and was very similar to present day CAI. Kromhout, Edwards & Schwarz (1969a) describe an introductory Physics course at Florida State University, in which an IBM 1500 was used. CAI was used to replace a lecture course which lasted one quarter. The lessons were prepared from the lecturer's notes and included diagnostic quizzes for each unit of instruction. Audio tapes and films were obtained to go along with the CAI materials.

There were no lectures in this course and the computer was used to manage the instructional process, providing on-line testing and keeping track of student progress. Kromhout et al. (op. cit.) reported a very favourable response from the students.

Kromhout, Edwards & Schwarz (1969b) reviewed the early Physics CAI. They noted that many of the computational programs were written in FORTRAN, while many of the conversational ones made use of the IBM Coursewriter authoring language, as did the Florida State Physics course. It is also apparent from the findings of Kromhout et al. that many students were confined to teletypewriter terminals.

The 1970s were characterized by significant reductions in hardware prices.

CRT terminals became affordable. Many useful programs were developed to run on a wide range of machines. A lot of these were computational simulations which made good use of graphics. John Merrill (1976) published a collection of programs written in BASIC.

Many Physics programs were published during this period by CONDUIT, and the CUSC project resulted in the development of a good collection. The Physics teachers who had access to PLATO developed a suite of PLATO Physics programs (Smith & Sherwood, 1976), many of which are still in use.

When the microcomputer revolution began in the mid-70s, Physics teachers immediately began exploiting the new low-cost medium. CONDUIT began converting some of their courseware to run on the new machines and other publishing houses began making software available for them.

Today there are many good Physics programs available which run on a wide range of computers.

### 1.3. The Physics Lessons

McKenzie, Elton and Lewis (1978, chapter 6), in discussing the CUSC project, devote an entire chapter to the merits of computers for teaching Physics. They list six features of CAL which they feel are most important for teaching Physics, viz.

- the ability to evaluate complicated expressions quickly,
  - using numerical methods to solve equations,
  - saving time in repetitive calculations,
  - analysing experimental data,
  - visualizing multi-dimensional relationships by means of graphical displays,
- and - simulation of experiments.

Since the first five may be regarded as computational uses of the computer and the sixth is simulation, only two of the modes of CAI are represented. The others, such as tutorial, drill and problem-solving, are ignored.

The computational mode is useful for the student because it takes the tedium out of calculations, while still requiring him to identify

correctly the numerical parameters which should be used. The results are produced rapidly and the student may ponder the physical principles involved at his/her leisure.

A simulation is designed to give the student first-hand experience of a physical process. This may be of an experiment which is too difficult, expensive or long for students to perform, or it may be used for comparison with an experiment performed in real-life. Laurillard and Murphy (1975) reported that some students greatly appreciated the fact that the computer-simulated experiments worked, whereas their own attempts at them had not.

The importance of a simulation lies in the fact that it gives a student the opportunity to experiment with and explore physical processes which might otherwise not be accessible. This can lead to a better appreciation for and a deeper intuitive understanding of the theoretical models presented in class.

Bork (1981) takes a broader view. He notes that different students learn in different ways and suggests that it is important to use all the modes of CAI, because what is effective for one topic may not be the best means of presentation for another. Bork has made extensive use of the computational mode with his students and stresses the usefulness of the tutorial mode. At its best, this can be made into a very effective dialogue. Bork has attempted to write tutorials which lead students through a problem or the discussion of a new concept by means of a Socratic dialogue.

Smith and Sherwood (1976) mention the use of a quiz within a computer lesson as means of self-assessment for the student. The instant feedback and self-diagnosis which this provides for the student is very valuable. Bork (1981) observes that interactive testing has produced the most favourable reaction with students in his experience. He suggests that this may be due to the meaningful way in which the testing can be blended in with the process of learning.

Tables 1-1 and 1-2 at the end of this chapter contain the results of a brief survey of the Physics CAI materials available on two machines. The

Apple courseware is fairly representative of what is available for that machine and the PLATO courseware reviewed is all available in the PLATO published courseware library.

Firstly, it should be noted that availability of lessons for a particular topic is by no means a guarantee of accuracy, suitability or quality. For example, most of the tutorial mode lessons on the Apple are extremely poor. Most of them are no more than electronic page turners with the occasional animated graphics. On the other hand, many of the simulations, particularly those from Intermediate Physics (Good, 1984) which allow a great deal of student control over well designed machine code animations, are well worth using.

Of the PLATO lessons, those from the University of Illinois, mostly designed by Bennett, Kane and Sherwood are probably the best. Many of these lessons make good use of graphics and the features of the PLATO system to provide highly interactive tutorials, which encourage the student to think his/her way through the topics covered (Kane and Sherwood, 1980). The newest Physics lessons are the ones from Control Data (U.S.A) which form part of the Lower Division Engineering Curriculum (LDEC). These lessons make exceptionally good use of graphics and animations but should be carefully checked before use as some of them contain misconceptions about elementary mechanics.

It is interesting to note that the emphasis has been on teaching the concepts of displacement, velocity, acceleration and Newton's laws of motion. Over 39% of the lessons reviewed deal with this general topic. This is an area which is both fundamental to the understanding of Physics and one with which students have difficulty.

It is disturbing to find that Physics CAI lessons today, although more generally available, are essentially no different from those used in the early 1970s. For example, the LDEC lessons published by Control Data in 1983 are similar in their approach to the lessons of Kane and Sherwood, many of which were produced in the early 1970's. In fact, although the use of graphics and animations in the LDEC lessons is superior, the inaccuracies they contain make them less useful than their older counterparts in some cases.

An examination of CAI programs described in the literature over the last 15 years reveals a similar emphasis to that noted in the present review, but the majority of these programs are in the form of computational simulations. Again, in the literature, one observes that programs being described today are not fundamentally different from those described ten years earlier. For example, Borghi et al. (1984) describe a program which deals with collisions in very much the same way as Kane (1976) and Cross (1982). The same is true of the many programs written to teach quantum mechanics.

The present work is an attempt to address the limitations of traditional CAI with particular reference to programs which teach problem-solving in Physics. In Chapter 2, the limitations of traditional CAI are discussed, together with an overview of the use of Artificial Intelligence techniques to improve the teaching capabilities of computers. The specifications for an intelligent computer-based Physics tutor, ALBERT, are presented towards the end of the chapter.

ALBERT is a natural language problem-solving monitor and coach capable of understanding elementary mechanics problems stated in textbook English, and can teach students how to solve them. In Chapter 3 the design of a natural language interface suitable for understanding textbook Physics problems is presented. Chapter 4 deals with the question of automatic problem-solving, and in Chapter 5 a methodology for teaching students how to solve elementary mechanics problems is discussed.

In Chapter 6, the design and implementation of the tutoring component of ALBERT, including the natural language tutorial dialogue system, is explained. Finally, in Chapter 7, the results of student use of ALBERT are presented along with their reactions to the system.

This work has been exploratory. Its aim has been to bridge the gap between the highly experimental tutoring systems of the AI researchers and the traditional computer lessons of the CAI community.

Apple Physics lessons

i) by mode of CAI

Source:	Mode:*	T	S	Q	D	P	Total
a. CONDUIT			3				3
b. Strassman			3				3
c. Vernier			7				7
d. Intermediate		1	12				13
e. Cross		62	8			4	74
f. Wits		35	6	6		3	50
g. Rhodes		3	14			1	18
Total							168

ii) by topic

Topic:	Source:	a	b	c	d	e	f	g	Total
Measurement/Graphs/Vectors				1	1	8	8	1	19
Motion/Dynamics/Newton			1	4		25	32	3	65
Force/Statics						3			3
Gravitation		1			1			1	3
Vibrations and Waves			2	1	4			5	12
Optics		1				4	2	1	8
Electromagnetism				1	1	3	3	1	9
Electronic Circuits						5	4		9
Heat and Thermodynamics					1	6	1		8
Gases					1				1
Quantum Mechanics					2			4	6
Special Relativity					2			1	3
Atomic and Nuclear		1				6		1	8
Astronomy						14			14
Total									168

Table 1-1: Survey of Apple Physics Lessons.

\* T-Tutorial; S-Simulation/computational; Q-Quiz; D-Drill; P-Problem-Solving.

PLATO Physics lessons

i) by mode of CAI

Source:		T	S	Q	D	P	Total
	Mode:*						
Univ. of Illinois		43	13		5	32	93
CDC (U.S.A.)		46	4			16	66
CDC (S.A.)		2	1			23	26
Total							185

ii) by topic

Topic:	Source:	U of I	CDC(USA)	CDC(SA)	Total
Measurement/Graphs/Vectors		7	7	2	16
Motion/Dynamics/Newton		35	26	13	74
Force/Statics		4	4		8
Gravitation		1		1	2
Vibrations and Waves		8			8
Optics		4	2		6
Electromagnetism			12	3	15
Electronic Circuits		1	5	5	11
Heat and Thermodynamics		18			18
Gases		2	4		6
Quantum Mechanics		6			6
Special Relativity					
Atomic and Nuclear		7	6	2	15
Astronomy					
Total					185

Table 1-2: Survey of PLATO Physics Lessons.

\* T-Tutorial; S-Simulation/comput.; Q-Quiz ; D-Drill; P-Problem-Solving.

## Chapter 2

### Intelligent CAI

#### 2.1. Learning theory and the modes of CAI

It is widely recognized that the computer, with all its power for data manipulation and speed of computation, should be able to teach a wide range of topics and, in some cases, even replace existing methods of instruction. But have computers in education achieved what was expected of them? Can computers really teach? To answer these questions, one needs to examine the various modes of CAI and their theoretical foundations. Then one must examine the programs themselves to determine the extent to which they meet the intended goals.

##### 2.1.1. Tutorial programs

Most of the guide-lines available to designers of CAI lessons appear to be based on an intuitive or empirical assessment of what is required for learning to take place. Too few authors are aware of the theoretical basis which underlies the techniques they employ.

Skinner (1968) suggests that behaviour modification can be brought about by appropriate positive reinforcement of the student's correct responses. His advice about how to develop a programmed learning sequence is similar to guide-lines given to the designers of CAI tutorial programs. Skinner advocates the use of learning objectives and the presentation of information in a series of frames which might be graded according to the level of difficulty. The need to involve the learner actively in the learning process, while allowing him to proceed at his own pace, is stressed, and Skinner maintains that students can learn more when the instructor points them in the direction of an answer, rather than supplying it explicitly.

Skinner's programs were linear and many CAI tutorials follow a similar pattern. However, the learning model used in the design of the CAI programs may differ substantially from the ideas of Skinner.

Branching programs proposed by Crowder (1960) extended the ideas of Skinner by diminishing the emphasis placed on obtaining the correct response from a student, and allowing the path to the next frame to be determined by the student's actions in the current one. The frames could be larger and the student received more detailed feedback on his responses. He could be required to repeat a frame if necessary. This leads to greater individualization of the teaching process and the feedback can be used to correct misunderstandings or even to initiate extensive remedial sequences of frames.

Author languages such as TUTOR, PILOT, TenCore, EnBASIC and others encourage authors to develop computer lessons which are structured as linear or branched learning sequences. However, languages such as these allow a level of sophistication not possible in programmed learning texts or machines of the kind used by Crowder. Student responses can be long strings of text, allowance can be made for misspellings and the route through a lesson can vary greatly because provision can be made for jumping to any specified frame depending on the student's performance in the current one.

Figure 2-1 shows a PLATO program constructed in this way. PLATO can allow extra words and misspellings in the student's answer. PLATO can also judge the numerical part of the response separately from the rest, allowing independent feedback about the number and the units. (The program extract shown is actually not the best way to judge answers to the question stated because it does not make use of this facility.)

The TUTOR "unit" may be thought of as corresponding to a frame of information. PLATO adds greater student control by allowing for student initiated branching (Sherwood, 1977). For example, the student may press the HELP key if he needs more information before answering a question. Upon completion of the help sequence, the student is normally returned to the frame from which help was requested.

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* An extract from a PLATO branching program *****
unit  question  $$ asks a question branches on response.
help  hint1     $$ activates the help key for branching to a help frame.
at    1010      $$ screen location for PLATO output.
write A ball is thrown straight up into the air.  What is the
      acceleration at the top of its flight?
arrow 1210      $$ give student a prompt and waits for response.
specs okextra,okspell  $$ can ignore extra words and misspellings.
answer 10 m/s2 downwards $$ this is not the best way to do this.
answer 10 m/s2 upwards  $$ PLATO provides a system of judging units
answer 0
no          $$ reject anything else.
write Sorry you have the wrong magnitude or units or you neglected to
      specify a direction.
endarrow
jump  anscht,x,x,upwrong,allok,zero,x  $$ new frame depends on answer.
* this kind of jumping from one frame to another allows highly complex
* branching but it can result in "spaghetti" programs and is thus not
* recommended.
*****

```

Figure 2-1: Extract from a PLATO lesson illustrates branching

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Gagne, Wager and Rojas (1981) have stressed the fact the desired outcomes of learning should be clearly specified in advance and taken into account when designing a CAI lesson. Gagne (1977) describes five outcomes of learning. They are

- verbal information,
- intellectual skills which include discrimination, concrete concept, defined concept, rule and problem-solving,
- cognitive strategies,
- motor skills and
- attitudes.

Gagne also relates the internal processes of learning to the external

events of instruction which support them as shown in Table 2-1. Gagne maintains that when one of the events of instruction is omitted this should be done so deliberately, because it is deemed to be unnecessary.

Internal Learning Process	External Event of Instruction
1. Alertness	1. Gaining attention
2. Expectancy	2. Informing learner of lesson objective
3. Retrieval to working memory	3. Stimulating recall of prior learning
4. Selective perception	4. Presenting stimuli with distinctive features
5. Semantic encoding	5. Guiding learning
6. Retrieval and responding	6. Eliciting performance
7. Reinforcement	7. Providing informative feedback
8. Cueing retrieval	8. Assessing performance
9. Generalizing	9. Enhancing retention and learning transfer

**Table 2-1: Internal Processes of Learning and the External Instructional Events which may be used to support them. (From Gagne et al., 1981.)**

Gagne et al. (1981) suggest that a tutorial program could contain all nine of the events of instruction. They accept that tutorials are of two kinds, viz. branched or linear, but note that in many cases only three of the events of instruction are employed. These would be presenting information, eliciting a response and providing feedback. Such programs can easily be extended to incorporate the more complete set of events to stimulate learning and effect the desired outcomes. Chambers and Sprecher (1983) point out that Gagne's approach is significant in that it places an emphasis on the motivational aspects of learning.

Many tutorial programs currently available, whether linear or branched, surpass the theories of Skinner and Crowder in that the authors have paid

particular attention to gaining the learner's attention and stating the learning objectives clearly.

Bork(1981) has further exploited the use of tutorials by developing the concept of the interactive dialogue. He attempts to create Socratic dialogues in which the student is lead through the material by a series of carefully designed questions. This approach is significantly different from the one in which the computer is used to present screens of information. In the Socratic tutor, the path through the dialogue is determined by the student's responses to the questions. However, these programs have been devised by attempting to predict every possible response which a student might make at each point, and they remain branching programs.

#### **2.1.2. Drill and practice programs**

Skinner's theory can also be applied to the drill and practice situation. Two important considerations suggested by Skinner are the emphasis on positive reinforcement and the need for a shift from continuous reinforcement to an appropriately reduced schedule of reinforcement.

Another important theory which may be considered when designing a drill is the Information Processing Model of Cognitive Psychology. This model is concerned with how knowledge is acquired and used. Accordingly, it has been suggested (Lindsay and Norman, 1972) that external stimuli have an effect on an organism's receptors which results in the storage of information in short-term memory. This information is either retained in short-term memory by rehearsal, or transferred to long-term memory by a process of "semantic encoding" (Hilgard and Bower, 1966) after a few seconds, or lost.

There has been a good deal of research on how to design effective drill programs. Alessi and Trollip (1985) review various schemes for item selection and retirement. Ways have also been devised of making the programs adapt to the needs of the learner (Merrill and Salisbury, 1984). However, many teachers question the usefulness of this mode as a means of learning. The emphasis is on rote learning rather than understanding and, while the level of difficulty may be adjusted by the program, there is

usually little scope for individualization.

Gagne et al. (1981) point out that drills contain only two of the events of instruction, viz., they elicit a response and provide feedback. However, they feel that drills are useful in that they can make lower level skills automatic by reinforcing the indexing to their characteristics for rapid recall to short-term memory. Drills are not advocated for learning new skills.

Drills can be written very efficiently with standard programming techniques as it is easy to make them generative in the sense that they can compose new examples by random number generation, or select from a large database of questions by imposition of a concise set of selection criteria. Bork (1981) recommends this as a means of providing problems for students and even suggests expanding the system to generate problems with defective or redundant information.

### **2.1.3. Simulation programs**

Simulations can allow a student a measure of flexibility in the learning process which is not possible with tutorial or drill and practice programs implemented as described above. Simulations, referred to as "experiential programs" by Thomas and Boysen (1984) and "controllable worlds" by Bork (1981), are designed to model a physical process or a set of circumstances which the student can manipulate in order to gain a better intuitive understanding of some concept.

Simulations offer students a high degree of control over the learning situation and often their power can lie in the simplification which they bring to bear on the example being studied. Simulations frequently take the form of an educational game and as such can be highly motivating for the students.

In accordance with the theory of Gagne, many simulations include a statement of objectives at the start and provide a stimulus in the form of a description of the initial conditions. They elicit a response from the learner and feedback may take the form of another stimulus which becomes a new set of initial conditions.

Chambers and Sprecher (1983) note that simulations may be used to close the gap between abstract learning and the application of what is learned. They apply Bandura's social theory of learning to simulations. This suggests that human behaviour is learned by observation and modelling. Chambers and Sprecher conclude that it is important for each student to repeat a simulation several times to reinforce the desired behaviour.

Pask (1976) identifies two learning styles, "operational learning" and "comprehension learning". Operational learning is procedural and involves derivations, manipulation of equations and data analysis. Comprehension learning is descriptive and involves interpreting a theory, making simplifications and drawing analogies between systems or parts of a system. In a computer simulation, the student is engaging in comprehension learning while the computer handles the operational aspect.

It is common to include the computational or emancipatory mode of CAI with simulations, as in most cases the type of modelling required is computationally intensive and the output may be a graphical representation of the behaviour of a physical system. Frequently a simulation will include an animation of the process being modelled, e.g. a simulation of Brownian motion may include animated atoms and molecules. Alessi and Trollip (1985) distinguish between process simulations which are often purely computational in nature, and physical, procedural or situational simulations.

Simulations are very important in teaching Physics where it is often difficult to demonstrate concepts for which a theoretical treatment has been presented. It is intended that the student manipulating a computer simulation of a phenomenon such as a nuclear reaction may be able to gain substantial insight into its operation without being exposed to its hazards. The CUSC project was based almost exclusively on the use of interactive graphics simulations to enrich the teaching process (Laurillard, 1977).

Bork (1981) points out that it is often difficult to integrate a simulation with the course content, and that unless this is done only the most highly motivated students will use it.

#### **2.1.4. Problem-solving programs**

For many students, particularly in Physics, the ability to solve problems is a skill which is highly desired. Students will often try to solve many problems of a particular kind in order to improve their proficiency. Often this leads to frustration and, in view of the staff-to-student ratio at most institutions, it is difficult for them to obtain personal assistance from a lecturer. Accordingly, there has been an attempt to write CAI lessons to teach problem-solving. (I do not wish to include here the use of the computer to teach general problem-solving skills through the use of languages such as LOGO.)

CAI problem-solving exercises range from those in which a problem statement is presented to the student who is then expected to work out a solution and type in only the final answer (e.g. Control Data SA, 1982) to tutorials in which the student is led through the solution step by step by means of a suitable dialogue (e.g. Control Data, 1983).

Bork (1981) refers to these as problem simulations and sees them as on-line tests. His programs can select the problem shell, decide which variables to make known and which to leave as unknowns, and then derive values for the variables of interest. (Generative CAI programs, of which these are examples, are discussed by O'Shea and Self (1983).) The particular problem which the student is required to solve has been pre-defined, up to a point, by the programmer and is partly determined by chance. Bork's dialogues appear to follow relatively inflexible paths designed in advance by the authors and programmers.

Bork also expresses the belief that the interactive and individualized nature of computer dialogues makes CAI highly suitable as an aid to the development of formal reasoning.

#### **2.2. Limitations of the existing modes of CAI**

In spite of the attempt to create an interactive, individualized learning environment, it is recognised that existing CAI programs fall far short of the capabilities of human tutors.

### 2.2.1. Limitations of simulations

Simulations appear to be the most useful of the traditional modes of CAI. Students value the control and the level of decision-making vested in them. The flexibility and the freedom to explore in a natural way builds insight and a sense of satisfaction which can engender a sense of confidence with the models being investigated.

However, simulations appear to be limited in the following ways.

- if a student observes a phenomenon which he does not understand, he cannot ask a question about it there and then. His confusion may persist until he can make an appointment to see the lecturer. However, there is evidence to suggest that few students bother to do this. (On the PLATO system, this is partly catered for by the electronic mail system, which students frequently use for the purpose of asking questions.)
- if a student using a simulation consistently applies a strategy which is incorrect or inefficient, the computer is seldom able to apply corrective coaching.
- time-sharing computers are not suited to the presentation of animations because of variable response times. Microcomputers are still limited by their computational speed. The power of available computing hardware thus still restricts the complexity of the models which can be employed.

### 2.2.2. Limitations of drills

If one chooses to use a drill and practice program at all, one should be aware that

- the algorithms for item selection and retirement are often rudimentary. (This is the subject of on-going research.)
- most of these programs do not maintain a detailed dynamic model of the student with whom they are working, as teachers do.
- the programs do not have the sensitivity to the needs of the individual which the teacher has and thus cannot adjust the level of difficulty and presentation strategy accordingly.
- coaching is not usually a feature of these programs.

- meta-strategies for homing in on and diagnosing the areas of difficulty and misconception are not provided.

### 2.2.3. Limitations of tutorials

The limitations of tutorial programs appear to be as follows:

- the emphasis tends to be on imparting knowledge rather than encouraging learning.
- branching is normally only determined by the user's most recent response.
- even in branched programs (which are rare), the path through the lesson is pre-conceived and relatively inflexible. The criteria for branching must be explicitly stated in advance.
- the text within a frame is fixed in such a way that the program cannot adjust the level of difficulty.
- even Bork's so-called Socratic dialogues are relatively inflexible, with the computer maintaining a tight control over the sequence of learning.
- the teaching strategy is usually fixed.
- responses made by the student must be anticipated by the author. This results in frustration when the students make valid responses which have not been anticipated.
- there is little scope for initiative on the part of the learner.
- very little account is taken of the user's prior knowledge or misconceptions. A student model is generally not used.
- tutorial programs tend to be very large and complex in their structure.

### 2.2.4. Limitations of problem-solving programs.

While students find programs of this kind generally acceptable, the following limitations and frustrations have been expressed.

- the problem statements are fixed. Often the student has a particular problem which he wishes to solve. The one selected by the computer may appear less relevant.
- there are often several ways of arriving at a solution. The method to which the program constrains the learner may not be the one he would have chosen. This can be frustrating and confusing when the

computer doesn't accept a valid approach, particularly for beginning students.

- a teacher wishing to assign a program of this kind for his students may not be able to enter the problems he wishes to set and he may teach a different approach to solving problems of this kind.
- in the computer dialogues, the computer retains tight control of the initiative. The student is not free to ask questions or make statements about his own state of knowledge. He cannot change the path of the discussion.

#### 2.2.5. General observations

Carbonell (1970) summarized the limitations of "classical" CAI as follows:

"The student has little or no initiative; he cannot use natural language in his responses, and systems usually look fairly rigid to him. The teacher has a considerable burden in the preparation of questions, answers, keywords and branching. From a systems point of view, the system controls the student, but it is in turn tightly ad hoc programmed by the teacher; the system has no real initiative or decision power of its own; and, of course, it has no real 'knowledge'."

O'Shea and Self (1983) list, among others, the following attributes of tutorial dialogues which are generally missing in CAI:

- " - the language used by both participants is a natural one.
- both participants can ask questions at any time.
- the topic of conversation can be changed on either participant's initiative."

It has also been observed that in a live dialogue, the spoken words form only a small part of the process of communication between the student and the tutor. The expert forms a detailed model of what the student knows and remains sensitive to his level of understanding, confusions and misconceptions. Woolf and McDonald (1984) call this the "tip of the iceberg" problem. Typical CAI programs have no way of handling this effectively.

Sherman (1977) states that "teaching individually is a significant step

forward only when the contingencies responsible for learning are adjusted in a way that is sensitive and responsive to each person".

In spite of these dissatisfactions expressed over a long period of time, the main stream of CAI in use today does not differ significantly from what was being used in the mid-70's.

### 2.3. Intelligent tutoring (ICAI)

In an attempt to address these problems, workers in the field of artificial intelligence (AI) have made use of their specialized techniques to develop so-called intelligent tutoring systems. Clancey (1981a) sums up the intelligent tutoring system as being "a computer program that uses artificial intelligence techniques for representing knowledge and carrying on an interaction with a student".

In traditional CAI, the emphasis has been on how to present information using the medium of the computer screen. However, if the computer is to become an effective teacher, an attempt must be made to build into the program a representation of the teaching process. Sleeman and Brown (1982) suggest that this can be achieved if the system has its own problem-solving expertise, its own diagnostic or student modelling capabilities, and its own explanatory capabilities. It should also have explicit control or tutorial strategies.

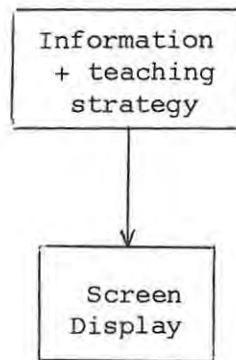
Self (1974) points out that this involves the representation of three distinct areas of knowledge within the CAI program, viz.

- a. knowledge of what is being taught;
- b. knowledge of how to teach (which includes knowledge of students in general);
- c. knowledge of who is being taught (one student in particular).

Figure 2-2 illustrates the difference between traditional CAI and intelligent CAI.

In the ICAI system, the tutorial management system (TMS) is responsible for overall program flow. It has access to an expert system which is a representation of the knowledge of the subject matter being taught. This

a) Traditional CAI:



b) "Intelligent" CAI:

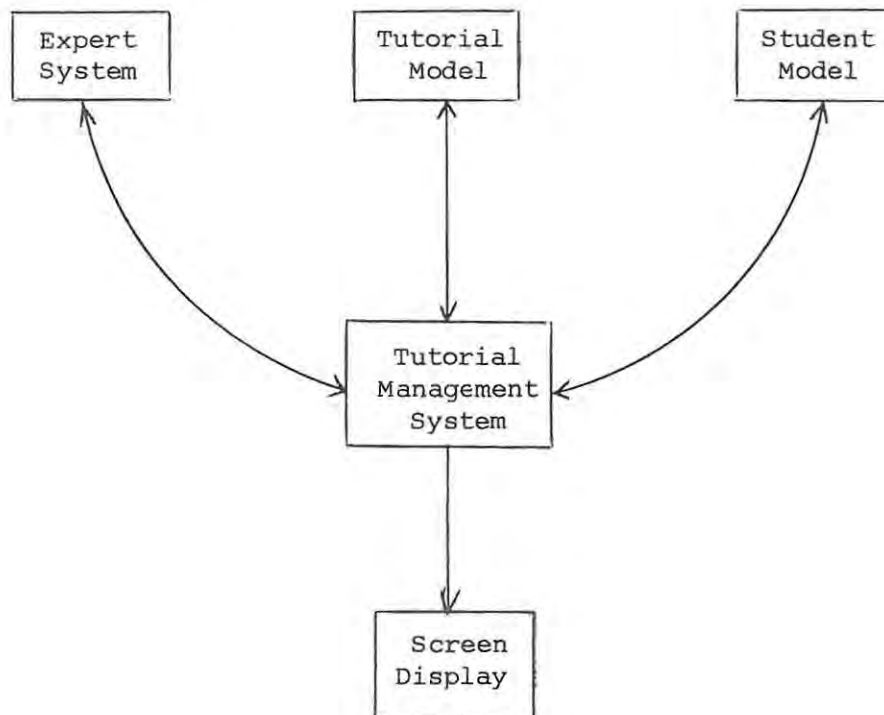


Figure 2-2: Elements of "traditional" and "intelligent" CAI systems.

may include declarative knowledge, such as the fundamental laws of Physics and relationships between quantities, and it may include procedural knowledge, such as problem-solving strategies. It can also include dynamic knowledge such as that particular to a problem under discussion.

The second major element to which the TMS has access is the tutorial model. This must include knowledge of which pedagogic strategies to use and under what circumstances. It must allow the student to take the initiative but it must also know when, why and how often to interrupt the student. The tutorial component should be able, through the TMS, to interrogate the expert system and update the student model. The tutorial model should also include dynamic knowledge of what has been discussed, what tutorial strategies have been used and under what circumstances these were most effective.

The third component in the the ICAI system is the student model. The student model is a representation of the knowledge which tutor has about the student. This could include knowledge about which concepts and/or skills the student has mastered, the student's misconceptions, his ability to solve problems of a particular kind, the student's preferences with respect to learning style, the student's progress thus far in the discussion, and specific items of declarative knowledge which the student has shown that he has. These may include knowledge of relationships between physical quantities, knowledge of equations or knowledge of the values of quantities specified in a problem statement.

The TMS itself is responsible for driving the tutorial. It is the vehicle through which communication takes place and as such must include utilities for handling the presentation of information on the screen. This may include text and graphics generation for the output of information and should ideally include a natural language processing system for accepting input from the student. The TMS also serves as an internal interface between the expert model, the tutorial model and the student model.

The Cybernetic Law of Requisite Variety (Battino,1986a) states that in any complex system, the element with the greatest variety has control. This may be applied to the tutorial dialogue where we conclude that the participant with the greater flexibility will have control. If the

computer can be made more flexible than the learner in a particular learning situation, it can retain control, even when the student takes the initiative.

Furthermore, a system such as this is not constrained to any particular theory of learning. The theoretical foundations form a part of the knowledge-base in the tutorial model. In principle, almost any pedagogic strategy or strategies can be incorporated into an ICAI program.

#### 2.4. Examples of ICAI systems

Over the last sixteen years, various ICAI systems have been developed. These programs have been predominantly experimental, rather than large-scale. Few of them have been used to any great extent with students. Each of them has concentrated on one or other particular problem, for example, the student model, rather than trying to produce a complete system.

##### 2.4.1. Expert systems

Every teacher should be an expert in his own domain in order to teach successfully. The same must be true of a CAI program which attempts to simulate the human tutor. An expert system requires a base of domain knowledge and a system of interrogating that knowledge-base to retrieve specific items of information. In addition, the expert requires a system for making logical inferences. For example, the knowledge-base may contain the following specific items:

- a resultant force acting on an object will bring about a change in its momentum;
- momentum equals mass times velocity;
- the mass of an object is constant at non-relativistic speeds.

From this the expert system can infer a new item of knowledge, viz, a resultant force acting on an object will bring about a change in its velocity.

This is important in providing explanations and in deriving solutions to problems. An important question in the field of AI is that of how best to represent the knowledge and how to devise an efficient means of

interrogating the knowledge-base.

Carbonell (1970) produced an intelligent tutoring program called SCHOLAR which could discuss the geography of South America. SCHOLAR's knowledge of the geography of South America was stored in a network in which the meaning of a node was represented by its relationship to other nodes. Such a network is known as a semantic network. SCHOLAR could respond sensibly to requests such as "Tell me about..." and "Tell me more about...".

Inference rules can be stored as a part of the network, thus making it possible for a system such as SCHOLAR to answer questions for which answers have not been pre-stored.

The procedural network is another device used for storing knowledge. As the name suggests, this is designed to hold procedural knowledge such as problem-solving expertise. Burton (1982), in the program BUGGY, used a procedural network to represent the way in which elementary students solve addition and subtraction problems. The network held information not only about the correct procedures, but also about "buggy" procedures.

Burton investigated the use of this program for the automatic diagnosis of procedural "bugs" among arithmetic students, and in particular studied algorithms for correct identification of the bugs and the relationship of the bugs to the requisite skills.

Networks have been used in various ways. For example, Koffman (1972) used a concept tree to represent the domain knowledge for digital circuit theory. In the concept tree, knowledge of the degree of complexity of each concept was stored along with its relationship to other concepts in the tree. From the student's record the system could determine how quickly a student should move through the tree of concepts, which concept to teach next, the degree of difficulty of the problems which it generated, and the depth of monitoring and explanation.

The use of production systems for knowledge representation in expert systems has gained much popularity in the last few years (Swigger, 1985). In a production system, knowledge about the domain and the teaching

strategy can be stored as a set of IF...THEN rules. An "interpreter" is used to apply the set of dynamic attributes which make up the "context" to the IF portion of the rules. When a match is found, the THEN portion of the rule "fires" and is used to update the context by modifying, adding or deleting attributes.

Production systems have the advantage that they can readily explain their reasoning by listing the rules which fired in the order which they did so. They can also be made to perform logical inferences. The results of these deductions may be new production rules which can be added to the rule-base to form meta-rules which model learning and the transition from novice to expert behaviour (Larkin, 1982).

MYCIN (Shortcliffe, 1976, also described in several other sources, e.g. O'Shea and Self, 1983) is an expert system which attempts to diagnose infectious diseases of the blood and which can make suggestions about the treatment of particular cases. It is an example of a rule-based expert system later used in a tutoring program. It is interesting to note that the knowledge-base of MYCIN had to be reorganized and expanded to make it suitable for tutorial purposes, rather than just diagnostic consultation. Clancey and Letsinger (1981) discusses the re-configuration of the program which resulted in the new version for tutoring, NEOMYCIN.

Production rules may be declarative, e.g. IF there is a resultant force acting on an object, THEN its acceleration will be non-zero, or procedural, e.g. IF the mass is known and the force is known THEN the magnitude of the acceleration is equal to the force divided by the mass.

#### 2.4.2. Student modelling systems

The systems described above for knowledge representation in experts can also be used to model the student in an ICAI system. Several extensions have been explored, particularly to cope with novice behaviour and misconceptions.

GUIDON (Clancey, 1981b & 1982a), the tutoring system built around MYCIN, uses an overlay model for the student. In an overlay model, the student's knowledge is assumed to be a subset of that of the expert. GUIDON

associates certainty factors with the knowledge in the student model. One certainty factor is used to indicate how sure GUIDON is that the student knows a particular rule. A second certainty factor measures GUIDON's confidence in the student's ability to apply the rule and the third component measures the student's ability to support partial conclusions by drawing on the knowledge-base. This information is used to drive the tutorial rules which govern decisions about what feedback to give the student. GUIDON makes no attempt to model misconceptions or alternative solution paths.

Goldstein (1982) proposed the use of a genetic graph for representing knowledge in an ICAI system. The genetic graph is based on the idea of a network representation. It uses nodes to represent procedural rules and links between nodes to indicate the evolutionary relationships between rules. These relationships describe such processes as generalization/specialization, analogy, deviation/correction and simplification/refinement.

The student's knowledge of what is being taught, in Goldstein's case the strategy for playing the game WUMPUS, can be overlaid onto the genetic graph in terms of the rules which he is believed to know. Since the links between nodes represent the way in which learning takes place, the graph can be used to predict which skills the student may learn next. The student's progress is later represented by his path through the graph and this information can be used to measure the effectiveness of the teaching strategy.

The process of deviation can arise in learning by mistaken analogies, over-generalization or over-simplification. Links of this kind are used in the genetic graph to portray errors commonly made. Such errors may arise on the correct application of an incorrect rule or the incorrect application of a correct rule.

Heines and O'Shea (1985) describe a rule-based tutor in which the requisite skills for learning to use the ReGIS instruction set are represented in the form of a directed graph. The graph contains knowledge of prerequisite skills which the student needs for the mastery of higher level skills. These relationships are represented in the form of

production rules.

In this system, the student model holds a value for each skill which takes on a value ranging from -3 for demonstrated non-mastery through -1 for non-mastery assumed due to demonstrated non-mastery of a prerequisite skill to +3 for mastery demonstrated in a test situation. For each skill, the value is zero to begin with, indicating that no data is available when the student starts. In addition, the student model holds information about the student's learning rate and his preferred learning style which may be "expository", "exercise" or "laboratory".

#### 2.4.3. Tutorial management systems

Tutorial guidance systems generally use the information in the student model to determine what to teach next and how to teach it. The system of Heines and O'Shea makes use of a set of means-end guidance rules. These rules relate the student model to specific teaching operations and govern the subject matter and level and speed of presentation. An example of one such means-end guidance rule stated in English by Heines and O'Shea is:

"if the student is re-entering a module she/he has already studied but done poorly on, make the subject matter presentations in EXPOSITORY style on all skills for which the student model indicates NO-DATA or NON-MASTERY, and (make) these presentations as if the value of LEARNING-RATE was SLOW or VERY-SLOW".

Many ICAI systems make use of rule-based tutors. In this respect, GUIDON (Clancey, 1981b & 1982a) is probably the most well-developed intelligent tutoring program produced to date. It makes use of over 200 tutorial rules in its production system. Clancey (1979) summarized the dialogue management by the tutoring component of GUIDON as "the coordination of tutorial goals within the constraints imposed by: 1) time available for the session, 2) student initiative and conversational (social) postulates, 3) the communication channel, and 4) human memory and learning capability".

GUIDON employs the case study method which means that MYCIN is allowed to solve the problem first. The problem-solving strategy used by MYCIN is then employed as a basis for monitoring the student's progress. Some of

the tutorial rules are designed to guide the discussion economically, as it is not possible to discuss every inference which the expert system makes. Other rules are used to ensure "dialogue connectedness and comprehensibility", while others handle student hypotheses and questions.

Clancey has attempted to address the problem of how to share and maintain the dialogue context. In the case of student hypotheses, GUIDON is capable of using "entrapment" to lead the student into a situation where he reveals the incorrect basis of his deductions.

Woolf and McDonald (1984) have organized their tutor in terms of a well-developed discourse management network which contains 40 tutoring states grouped into three levels. Each level is used to determine the teaching strategy more specifically. At the highest level, the general approach is set (e.g., probe a misconception). At the next level, the specific teaching strategy is determined (e.g., explore the student's competence by asking a question). At the lowest level this is refined into a definite tactic, perhaps by choosing a topic for presentation or formulating a question.

Their dialogue management network is traversed iteratively, but a set of 20 meta-rules is used to divert the student from the default path when certain conditions prevail. Meno-tutor, as the system is called, has been used to teach computer science students concepts of PASCAL programming. However, it has been set up in such a way that it provides a general framework within which to test tutoring rules. It is possible to change the knowledge-base to represent a different domain without making changes to the tutoring rules and strategies.

Another valuable role which the computer-based tutor can play is that of a coach. This is particularly useful in simulations and games where discovery learning is taking place. The coach can deal with two types of situation, the first being the case where the student is consistently making an error, but is unable to correct it. Brown and Burton, (1982) refer to this as a "non-constructive bug." In this case the computer coach can supply additional information to help the student turn the "non-constructive bug" into a "constructive bug" thereby allowing him to repair the situation.

In the second case, the student may not be aware that he is making an error. In fact, it might be that he is employing a correct strategy, but not the optimal one. In this situation, the coach could make a suggestion about how to improve one's strategy. Often the most useful kind of student modelling associated with this kind of tutor is the differential model. This model is constructed by comparing student actions with possible actions on the part of the expert in the same situation.

The two key issues for the computer-based coach are (Brown and Burton, 1982):

- when to interrupt the student, and
- what to say when the student is interrupted.

Brown and Burton have developed a coaching system for the game of WEST, originally written for the PLATO system. The coach was designed to distinguish suboptimal strategies from weaknesses on the part of the student. One of the most interesting of their early results was that students using the "coached" version enjoyed playing the game more than students who played without it.

#### 2.4.4. Communications and the user interface

In person-to-person dialogues, we communicate freely in "natural language" thereby expressing ourselves clearly and unambiguously and allowing our tutors insight into our thought processes. In the absence of reliable and fast voice input systems for computers, our communication with them is immediately limited by our typing ability. Unfortunately, a further limitation has been the lack of robust, efficient and compact natural language interpreters.

None of the programs described thus far has incorporated a well-developed natural language system. Most of them work on the basis of keyword recognition. A further problem is that of language generation within the program. This typically involves the conversion of an idea stated in the form of a production rule to plain English text. Very little attention has been paid to the design of appropriate screen displays for these systems and, apart from the game of WEST, graphics has hardly been used.

SOPHIE (Brown, Burton and de Kleer, 1982), an ICAI system for electronic trouble-shooting exercises incorporated a natural language component, as did ACE (Sleeman and Hendley, 1982), a chemical analysis problem-solving monitor. The language capabilities of these and other programs are discussed in a later chapter.

#### 2.4.5. General observations

Intelligent tutoring systems attempt to model the behaviour and teaching ability of human tutors. Their shortcomings are recognized and commented upon by several authors. Sleeman and Brown (1982) point out that ICAI systems have not fully solved the problem of presenting material at the correct level of detail. They tend to force the student to work within their conceptualization of the domain rather than trying to find the student's conceptualization and using that as a basis for entering into a discussion. Also, refinements to the techniques for knowledge representation, student modelling and the theories of teaching and learning are required.

Most significantly, these programs are still too restrictive in their interaction with the student. The student's freedom express himself naturally is limited, and this in turn limits the system's ability to model and diagnose learning difficulties. Very few of the systems described have been used extensively with students.

#### 2.5. ICAI in Physics

Taylor (1967) describes what was probably the first use of an artificial intelligence program for CAI in Physics. This was an attempt to use ELIZA (Weizenbaum, 1966 & 1967), a conversational tutoring system, to teach students about the concept of four-vectors in special relativity. ELIZA appeared intelligent in that it was capable of carrying on a meaningful discussion about any topic for which a suitable script had been programmed. Figure 2-3 shows an extract from a student's dialogue with ELIZA.

ELIZA did not include an expert system with any knowledge of Physics nor

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INTRVW SCRIPT  
 WHAT ARE THE LORENTZ TRANSFORMATION EQUATIONS USED FOR. QQ  
 these equations involve the transformation from a stationary  
 to a moving frame.

WHAT IS IT THAT THE LORENTZ TRANSFORMATION TRANSFORMS.  
 a transformation is the apparent transformation observed  
 between two inertial frames moving at some constant velocity  
 with respect to each other. this transformation may occur  
 in the fundamental units, mass, length, and time.

THE LORENTZ TRANSFORMATION TRANSFORMS COORDINATES.  
 THE LORENTZ TRANSFORMATION TRANSFORMS COORDINATES OF WHAT,  
 coordinates of length vs time

THE LORENTZ TRANSFORMATION TRANSFORMS COORDINATES OF EVENTS.  
 YOU MISSED SEVERAL OF THESE QUESTIONS. WOULD YOU LIKE TO RUN  
 OVER THIS SECTION AGAIN.  
 yes

WHAT ARE THE LORENTZ TRANSFORMATION EQUATIONS USED FOR. QQ  
 the lorentz transformation equations perform functional  
 operations on a coordinate frame.

WHAT DOES THE LORENTZ TRANSFORMATION DO TO THESE  
 COORDINATES.  
 It transforms them in space and time

THE LORENTZ TRANSFORMATION TRANSFORMS COORDINATES OF WHAT,  
 events

SO MUCH FOR THE LORENTZ TRANSFORMATION TRANSFORMATION FOR  
 NOW.  
 VELOCITY IS AN ORDINARY 3-VECTOR, I.E. A VECTOR WITH THREE  
 SPACE COMPONENTS. PLEASE NAME SOME MORE 3-VECTORS USED IN  
 THE STUDY OF NEWTONIAN MECHANICS.  
 momentum force

YOUR LIST OF APPROVED VECTORS.....  
 MOMENTUM FORCE  
 ANY MORE. QQ  
 yes

WHAT ARE THEY,  
 angular momentum

YOUR LIST OF APPROVED VECTORS.....  
 MOMENTUM FORCE ANGULAR MOMENTUM

Figure 2-3: Extract from a Physics dialogue with ELIZA from Taylor (1967)

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did it include a student model. Its usefulness lay in its ability to recognize what the student was saying, although, in most of the Physics dialogues, this seems to have been only just adequate enough.

ELIZA responds to the student using pre-stored messages, or text assembled using parts of the student's input. It can automatically call up an alternative script when required by the student's line of argument. Although the student has some degree of control over the flow of the dialogue, the teaching strategy and the conceptualization of the topic was

explicitly programmed into the script.

Taylor had hoped that a friendly system of this kind would encourage self-study on the part of the students. In fact, he found that the students were reluctant to take control of the learning situation and did not make much use of control words which would have let them take more control in directing the conversation. After the brief experiment of 1967, ELIZA was not used for further Physics instruction. It seems a pity that the system was not tried at a more elementary level.

Since electronics is taught in most Physics courses and laboratory work is a characteristic of the Physics curriculum, SOPHIE (Brown, Burton and de Kleer, 1982) has made a significant contribution to ICAI in Physics.

---

the student >>WHAT IS THE OUTPUT?  
THE OUTPUT VOLTAGE IS 11.7 VOLTS.  
>>WHAT IS IT IN A WORKING INSTRUMENT?  
IN A WORKING CIRCUIT THE OUTPUT VOLTAGE IS 19.9 VOLTS.  
THAT VALUE IS INCORRECT.  
>>WHAT IS THE VOLTAGE BETWEEN R8 AND Q1?  
THE VOLTAGE AT N1 IS 47.6 VOLTS.  
>>WHAT IS THE BSE EMITTER VOLTAGE OF THE VOLTAGE  
LIMITING TRANSISTOR?  
=BASE  
=TRANSISTOR  
THE BASE EMITTER VOLTAGE OF Q5 IS -0.037 MILLIVOLTS.  
>>WHAT ABOUT FOR THE CURRENT LIMITING TRANSISTOR?  
THE BASE EMITTER VOLTAGE OF Q6 IS 0.349 VOLTS.  
>>WHAT SHOULD IT BE?  
IN A WORKING CIRCUIT THE BASE EMITTER VOLTAGE OF Q6  
IS 0.593 VOLTS.  
>>REPLACE Q6  
I AM GOING TO ASK YOU SOME QUESTIONS ABOUT HOW Q6 IS  
FAULTED.  
ARE ANY JUNCTIONS SHORTED?  
>I DON'T KNOW

Figure 2-4: Extract from a student dialogue with SOPHIE from Brown, Burton and Bell (1975)

---

SOPHIE provides a "reactive environment" in which students can build trouble-shooting skills. Students were encouraged to use SOPHIE to perform experiments in which they made a modification to a given circuit and tried to predict the outcome. Figure 2-4 shows an extract from a student dialogue with SOPHIE.

The expert system in SOPHIE is a general purpose electronic circuit simulator. SOPHIE can not only answer questions about a given circuit but can also discuss a circuit modified by the student. In such a case, the modified circuit is applied to the simulator and SOPHIE can predict the voltage levels and the operation of the components in it.

SOPHIE can also evaluate student hypotheses and generate hypotheses as required in answer to questions from the student. However, student modelling in this system is minimal, partly because it is designed around the circuit simulator rather than an educational model of the skills being taught. Also, the simulator itself was a "black-box expert" in that its problem-solving mechanisms were not intended to mimic those of humans and were thus not apparent to the students.

The third Physics ICAI system worthy of note is one currently under development at North Texas State University (Brown, Miller and Swigger, 1985). This system, which is intended to run on a personal computer, uses a networked hierarchy of learning objectives which represent the expert's knowledge of a first-semester non-calculus Physics course. Ausubel's theory of advance organizers has been used to plan the incorporation of material into the "netarchy", the idea being that a student must learn that material at any one time which has meaning in relation to his existing knowledge.

The amount of learning which takes place at a node in the network will be path dependent. Bloom's taxonomy for assessing cognitive behaviours is used as a measure of learning. By devising appropriate questions, a number can be obtained for the student's level of learning at each node and this can in turn be used to direct the path of future instruction. The tutorial system is rule-based and will be capable of experimenting with different teaching strategies to optimize student learning. Student control of the learning path will be permitted.

The system will be capable of problem generation and will be able to interrogate the expert rule-base to provide explanations and to answer questions. This system, which is very ambitious in its scope, is being written in LISP to run on a personal computer. A natural language system will not be incorporated, partly due to memory limitations.

Although there have been very few ICAI systems implemented for Physics instruction, there has been a great deal of research in the areas important to the development of such systems. Several workers have studied student learning in Physics and expert and novice problem-solving (e.g., Larkin et. al., 1980, and Reif and Heller, 1982). Various systems for representing the domain of knowledge in Physics have been explored and many strategies have been suggested for teaching Physics and Physics problem-solving (e.g., Reif and Larkin, 1979, and Novak, 1983). Computer-based expert Physics problem-solvers, some of which were capable of natural language understanding have been developed and evaluated (e.g., Novak, 1976 and de Kleer, 1977).

The present work is intended to explore the possibility of using some of the techniques discussed in this section along with the results of some of the research just mentioned to provide an intelligent mechanics problem-solving environment for elementary Physics students.

## 2.6. ALBERT

All Physics students are required to solve problems. This activity may take several hours per week outside of lectures for the average student. Problem-solving in Physics is thought to be a desirable activity because it helps students apply what they have been taught in lectures to concrete examples. Problems chosen are often selected because they illustrate particular ways of applying the principles and laws taught. However, there is usually very little explicit instruction in methods of problem-solving.

As a result, problem-solving is an activity which can lead to much frustration on the part of the students, when they are either unable to arrive at a solution at all or when their solution differs from the one published as being correct. Students who find themselves in this position

generally have recourse to one of the following three actions:

- give up (and perhaps try another problem);
- seek help from a peer;
- arrange to obtain assistance from the lecturer/tutor.

In my experience, the majority of students appear to give up when they are unable to solve Physics problems. A few seek out assistance from other members of their class and very few indeed approach the lecturer directly. The reasons for this reluctance to obtain help on the part of students may lie in a lack of motivation on their part or in the rather formal nature of our institutions of learning, even when the classes are small.

Ideally, one would want to give every student immediate access to one-on-one tutoring at any time of the day or night. Unfortunately, this is not possible for several reasons, two being that it would be too teacher intensive and too costly. However, if one could provide an expert computer-based tutor, it might be possible to approach the ideal situation, depending on how closely one could model the activities of human tutors in teaching problem-solving. For students, access to a computer terminal is far more immediate and extended than their access to lecturers or other human tutors, and a lot less threatening in some cases.

ALBERT has been designed with this ideal in mind.

#### 2.6.1. Design specifications for ALBERT.

It is intended that ALBERT should ultimately incorporate all of the following external features.

- a. Students must be able to type in the problem of their choice. In most cases when a student needs help with problem-solving, it is with a specific example. It is not very helpful or relevant to have the computer system thrust a problem upon the student. Occasionally, a student will identify a general area of need and ask for assistance, but in these cases, a theoretical explanation is required more often than a discussion of problem-solving.

- b. Students must be able to type in the problem directly from the textbook, just as it is stated there in plain English without having to make any changes. Programs which require the student to extract the relevant information from the problem statement and type this in as data (e.g., GEORGE by Cornelius, Cabrol and Cachet, 1985), are making assumptions about the student's ability to understand the problem statement and identify the relevant information. These assumptions may not be valid and recent research (Mehl, 1985) has shown that some students fail to extract all the relevant information from problem statements due to semantic and other difficulties.
- c. Students must be encouraged to solve the problem for themselves as far as possible. This is of more worth in developing the higher cognitive skills of problem-solving, than merely showing the student a solution would be.
- d. Students must be able to employ any valid solution method of their choice, even if this differs from the one which the system would generate automatically. If the system detects that the student is diverging from the possibility of obtaining a solution, it may interrupt at some appropriate stage to make a corrective comment or suggestion.
- e. The student must be able to ask for explanations and suggestions at any stage.
- f. When the student is stuck, the system must be able to make a suggestion about how to continue. Just enough information should be given to allow the student to continue. Help given must be relevant to the path the student has chosen to follow, unless that is completely the wrong approach, in which case, the system must be able to offer a complete and clear explanation of why a totally different strategy should be employed.
- g. The system must appear to respond instantaneously. As a guide-line, a response time of half a second for any student input should be regarded as a maximum. Many of the early ICAI systems already described were considerably slower than this. For example, Koffman

(1972) mentions response times of up to three minutes!

To achieve these goals, ALBERT has been designed to incorporate the following internal features, although it has not been possible to implement all of them fully as yet.

- a. ALBERT must have a natural language system capable of handling two distinct classes of language input, viz., a Physics problem statement taken from a typical Physics textbook, and the language of a student-tutor dialogue.
- b. ALBERT must have an expert system capable of solving Physics problems of particular kinds and must be able to follow and assess different possible solutions to any given problem. In addition, the expert must be a "glass-box" expert (Brown and Burton, 1982) capable of explaining in detail what it is doing and why.
- c. ALBERT must incorporate a tutorial system designed to achieve the following goals. First, it must achieve the immediate goal of assisting the student with the solution of any given problem. Secondly, it must help the student build up his/her problem-solving skills. Thirdly, it must be able to identify, intercept and remedy common misconceptions about the Physics being studied.
- d. ALBERT must maintain a dynamic model of the problem-solving context. The context model contains the student model and general information about the current state of the discussion. This allows ALBERT to drive the tutorial system in a meaningful way. The student model would have to include information about the student's problem-solving skills, his/her ability to extract information from the problem statement and his/ her misconceptions.
- e. In addition to the natural language system, adequate provision must be made for handling the user interface in a friendly way. Screen capabilities must include graphics, a feature important to problem-solving in Physics, where diagrams are often highly desirable. (This is an area which was neglected in many of the early ICAI systems already described.)

- f. When each problem is completed, ALBERT must be able to show the student his solution, for purposes of comparison.

A further requirement for ALBERT, brought about by the need for testing and the desirability of research in novice problem-solving and misconceptions, is that ALBERT must be able to keep a complete record of every tutorial dialogue.

ALBERT is thus intended to be an intelligent tutor capable of acting as a problem-solving monitor and coach.

#### 2.6.2. ALBERT's domain of expertise.

Ultimately, ALBERT should be able to handle a wide variety of problems in a wide range of topics in Physics and other subjects. However, it was decided to limit the domain of expertise to begin with so as to confine the problem to reasonable proportions.

Elementary mechanics is fundamental to the study of Physics. It is here that students must get to grips with the concepts of scalars, vectors, scalar components of vectors, displacement, velocity, acceleration and time. Students have a lot of difficulty with this. Larkin, Heller, Reif and the others mentioned have all directed their attention to this area of Physics.

ALBERT is at present designed to teach students to solve problems in one-dimensional kinematics. The problems with which ALBERT can cope must meet the following criteria.

- a. The motion must be one-dimensional.
- b. The acceleration must remain constant during the time period of interest.
- c. Only single particle problems are catered for.
- d. Only motion in a frictionless medium is permitted.
- e. Problems which are "implicitly multiple" not permitted. Figure 2-5 shows an example of an "implicitly multiple" problem.

- f. Problems which include the resultant force and the mass are permitted.<sup>2</sup> (This does not include problems in which the resultant force must be derived from other known forces.)
  - g. Only one question may be specified at a time.
- 

An "implicitly multiple" problem statement:

A ball is thrown straight up into the air with an initial velocity of 12 m/s. How far does it travel during the third second?

This problem is "implicitly multiple" in that one is first required to calculate the velocity at the start of the third second. There are thus two problems in one. The first is to calculate the velocity of the ball after 2 seconds. In the second, one takes that as the initial velocity and calculates how far the ball travelled in the next second.

**Figure 2-5: An example of an "implicitly multiple" problem**

---

Students on working problems in 1-D kinematics must bring together their knowledge of all of the concepts mentioned above and be able to apply them to problems of motion in a straight line. By observing students solving problems of this kind, one may discover a great deal about their knowledge of each of these concepts and their ability to relate them one to another.

A human tutor, helping a student solve a problem, does more than just show him/her how to arrive at the correct answer. When the student demonstrates that a concept has not been fully grasped or that he/she has a misconception about it, time will be taken out to explore the concept itself and to remedy the situation. A problem-solving monitor such as ALBERT can be made to perform a similar function, when students reveal

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2. Although this extends ALBERT's capability into the domain of simple dynamics problems, this would usually be in the context of 1-D kinematics. I shall therefore refer to the problems being studied as 1-D kinematics problems throughout this thesis.

their weaknesses. Since all the dialogues are recorded in detail, one hopes that this might be a valuable source of information about student thinking on elementary mechanics.

### 2.6.3. Structure and flow of ALBERT

ALBERT has been constructed in terms of the five elements shown in Figure 2-6.

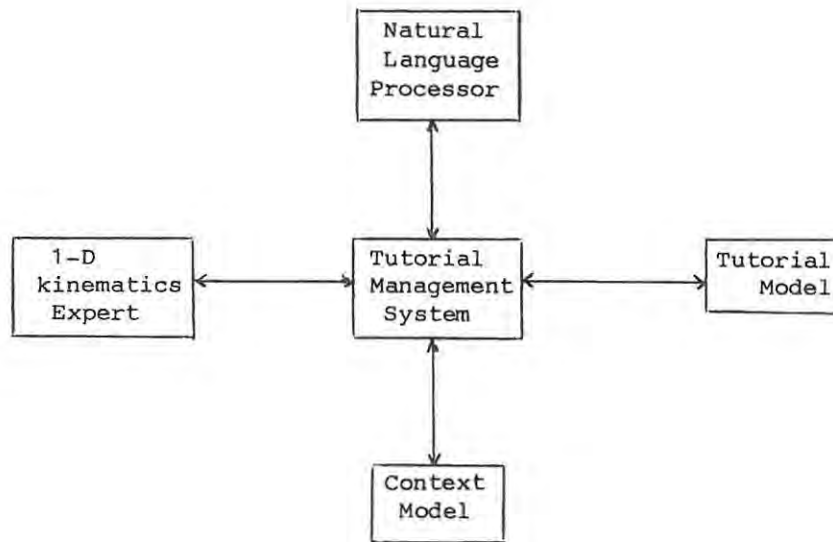


Figure 2-6: Structure of ALBERT

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The tutorial management system is responsible for overall program flow and hence for the general flow of the dialogue. The 1-D kinematics expert is capable of solving problems of the kind described using two fundamentally different approaches. It is capable of checking on the progress of a student and can make suggestions, even when the student's approach is different from both of these.

The natural language processor is capable of handling a wide range of problem statements in the domain of interest and is designed to cope with

the typical forms which student dialogues in these problems take. Language generation in ALBERT is somewhat rudimentary, the responses being synthesized from pre-stored sentence fragments which are tailored by the particular context in which they are required.

The context model in ALBERT consists of a large collection of registers and flags which are used to keep track of the current state of the discussion and what has gone before. The context model has three components, a student model, which takes the form of an overlay model, a tutorial status model and a dynamic dialogue model.

In ALBERT, the tutorial model forms an integral part of the tutorial management system and, while the teaching strategy is relatively inflexible, the mixed initiative capability of the dialogue system results in widely varying discussions for the same problem, depending how much control the student chooses to take in driving the system.

Figure 2-7 is a flowchart for ALBERT showing the overall operation of the system.

When the student enters the system, he/she must begin by typing in the problem. This is done via the PLATO student notes editor with which many students are already familiar. When typing is complete, the TMS hands the problem statement to the natural language processor which reads the problem. If there is insufficient information or if there are unrecognized words, the student is asked to amend the problem statement.

Once ALBERT is satisfied with the problem statement, the TMS calls the expert system which solves the problem twice, using two different methods. This takes approximately 0.5 seconds. The expert system then contains the knowledge extract from the problem statement and the new information generated in the solution process.

ALBERT then initiates the discussion with the student. The discussion is divided into three sections. First there is a qualitative discussion in which the student must show that he/she has understood the problem statement and identified the problem type. At the end of this, ALBERT provides a summary of the discussion thus far and the student is then

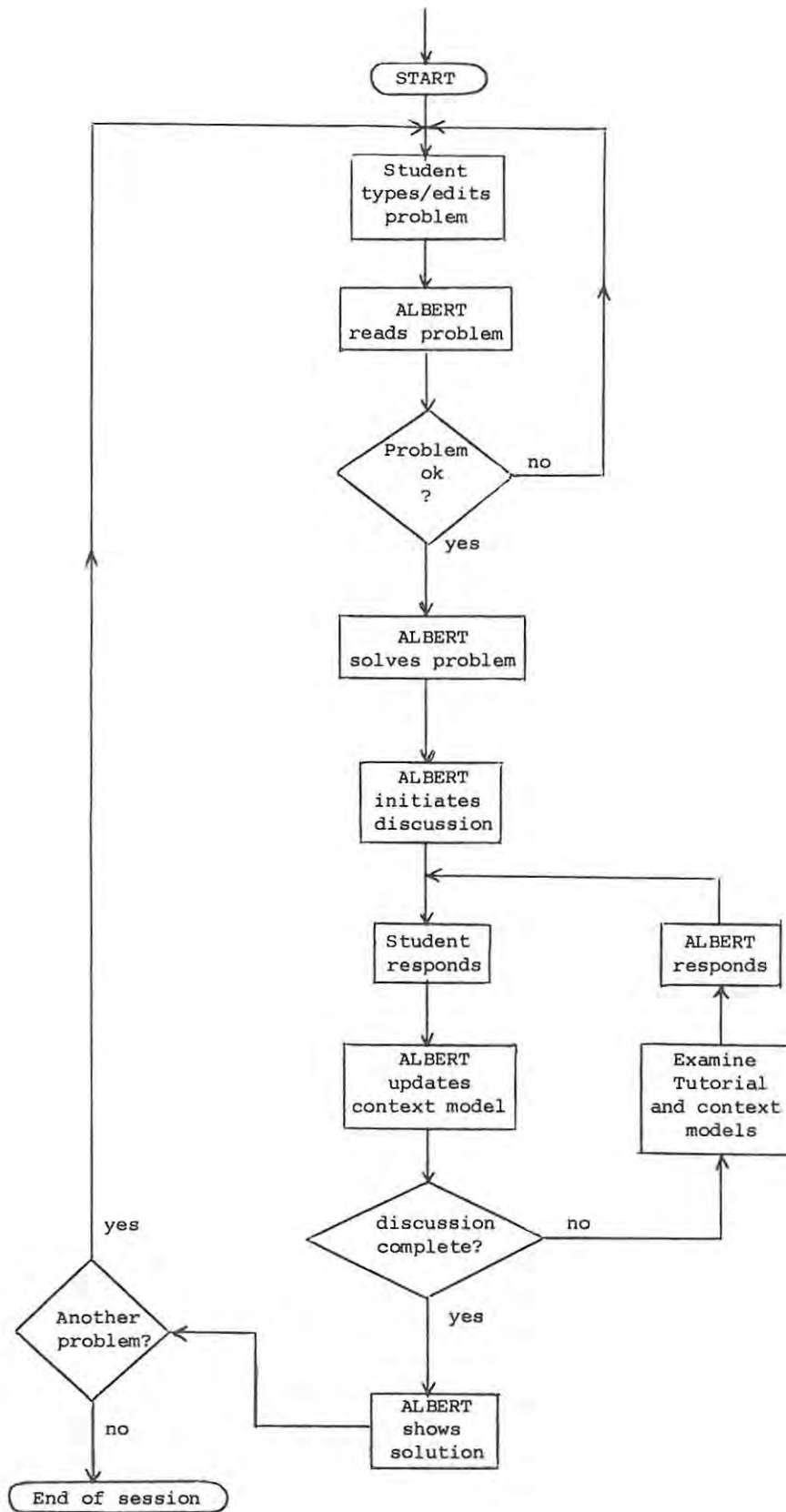


Figure 2-7: A flowchart of ALBERT

required to show that he/she has extracted all the useful information from the problem statement.

The discussion of the solution then begins. Every statement made by the student is used to update the context model. The TMS examines this model to formulate ALBERT's response. In doing so, the TMS may have to interrogate the expert system, as would happen when the student is stuck and ALBERT needs to make a suggestion about how to proceed.

When the TMS discovers from the context model that the student has solved the problem, the discussion is terminated and the student is shown how ALBERT would have solved the problem. At this stage, the student may elect to enter another problem or end the session.

It has been impossible to develop the various components of ALBERT fully within the scope of this project. However, it has been possible to produce a system which is capable of teaching a wide range of problems by conducting a natural language discussion with the user. This work has been exploratory. It represents a departure from the techniques of classical CAI but it is also a departure from the classical approach to AI.

#### 2.6.4. A programming language for ALBERT

In the development of a system such as ALBERT, one must consider at the outset which programming language to use and on which delivery machine to implement it.

In considering an implementation language, three broad classes of languages must be taken into account. First there are the traditional programming languages which include BASIC, FORTRAN, PASCAL and others. Secondly there are CAI author languages which include PILOT for microcomputers, TUTOR for PLATO, PLANIT and others. Then there are the so-called AI languages, viz., LISP, PROLOG and lesser known ones like SAIL, PLANNER and KRL.

In spite of their power, traditional programming languages have not proved to be very useful for either computer-assisted instruction or for

artificial intelligence. BASIC has severe limitations, particularly with respect to its structure and flow, and enhancements such as EnBASIC have been provided to assist users who develop CAI lessons. FORTRAN is designed to serve the scientific community, but programs for dialogue handling and logical inference can be very cumbersome in FORTRAN. PASCAL is better in this respect and has the advantage of being available in an advanced form for common microcomputers, e.g. Turbo-PASCAL on the IBM pc.

Many author languages make adequate provision for graphics and text manipulation, but are often restricted in their computational power. I tend to agree with Bork (1981) who believes that the development of specialized languages for dialogues is a mistake. The TUTOR language, however, is a unique example of an authoring language. It has evolved over a period of 16 years and allows a great deal of flexibility in program development. The commands in the language range from the high level operations of sorting and searching to bit level manipulation. One of its chief disadvantages is that it does not allow recursion.

LISP has been the preferred language of the artificial intelligence community for a long time. It is argued that one characteristic of intelligence is the ability to manipulate lists of symbols efficiently and to form meaningful associations between lists of symbols. LISP is a list processing language and this is what makes it attractive in the development of AI systems.

PROLOG is a logic programming language very popular for the construction of expert systems because it makes knowledge representation in the form of a rule-base easy. The rule-base may be manipulated for inference purposes. Although a version of PROLOG (micro-PROLOG) is available for microcomputers, it lacks convenient graphics capabilities.

The requirements for an intelligent CAI system differ from those of a general AI working environment and may be listed as follows:

- user interface. The facility to provide good quality displays with both text and graphics is fundamental in any CAI system.
  
- symbol manipulation. The facility to manipulate lists of symbols of varying lengths is of critical importance in any dialogue system.

- data structures. There is a need to represent knowledge in the form of declarative and procedural data. In addition, it is frequently necessary to represent knowledge of associations among the data elements.
- pattern matching. This is needed both for data manipulation and for control, e.g. in a production system.
- computational ability. Efficient implementation of mathematical models is often required in CAI systems. General speed is extremely important in any CAI program.
- flexible control structures. For automated reasoning in inference and problem-solving systems, a goal-directed approach is common. For this control structures which allow the efficient coding for recursion and back-tracking are needed.
- program structure. A system which can be constructed in modular fashion is easier to understand and to test than one with an amorphous structure.

No single language can provide all of these features. Table 2-2 provides a comparison of FORTRAN, PASCAL, TUTOR, LISP and PROLOG by assigning a numerical rating to each of the requirements for ICAI. It should be noted that these ratings are entirely subjective and are based on my knowledge and experience of these languages, all of which I have used. Also the criteria have all been given an equal weighting in the calculation of an overall figure of merit. This may not be justified as the difficulties related to some features may be more easily overcome than those related to others.

	F O R T R A N	P A S C A L	T U C O R	L I S P	P R O L O G
user interface	2	4	5	1	1
symbol manipulation	2	3	4	5	4
data structures	3	4	2	5	4
pattern matching	2	3	4	3	3
computational ability	5	4	4	2	2
control structures	2	4	2	4	5
program structure	3	4	4	4	3
overall rating for ICAI	2.7	3.7	3.6	3.9	3.0

- 1 - Not catered for. Can only be done with great difficulty.
- 2 - Not catered for explicitly. Moderately difficult.
- 3 - Fairly straightforward.
- 4 - Partially catered for. Easily implemented.
- 5 - Explicitly catered for. Very efficient implementation possible.

Table 2-2: Ratings of languages for ICAI

In summary,

**FORTRAN** provides excellent computational capabilities, but neglects the user interface. Flexible control structures are not provided which makes automated reasoning difficult. Modularity can be achieved by extensive use of subroutines and functions.

**PASCAL** provides a much better user interface with reasonable graphics capability, depending on the version used. Symbol manipulation is partially catered for but explicit programming is required. Flexible control including recursion is provided and automated reasoning can be implemented fairly efficiently.

**TUTOR** offers an excellent user interface and there is provision for symbol manipulation. Pattern matching can be fairly efficiently contrived via the answer judging and bit manipulation features. Programs can be highly structured, but control is very rigid, making automated reasoning difficult. Data structures are limited, but bit level manipulation is useful for knowledge representation.

**LISP** provides for efficient symbol manipulation, knowledge representation via property lists, and flexible control for automated reasoning via recursion. However, the user interface is very poorly developed and LISP is not intended for computationally intensive applications.

**PROLOG** handles symbols by means of lists and records and provides for recursion and back-tracking for automated reasoning. However, it is poor for computational purposes and the user interface is not well developed.

Ideally, one requires a system with the FORTRAN computational speed, the PLATO user interface, the symbol manipulation ability of LISP and the automated reasoning ability of PROLOG. There has been an attempt to combine LISP and PROLOG in the language POPLOG and Morris (1985) describes an expert system extension to PILOT which allows the lesson developer access to LISP structures from the PILOT system. Although these systems are not in general use, one might expect to see further developments along this line in the near future.

For ALBERT, several additional factors were brought into consideration. First, as a Physics teacher rather than a Computer Scientist, I wanted to develop an ICAI system which could be put into use with large numbers of students. Secondly, I believe that the user interface is of the utmost importance. Any CAI system in general use must incorporate full graphics capability and allow screen presentations of a similar standard to the best traditional CAI lessons currently available.

I did some preliminary studies using LISP (on a VAX 11/780) to implement an intelligent multiplication drill and practice system that incorporated a rudimentary student model which determined item selection and controlled the amount of time allowed for a response. The same system was implemented on PLATO using TUTOR. While the LISP program was much more compact, the PLATO presentation was far superior to that which could be achieved with LISP and in fact incorporated several additional features.

In addition, I implemented a procedural network for multi-digit multiplication on PLATO and used that to drive a PLATO program which simulated the process of multiplying two multi-digit numbers. It was possible to introduce "bugs" into the network at run time to mimic the operation of BUGGY (Brown and Burton, 1982). The driver program was complex but readily transportable into other domains. This data-base driven lesson was not constrained to the rigid control structure of the tutor language.

Later, I began investigating the use of TUTOR for natural language processing and found that an efficient system could be built on top of the existing answer judging capabilities of the system.

The biggest drawback of TUTOR is the difficulty associated with automated reasoning. On the basis of the information in Table 2-2, PASCAL would be a fair compromise if one wanted to avoid the short comings of LISP and PROLOG for CAI delivery. However, for ALBERT, favourable in depth experience with the TUTOR language, ready access to PLATO, and the daunting prospect of developing a large number utilities for screen handling and text manipulation on other systems resulted in a decision to use the PLATO system. Deficiencies in the final product were more likely to stem from the limited inference ability than anything else.

## Chapter 3

### Natural Language Understanding

#### 3.1. Background

One of the characteristics of intelligent life is the ability to communicate. In the case of humans, this is by means of language, either spoken or written. One view of language understanding (Ritch, 1983) is that it is the transformation of source input, e.g., a piece of written text, into some target representation, appropriate to the situation. For humans that may mean mapping into a conceptual framework which will allow further cognitive processing.

For anyone, novice or expert, the first step in attempting to solve a Physics problem is one of language understanding. This initial "understanding" of the problem statement often embodies two steps. First, one must identify the problem type, e.g., one-dimensional kinematics. Secondly, one must be able to extract all the useful information and relate it to one's knowledge of the topic; i.e., the information in the problem statement must be transformed into an internal cognitive representation which allows it to be related to one's conceptual framework of the domain of interest.

The process of identifying the problem type and transforming the information in it into a useful internal representation had been studied by McDermott and Larkin (1978) and Larkin, McDermott, Simon and Simon (1980), among others. The authors mentioned have compared novice and expert performance at these tasks.

If ALBERT is to understand Physics problems stated in natural language, the facility to perform this kind of transformation from one representation to another is essential. A natural language interface was therefore designed to handle the task.

Bonnet (1985) lists several criteria which can be used as a measure of language understanding. Three of these which are particularly relevant to

ALBERT are

- the capacity to paraphrase or summarize a passage of text;
- the capacity to make inferences or process the information further;
- the capacity to respond to questions about the content in an appropriate manner.

### 3.2. Techniques for natural language processing

Attempts at using the computer for language processing began with the machine translation projects of the 1950's. Charniak and McDermott (1985) describe some of the attempts to automate two-language machine translation. It was soon discovered that simple word-for-word substitutions would not work reliably because of ambiguities. The approach was then modified to include a small set of syntactic rules which allowed phrase-by-phrase and sentence-by-sentence translations with more success. However, these systems were devoid of understanding and it was soon realized that this severely limited their capabilities. Even today, although techniques for natural language processing have been more fully developed, machine translation remains a difficult task.

#### 3.2.1. Keyword recognition

Keyword recognition is the most simple approach to language understanding. It is possible to write a program which will recognize one or more keywords in a piece of text and respond accordingly. This can be useful when one is working in a very restricted domain, or when the input text is likely to be grammatically unpredictable. Such programs can create a convincing illusion of understanding.

ELIZA (Weizenbaum, 1966) was one of the most highly developed programs of this kind. ELIZA could simulate the dialogue of a Rogerian therapist by looking for keywords in the "patient's" input. A template of one or more keywords was matched against the input text and, when a match was found, an associated output template was used to generate a response. In ELIZA, the keywords were ranked and, in the event of more than one being matched, the one with the highest ranking was used.

Many CAI systems make use of a keyword matching system for answer

recognition. In the PLATO system, this has been particularly well developed (Tenczar and Golden, 1972). The PLATO keyword matching system in the TUTOR language incorporates the following features which are illustrated by the program in Figure 3-1:

- keyword ranking through the use of successive answer commands. The first one matched determines subsequent system action.
- synonyms can be matched with equivalent ranking.
- phrases several words long can be matched as an entity.
- matching can take place even when words have been misspelled (Nesbit, 1985).
- the concept command can be used in conjunction with an extended vocabulary to provide a global definition of keywords.

---

```
*
at      1010          $$ specifies screen location
write  What kind of pet do you have?
arrow  1012          $$ accepts student input
specs  okextra,okspell  $$ will search for the keywords in a large
                        piece of text, misspellings accepted
answer dog,hound     $$ synonyms with equivalent ranking
answer cat,feline*creature  $$ matches the phrase specified
concept animal      $$ refers to globally defined vocabulary
no          $$ unconditional trap for unmatched words
endarrow
*
```

In this case the student answer "I see a dawg and a cat." would match "dog" and the system would respond accordingly. The "cat" would be ignored.

**Figure 3-1: An example of PLATO keyword judging.**

---

The most serious drawback of keyword recognition systems is that they ignore much of the useful information in the sentence. In the example above, the response "I do not have a dog but I do have a cat" would be incorrectly interpreted by the program. While it is possible to trap

negatives such as the word "not" explicitly, keyword matching breaks down rapidly as the semantic richness of the domain increases and as the scope of the topic is broadened.

### 3.2.2. Sentence structure analysis

To ensure that the full meaning of a piece of text is extracted, it is necessary to examine in detail the structure of each sentence. In general, this process involves three stages, viz. lexical analysis, syntactic analysis and semantic processing (Figure 3-2).

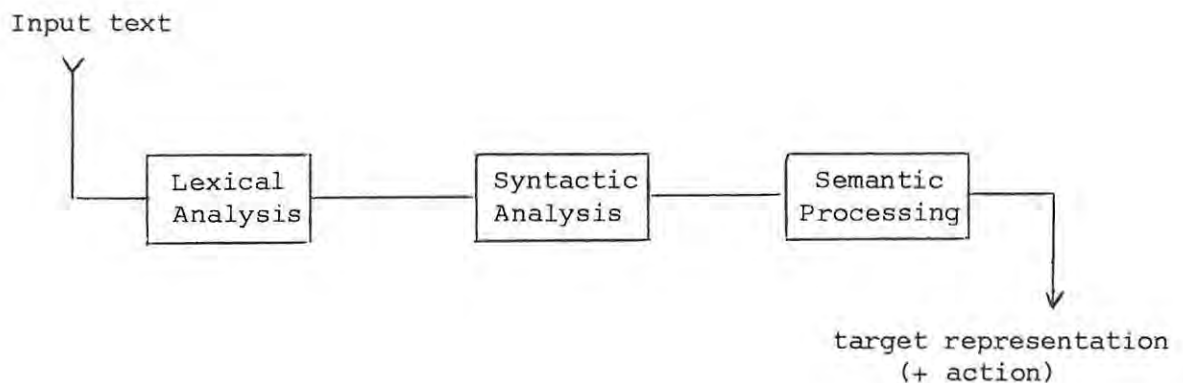


Figure 3-2: The formal approach to language processing.

---

#### 3.2.2.1. Lexical analysis

This is the first step in formal language processing and involves dividing the textual input into discrete segments, usually words, and relating these to a dictionary associated with the program. Semantic information is often associated with words in the lexicon but due to the fact that one word may have more than one meaning, disambiguation during syntactic and semantic processing is required.

#### 3.2.2.2. Syntactic analysis

The process of syntactic analysis, or parsing, attempts to assign a structure to the input sentence. Generally, the parsing process consists

of the application of a set of grammar rules to the input and the output thus produced is referred to as a parse tree. Figure 3-3 shows a simple grammar and a parse tree for a simple sentence. For the grammar shown, the lexicon forms an integral part of the grammar rules.

---

Grammar rules:

- S - NP VP
- NP - the NP1
- NP - NP1
- NP1 - ADJS N
- NP1 - N
- ADJS -  $\epsilon$  / ADJ ADJS
- VP - V
- VP - VP NP
- N - dog / cat
- ADJ - black / large
- V - chased / bit

(S - start symbol; NP - noun phrase; ADJ - adjective; ADJS - adjectival string;  $\epsilon$  - nothing; VP - verb phrase; V - verb.)

Example sentence:

"The little dog bit the big cat."

Parse tree:

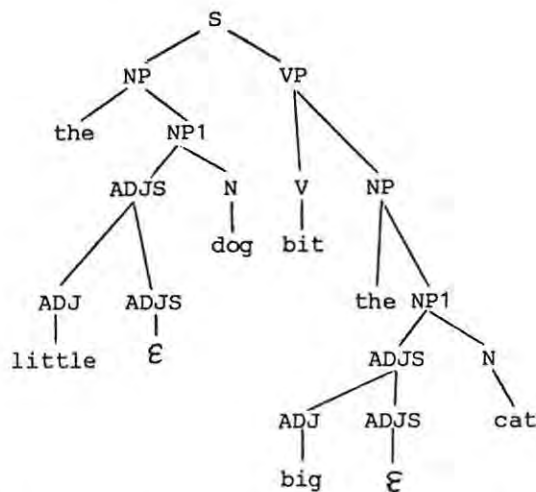


Figure 3-3: Simple grammar and parse tree produced for an example sentence

---

Parsing may be either "top-down", in which case one begins with a start symbol and proceeds by applying the grammar rules until the bottom of the tree matches the input sentence (Figure 3-3), or "bottom-up" in which case one begins with the input sentence and applies the grammar rules backwards until the start symbol is reached. In either approach, parsing fails when the structure cannot be completed.

One of the most commonly used parsing techniques is that of encoding the grammar in the form of an augmented transition network (ATN) (Woods, 1970). The ATN offers several useful features, such as the ability to backtrack when parsing fails, and the facility to encode additional knowledge on the arcs of the network to assist in building the parse structure.

#### 3.2.2.3. Semantic processing

Once the syntactic structure of the parse tree has been completed, a semantic interpreter can be used to assign meaning to the text being understood. This process may incorporate an action by the target program, sometimes referred to as "pragmatic processing" (Ritch, 1984).

The difficulty with the approach just described is that in general, semantic information may be required in order to derive the correct syntactic interpretation. For this reason, various attempts have been made to combine the syntactic and semantic operations. One solution is to include semantic knowledge in the ATN. This can help drive the parser to the correct structure. Another technique is to encode semantic information directly into the grammar rules. The resulting grammar is referred to as a semantic grammar and contains semantic categories rather than syntactic ones such as noun, verb etc.

The case grammar is yet another approach. In a case grammar the rules are purely syntactic but the structure produced is semantically significant. A case grammar can be used to produce a semantic network, a network representation which can be interrogated about the meaning of the input text. These techniques are discussed in detail in the standard textbooks on Artificial Intelligence, e.g. Ritch (1983).

### 3.3. Natural language understanding of Physics problems

Several programs have been written to solve Physics problems. Of these, ABLE (Larkin 1981a) and NEWTON (de Kleer, 1977) require the information given to be encoded as data for the program. ABLE and NEWTON are not capable of natural language processing. MECHO (Luger, 1981) uses a keyword system for extracting information from the problem statement. This is similar to Bobrow's program STUDENT (1968) which could solve algebra word problems. STUDENT used a hierarchy of keywords to locate the important concepts and then converted phrases around the keywords into variables. The limitations of this approach have already been mentioned.

Only Novak's program, ISAAC, (Novak, 1976 and 1977) has applied a fully developed natural language processor to the task of understanding Physics problems. ISAAC can understand and solve statics problems and is capable of re-representing the knowledge in the problem statement in the form of a diagram. ISAAC's parser is controlled by an augmented transition network grammar implemented in LISP. Semantic processing is interwoven with syntactic processing and the output is a case-structured semantic network.

As the semantic processing proceeds, knowledge of the problem statement is built up in the form of semantic frames (Minsky, 1975) which are ultimately transformed into "canonical object" frames. The system then uses this knowledge and geometrical knowledge of the objects to draw a diagram and to produce equations to solve the problem. ISAAC includes inference routines which allow information in the frames to be inferred from information given in the problem statement.

### 3.4. A cognitive view of language processing

One formulation of a cognitive model of human language processing may be stated as follows:

1. A passage of text is seldom read in isolation. It is always related to a highly specific context. Within a story, the specific context changes as the narrative moves from one situation to the next. This is in accordance with Minsky's (1975) use of "frames" for representing stereotyped situations.

Frames have "terminals" or slots in which specific data are stored. In process of understanding a passage of text or a particular situation, the slots in the frame are filled with data representing the instance being considered. This process of filling the slots is referred to as instantiation.

Collections of frames are linked together into systems of frames and frame systems are linked by information retrieval systems. Minsky suggests that language understanding is context-based, and meaningless statements are so, because they cannot be used to instantiate any known frame. In Minsky's view, a story would consist of a network of instantiated frames.

2. Associated with a particular frame is a contextualized vocabulary. This will be of limited extent and word usage within the context of that frame will generally be unambiguous. One view of lexical disambiguation is that it must be context driven. The suggestion here is that if the context is sufficiently limited, ambiguities will be excluded for exactly the same reasons.
3. Understanding is expectation driven. Once the context has been established, the reader looks for certain pieces of information which he/she expects to find in this context. When some information is missing, he/she will make use of default information, known to apply to the situation. An example of this in mechanics would be to assume frictionless motion unless there is specific information to the contrary. When information is present, which conflicts with the expectation, an attempt will be made to find a new context within which the conflict is resolved.
4. Human readers seldom resort to conscious syntactic processing. Within a context, particular syntactic patterns are expected. Lehmann and Bennet (1985) note that characteristic syntactic patterns are used in accordance with the situations in which they arise. The syntactic patterns are cues to the presence of specific data needed to instantiate a frame. Syntactic patterns are recognized automatically and as a whole, in a manner analogous to the aural recognition of a

popular tune or a spoken word.

Minsky also questions the extent to which grammar has a separate identity in the working of the human mind.

5. When a syntactic pattern, important within a context, is recognized, semantic processing is used to extract the data. Only those fragments of the text which are recognized as being important will be processed in this way. The contextualized vocabulary allows unambiguous extraction of the data from the syntactic patterns.

According to Minsky, this is the matching process by which values are assigned to the terminals of a frame. If the frame is not fully instantiated when reading is complete, the text may be re-read, a phenomenon commonly observed. Syntactic patterns important in one context may not be important in another and vice versa.

6. A piece of text has been "understood" when the associated frame is fully instantiated, i.e. all the values of the slots are known. Slots which have not been instantiated from the text are either filled by inference from other known slots or allowed to take on their default values provided that conflict does not arise.

If one applies this model to the understanding of Physics problems, one may suggest that the expert first examines the problem statement to establish the problem type. The problem type is established by recognition of particular syntactic patterns. Recognition of these patterns is driven by the expectation that the problem is a Physics one. In Figure 3-4, the broken underlining marks patterns which give an indication of the problem type.

Once the problem type has been established, an appropriate frame or schema will have been selected<sup>3</sup>. The expert then tries to match syntactic patterns which could hold important information needed to solve the

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3. This idea is supported by the work of Anderson, Greeno, Kline and Neves (1981) who discuss schema-based problem solving in mathematics.

problem. These patterns are indicated by the solid underlining in Figure 3-4. When a pattern is matched, detailed semantic processing follows, during which the data are slotted into the frame or schema in a way which will be useful for later solution of the problem.

---

A block which has a mass of 10 kg is subjected to a horizontal force of 10 N. Calculate its acceleration.

**Figure 3-4: Illustration of syntactic patterns.**

---

This process of re-representation is in agreement with Larkin, McDermott, Simon and Simon's (1980) linked lists and production system analogy of human memory. The linked lists in their case make up the schema and the condition parts of the production rules are analogous to the patterns. Novak's work (1977) illustrates the efficacy of frames in problem-solving, and McDermott and Larkin (1978) and Larkin (1981b) discuss the importance of the internal representation.

During the final stage, viz., semantic processing of the patterns, the meanings of the words are examined. Within the limited context of the schema established by this time, alternative meanings are generally not even considered. For example, the word "block" in Figure 3-4 is taken to refer to an object of regular shape and is associated with the drawings frequently seen in elementary Physics textbooks. Meanings associated with phrases such as "block and tackle", "city block" and others are not even considered in this context. The ambiguities do not arise because the vocabulary associated with the frame being instantiated does not readily include those meanings.

### **3.5. ALBERT's natural language processing system**

The natural language processing system used by ALBERT does not entail rigorous syntactic processing. It is intended to parallel the cognitive model described above, rather than a linguistic one. In this regard, the language system of ALBERT is designed to operate within the stereotyped

situation of a one-dimensional kinematics problem. It searches for syntactic patterns which are known to hold important information in this context and uses the data extracted from them to instantiate a frame which represents the problem. A contextualized vocabulary is used to provide an unambiguous link between the pattern recognition system and semantic interpretation by which the frame is instantiated.

This approach is believed to be novel in natural language processing in that it surpasses the keyword and key phrase recognition systems but stops short of full syntactic processing in terms of a formal grammar. The system has been proved to be effective and robust within the domain of interest.

### 3.5.1. Overall structure of ALBERT's NL processor

In ALBERT, it is assumed that the problem-type has already been identified. ALBERT thus works with a specific frame or schema, a contextualized vocabulary and an associated set of syntactic patterns.

The natural language processor built for ALBERT comprises the six elements shown in Figure 3-5. A flexible text editor is provided for the typing in of the problem statement and for the editing of it, should that be required. From the text editor, the problem statement is handed to the lexical analysis routine which establishes the word boundaries and converts the input text into an abstract bit representation. This numerical pattern is scanned by the syntactic pattern processor which attempts to find a match with one of the anticipated syntactic patterns. When a match is found, the textual fragment is processed semantically to instantiate values in the appropriate slots of the schema.

Syntactic and semantic processing are interwoven and continue until no further pattern matches can be found. At this stage, if there is sufficient information in the schema to make a solution possible, the problem-solving routines are called.

---

from the text editor

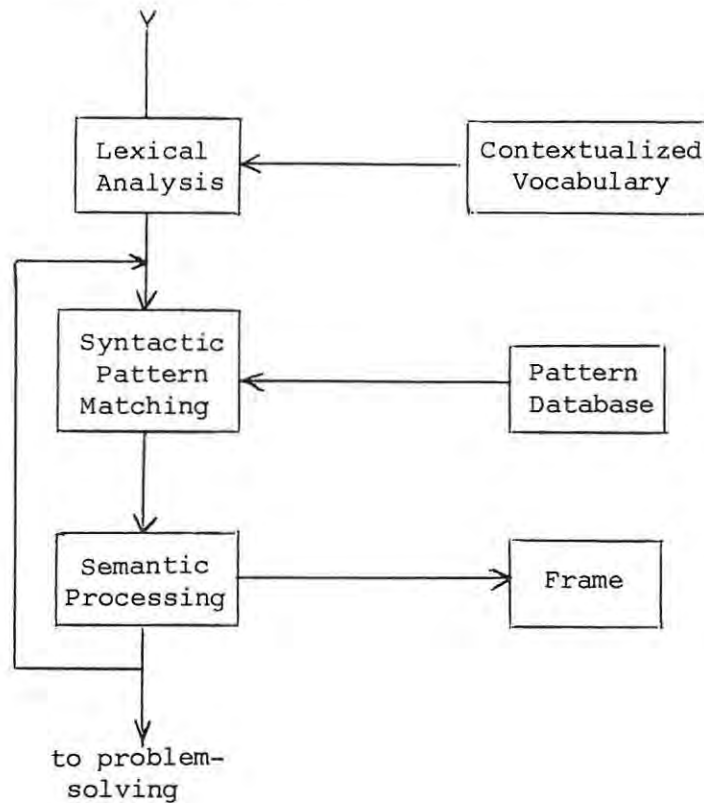


Figure 3-5: Structure of ALBERT's natural language processor

---

### 3.5.2. The text-editor

The PLATO notes editor used for writing inter-user electronic mail is well documented (Control Data, 1982) and can be hooked onto almost any PLATO program, provided that sufficient memory can be made available. For ALBERT, there is the added advantage that the "easy" version of this editor is familiar to most students using the PLATO system, as it forms an important means of communication with their course lecturers.

It was therefore decided to use this as the text-editor for typing in the problem statement. Figure 3-6 shows a typical problem statement typed in using the editor.

---

Please type in the problem:

```
A ball rolls down a hill with a constant acceleration
of 0.3 m.s-2. If it starts from rest, what will be its
speed after it has travelled a distance of 350 m?
```

Press:

NEXT	for the next line	SHIFT-NEXT	when finished
BACK	for the previous line	SHIFT-BACK	to exit and not send
EDIT	to change the line	SHIFT-LAB	to insert a line
HELP	for more directions	SHIFT-HELP	to delete lines

Figure 3-6: The PLATO notes editor

---

The "easy" editor allows correction of typing mistakes using the PLATO "EDIT" and "COPY" keys without having to re-type the text and provides for the insertion and deletion of lines. For ALBERT, a maximum of 8 lines (100 computer words) has been allocated and found to be adequate. (Longer problems can generally not be handled by ALBERT for reasons which are made clear in section 3.6.1.)

### 3.5.3. Lexical analysis in ALBERT

The syntactic patterns in ALBERT are assumed to be general, i.e., any one pattern does not represent a unique set of words in the vocabulary. Lexical analysis in ALBERT thus performs two functions.

- a. It establishes the word boundaries and maps the words into a large pseudo-array for later recovery during semantic processing.
- b. It converts the entire input text into a bit pattern, spanning several computer words. This overall pattern is scanned by the pattern-recognition system for the sub-patterns which are used to instantiate the frame.

### 3.5.3.1. Establishing word boundaries

When the notes editor is used to type in several lines of text, several consecutive computer words, each 60 bits long, are filled by the characters being typed (6 bits per character). One of the problems with the PLATO notes editor is that it places nulls at the end of each typed line. This is done to facilitate the use of the `-text-` command to display the note. However, it means that some words are separated by nulls (octal 00) and others by spaces (octal 55).

For ALBERT, I have chosen to regard the "space" as the unique indicator of a word boundary. The PLATO `-getword-` command is not suitable for extracting the words in the input, as PLATO regards the comma, the slash and others as word boundaries. Nulls are thus undesirable and must be removed. The `-clean-` command will do this but unfortunately removes other characters such as the subscript and superscript as well. This is in turn undesirable and nulls are removed by first finding all occurrences of nulls (o00) using the `-findall-` command and then using `-pack-` to put a space (o55) at the end of the word. (The original text is preserved for editing purposes.)

Once the nulls have been converted to spaces, the `-search-` command can be used to find all the word boundaries and each word of input is transferred to a large pseudo-array using the `-move-` command. In the array, each word of input is allocated two computer words of storage. This allows a maximum input word length of 20 characters, which has not been found to be a limitation.

The `-findall-` command and the `-search-` command are extremely fast and this process takes less than 50 ms on average for a four-line problem statement.

### 3.5.3.2. The contextualized vocabulary

The TUTOR language allows one to establish a large vocabulary of words at the start of a program. The `-concept-` command can then be used to check the student's answer for a particular word or its synonyms. "User information" in the form of a number may be associated with any word in

the vocabulary. When the word is matched, the number can be assigned to a variable. ALBERT makes use of this to establish an overall bit pattern for the problem.

The vocabulary for ALBERT is set up as one enormous list of synonyms. The list was assembled by analysis of 1-D kinematics problems in several elementary Physics and Applied Mathematics textbooks (Kane and Sternheim, 1984; Warren, 1979; Fleming, 1978; Cromer, 1974; Bueche, 1972; Bueche, 1969; Freeman, 1968; Shortly and Williams, 1965; Broad, 1965; Sears and Zemansky, 1957) and various computer lessons (Wits, 1982; Control Data SA, 1982). A different list of synonyms would be associated with a different problem-solving context.

Within the vocabulary thus established, words are grouped into classes according to their functional significance in 1-D kinematics problems and assigned a user information number accordingly. For example, words describing fixed objects have the number 1 associated with them. Moving objects are in class 2 and words which imply assignment are in class 6. At present there are approximately 430 words and 22 classes of words in the vocabulary. For a different type of problem, the classification would be different.

Table 3-1 shows how the classes of words have been defined. Appendix A contains ALBERT's vocabulary.

An overall pattern of the words in the problem statement is produced by matching each word in turn using the `-concept-` command and so assigning the user information number associated with each word to consecutive 6-bit segments of a succession of computer words. Figure 3-7 illustrates the formation of such a bit pattern.

Numbers in the input text are not matched against the stored vocabulary. Instead, they are trapped using the `-ansv-` command and assigned to class 11. (`ansv 0.0,1010` is used to accept any number with an absolute value of less than  $10^{10}$ .) Unrecognized words produce a 00 six-bit segment in the pattern.

ALBERT performs a rudimentary check for unrecognized words of certain

types. For example, a human expert can infer from the sentence, "a zikaboo is thrown straight up into the air", that a "zikaboo" is a moving object in this context. ALBERT comes to a similar conclusion by considering the classes of words around the unknown one. This aspect has not been developed to any great extent because of the dangers associated with it.

- 1 - objects which do not move, e.g., table, tree, plane; also certain abstract concepts, e.g. gravity, coordinate.
- 2 - moving objects, e.g., block, car, train.
- 3 - physical quantities, e.g. mass, force, time; also instances, e.g. point, instant.
- 4 - verbs and words indicating motion, e.g., moves, travelling; did, could, had; experience, subjected.
- 5 - adjectives relating to forces, e.g., rough, smooth, inclined.
- 6 - assignment words, e.g., is, equals.
- 7 - articles, a, the, an.
- 8 - adverbs of speed and direction, e.g., along, slow, away.
- 9 - referents, e.g., its, that.
- 10 - units, e.g., m/s, ft, kg.
- 11 - (unassigned, used for pure numbers.)
- 12 - words indicating elapsed time, e.g., taking, until, for.
- 13 - questions, e.g. what, how, find, calculate.
- 14 - spatial configuration, e.g., top, bottom.
- 15 - connectives, e.g. and, which, if.
- 16 - words relating to magnitude, e.g. increasing, decreases, uniform; big, small; motor, toy.
- 17 - position/direction, e.g. on, positive, backwards.
- 18 - negatives, e.g. not, can't.
- 19 - zero speed special cases, e.g. stops, resting.
- 20 - implied gravitation, e.g. falls, drops.
- 21 - first person, e.g., I, my, let's.
- 22 - interjections, e.g., yes, no, wow, gee.

Table 3-1: Classification of words in the contextualized vocabulary

---

Input text:      A block of mass 10 kg is subjected to a force of 5 N.

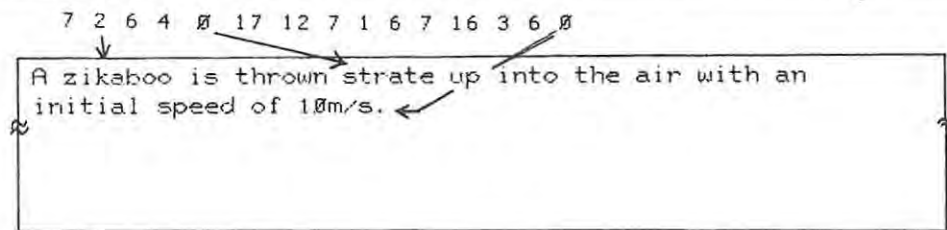
Numerical pattern:      07 02 06 03 11 10 06 04 17 7 3 6 11 10

(The numbers are the decimal values of each 6-bit segment of successive 60-bit computer words.)

**Figure 3-7: A problem statement and the corresponding numerical pattern**

---

If there are any zeros in the overall pattern, the associated words are pointed out to the user who is then requested to edit the problem statement. Figure 3-8 illustrates this. (Note that the word "zikaboo" has been assigned to class 2 by inference.)



There is a problem with the following words:

"strate" Unrecognised word.

"10m/s" There must be a space between number and units.

**Figure 3-8: Unrecognized words and inference**

---

When an overall pattern containing no zeros has been produced, lexical analysis is complete.

#### 3.5.4. Syntactic pattern matching in ALBERT

The overall pattern of the problem statement thus produced contains sub-patterns some of which are more important than others. It is the task of the pattern matching routine to identify these sub-patterns within the input text.

The important characteristic patterns in 1-D kinematics problems were identified by further analysis of the textbook problems. Figure 3-9 shows some examples of the patterns. A full list is given in Appendix B.

---

Pattern 1: 03 06 11 10

Examples: mass of 10 kg; velocity is 3 m/s; displacement equals 5 m

Pattern 2: 04 17 19

Examples: starts from rest; comes to rest; is at rest;

Pattern 3: 13 16 04

Examples: how long did; how far does; how high would;

Figure 3-9: Examples of syntactic patterns used by ALBERT

---

The patterns are unique and are mutually exclusive in the sense that no pattern can be a sub-pattern of any other. At present there are 51 patterns. The patterns are stored as data and are set up in a large pseudo-array during program initialization. Each syntactic pattern is stored in a pair of 60-bit words. The first word contains the pattern, the second contains information about which semantic routine to use if the pattern is matched. In some cases additional data are stored which are passed as parameters to the semantic routines. Figure 3-10 shows how the patterns are stored.

---

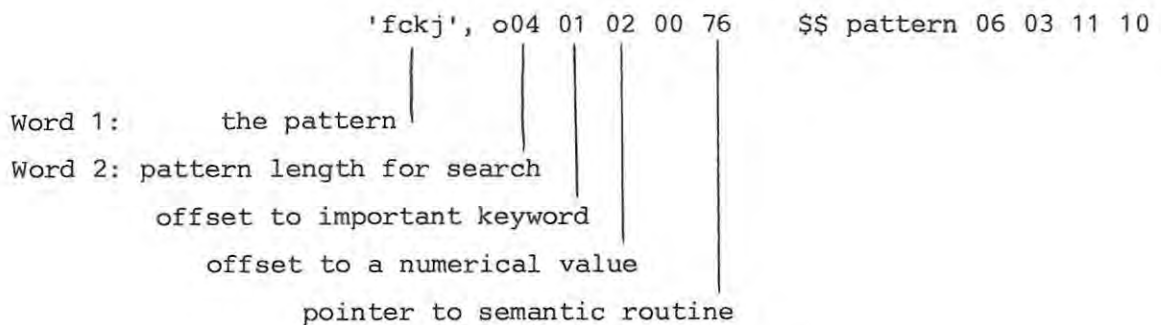


Figure 3-10: Structure of the pattern database

---

In order to "find" a pattern in the input text, ALBERT must "slide" the pattern template along the input text pattern until a match occurs. This process is illustrated in Figure 3-11.

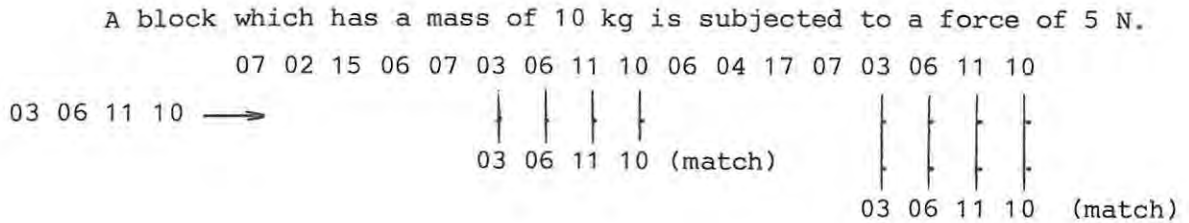


Figure 3-11: Illustration of the pattern matching process

---

Since the patterns are represented by 6-bit elements which also happens to be the number of bits per character for normal text storage, the `-search-` command can be used to perform this task. The `-search-` command will find a string of characters anywhere within a piece of text. It has return arguments which indicate the number of matches if any, and the positions of the matches within the text.

The `-search-` command is very fast, performs exactly the required matching function and is used to test each of the pattern templates on the overall input pattern. If one or more matches are found for a particular pattern template, semantic processing is initiated for those patterns. When this semantic processing is complete, the pattern matching is resumed until all the patterns have been tried.

The syntactic pattern processor is analogous to a production system. The pattern data are the production rules, the first word being the condition part, the second being the action part. When a rule fires (pattern is matched) the action (semantic) part is executed.

### 3.5.5. Semantic processing in ALBERT

The purpose of semantic processing in ALBERT is to instantiate the frame as far as possible from the problem statement. (Further instantiation is achieved by inference when the natural language processor has completed

its task.)

### 3.5.5.1. A framework for representing 1-D kinematics problems

Figure 3-12 shows the frame used in ALBERT for problem representation.

In 1-D kinematics problems, the problem statement usually contains information about three of the following quantities: initial velocity, final velocity, displacement, time and acceleration. There is also a question which requires the calculation of a fourth. In some problems,

---

moving object: train  
initial velocity: 10 m/s                      final velocity: 5 m/s  
displacement:                                      acceleration:  $-3 \text{ m/s}^2$   
time:    force:  
mass:    average velocity:  
change in velocity:  
question asked: displacement

direction of frame of reference: to the right

knowledge of what is known (10-bit binary pattern):

1	1	0	0	1	0	0	0	1	
$v_0$	$v_f$	$x$	$t$	$a$	$m$	$F$	$v_{av}$	$\Delta v$	question

---

equations:

$$\begin{aligned}v_f &= v_0 + a \times t \\x &= ((v_f + v_0) \div 2) \times t \\x &= v_0 \times t + \frac{1}{2} \times a \times t^2 \\v_f^2 &= v_0^2 + 2 \times a \times x \\F &= m \times a\end{aligned}$$

$$\begin{aligned}x &= v_{av} \times t \\v_{av} &= v_0 + \frac{1}{2} \times \Delta v \\v_{av} &= v_f - \frac{1}{2} \times \Delta v \\v_{av} &= \frac{1}{2} \times (v_f + v_0) \\ \Delta v &= a \times t \\ \Delta v &= v_f - v_0\end{aligned}$$

knowledge of which quantities are related by which equations.

---

Figure 3-12: The framework for 1-D kinematics problems

the mass and the applied force are given and Newton's Law must be used to calculate the acceleration. The frame contains slots for all seven of these quantities. (The stored values are the scalar components of the vector quantities in a chosen direction.) A 10-bit binary array (9 quantities and a question) is used to hold separately information about which quantities are known and which are not. This avoids ambiguities associated with default values and makes interrogation more efficient.

Depending on the approach taken to solving the problem, the average velocity and the change in velocity may be calculated. Although these quantities do not generally appear in the problem statement, slots to be filled later by calculation have been included for them in the frame. A slot is also included for the direction of the axis of reference, the type of moving object and the question. The type of object is only stored explicitly for use in text generation.

Also associated with the frame is the set of equations shown, viz. Newton's Law, the four "kinematic" equations of motion, and a set of fundamental relationships between displacement, velocity, acceleration and time. Knowledge of which quantities appear in each equation is stored explicitly as a 9-bit binary pattern (Figure 3-13) to facilitate equation selection in the problem-solvers. The content of the frame represents the full extent of ALBERT's knowledge of the problem and of this aspect of Physics.

---


$$v_f = v_0 + at : \quad 1 \quad 1 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0 = \text{octal } 660$$

$$v_0 \quad v_f \quad x \quad t \quad a \quad m \quad F \quad v_{av} \quad \Delta v$$

Figure 3-13: The 9-bit pattern of knowledge associated with an equation

---

### 3.5.5.2. Identifying the quantities

At the start of the pattern matching process, a search is made for class 2 words (moving objects) in the input text. There should be only one of these. If a word of this type is found, the literal text from the array of input words is transferred into the "moving object" slot of the frame.

If no such word is found, the slot takes on the default value of "object".

The function of the semantic routines is to extract the useful information from those patterns found by the pattern matching routine. There are two steps in this process. First, the quantity being described must be correctly identified, and secondly, the value of the quantity must be obtained.

Figure 3-14 shows the structure of ALBERT's semantic processor.

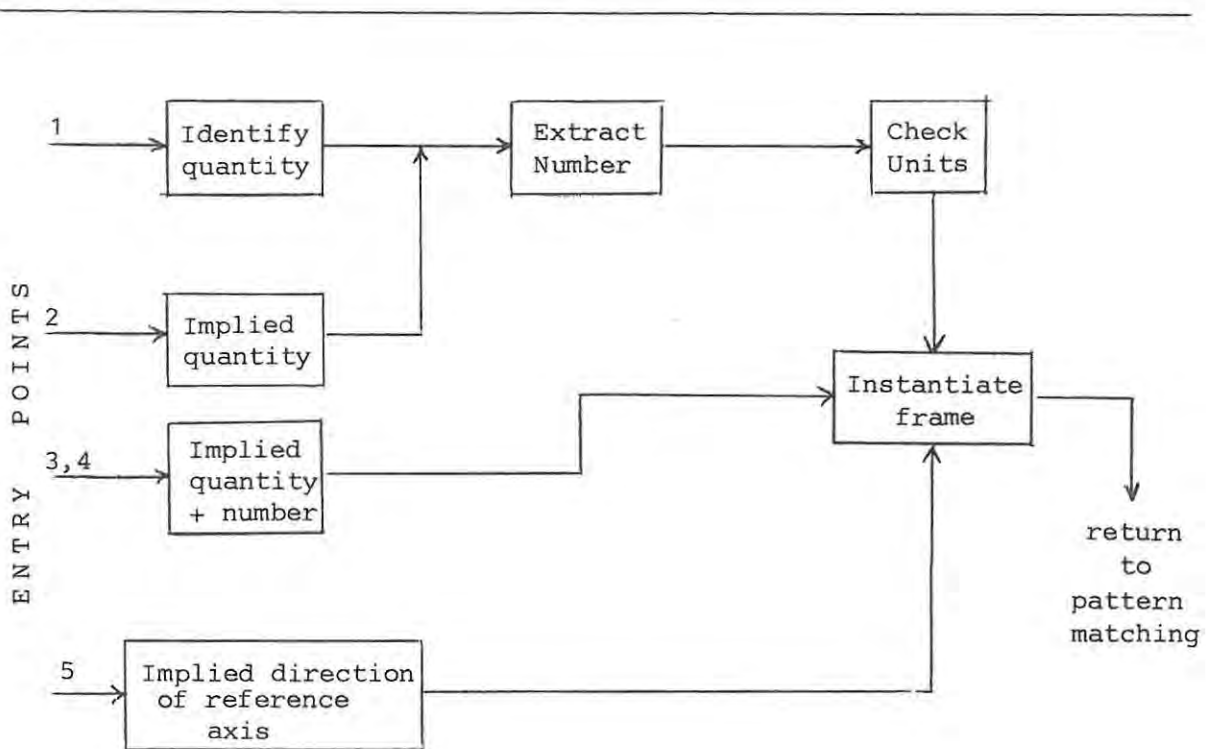


Figure 3-14: Semantic processing in ALBERT

---

There are two broad categories of phrases which correspond to the patterns, viz., those in which the numerical values are explicitly stated and those in which they are not. For example, "the initial velocity is 0 m/s" is equivalent to "started from rest". In cases where the value is explicit, there are two sub-categories, viz., those in which the quantity is explicit and those in which it is not. For example, "10 kg block" implies a "block of mass 10 kg" although the word "mass" does not appear.

Implicitly stated values relate to velocity or gravitational acceleration; the implicitly stated quantities in these problems can be mass, time or velocity.

There are five points of entry into the semantic routines. These correspond to explicit quantity and value, implicit mass/time, implicit velocity, implicit acceleration and a routine to extract explicitly stated information about the frame of reference. The data associated with the syntactic patterns determine the point of entry into the semantic routines for each of these cases.

When the quantity and its value are explicitly stated, the semantic routine called retrieves the word describing the quantity and initiates PLATO judging to determine which quantity it is. This is done by matching the word against a list of synonyms for each quantity. If the quantity can be identified, a pointer is set up to the appropriate slot in the frame. If the quantity identified is velocity, there is always ambiguity as to whether it is the initial velocity or the final velocity. An attempt is then made to resolve the ambiguity by checking around it for words such as "initial" and "final" or phrases such as "after this".

It is not always possible to resolve the ambiguity immediately. Consider the following example:

"A car moving with a speed of 10 m/s experiences a uniform acceleration of  $3 \text{ m/s}^2$ . What is its speed after 3 s?"

The first phrase examined would be "speed of 10 m/s". ALBERT would not be sure whether this is the initial or the final speed because there is no information in the immediate vicinity of the word "speed" which can be used to resolve the ambiguity. However, when the word "speed" in the question is examined, the phrase "after 3 s" is used to establish the fact that the question refers to the final speed. The ambiguity is then resolved and it can be confirmed that the "speed of 10 m/s" is the initial speed.

ALBERT handles the resolution of these ambiguities by associating a certainty flag with each of the two velocity slots in the frame. If both velocities are unknown and ALBERT is uncertain about the first one found,

it is assumed to be the initial velocity. This can be modified later as is the case in the following example:

"A car moving with a speed of 10 m/s started from rest and experienced a uniform acceleration of  $3 \text{ m/s}^2$ . How long did it take to reach its final speed?"

In this case, ALBERT considers the phrase "speed of 10 m/s" first and assumes that it refers to the initial velocity. However, the uncertainty flag for initial velocity is set to "uncertain". When the phrase "started from rest" is encountered, ALBERT knows for sure that this refers to the initial velocity and infers that the other speed reference must have been to the final velocity. The value of 10 m/s is then transferred to the final velocity slot and the initial velocity slot takes on the value of zero.

Another ambiguity which is easier to resolve is that of acceleration. In some books, a backwards acceleration is referred to as deceleration. If the quantity identified is acceleration, ALBERT checks after the slot has been instantiated to see whether the reference was to deceleration, in which case, the sign of the value is changed<sup>4</sup>.

When velocity is implied, as in the phrase "starts from rest", the semantic routine called determines whether it is initial or final by examining specific words in the phrase and instantiates the slot in the frame. These phrases always allow unambiguous determination of the quantity and leave the uncertainty flag for the slot set to "certain". With these phrases and those for implied gravitational acceleration, values can be instantiated immediately as they are implicit in the phrase.

---

4. The "expert" ALBERT simply notes that the use of the word deceleration implies that there is a backwards acceleration and uses a negative sign with the scalar component. In tutoring students, it is necessary to explore this further in the light of misconceptions about "negative" acceleration which some students have. This point is taken up in section 6.9.1.

Finally, in a few cases, the axis of reference can be established by examining a phrase in the input text, e.g., "down the hill" or "up the plane". Semantic interpretation of such phrases is provided for. However, the direction of the axis of reference is usually ascertained by inference.

### 3.5.5.3. Instantiating the values


In any cases where the value of a quantity is explicitly stated, this must be extracted from the input text. The semantic routine which does this also performs a consistency check on the units. This is explicitly catered for in the TUTOR language by the `-storeu-` command which stores the numerical information in a student's answer as well as dimensional information about the units used.

However, this command has the limitation that it cannot handle units written in the form  $"m.s^{-2}"$ . This is judged to be an illegal format and is rejected by the answer judging routine. To get around the problem, the `-storen-` command is first used to store the numerical part of the response. This does not modify the judging copy. The `-putd-` command can then be used to change all the `"."`'s in the judging copy to `"x"`'s and `-storeu-` then operates in the desired way. This means that  $"m.s^{-1}"$  becomes  $"m \times s^{-1}"$  which is interpreted correctly.

To make the routine as efficient as possible, the dimensions of the units are transferred into 6-bit segments and the `-match-` command is used to compare the patterns thus produced with pre-stored patterns of the units. In the process, a second determination of the quantity specified is obtained. This depends on the dimensions used and should match the slot being filled. If there is a discrepancy, an error message is generated and the user is requested to edit the problem statement as shown in Figure 3-15.

The `-storeu-` command can also be used to do unit conversion, e.g. into SI from any other system. ALBERT automatically converts any quantities in the problem statement into SI units. However, this facility has not been fully developed to handle a discussion in non-SI units, because our students are only required to work on problems stated in SI units.

---



A block of mass 10 m/s is moving

The units of mass are not m/s.

Press shift-HELP and make the necessary changes.  
Press HELP if you don't know what is wrong.  
Press NEXT to start over. (You lose what you typed.)

Figure 3-15: Inconsistent units for the quantity specified

---

When semantic processing is complete, the problem-solving routines are called. They draw on the knowledge in the frame to solve the problem.

#### 3.5.6. User-mediated frame instantiation

It has already been noted that there are two ways in which the language processor can fail to complete its task.

- a. Lexical analysis may fail due to the presence of unrecognized words in which case pattern matching and semantic processing is not initiated. The user must edit the problem statement.
- b. Semantic processing will fail if there are inconsistencies among quantities specified and their units. In this case, the user is also required to edit the problem statement.

However, even when the language processor has run to an apparently successful completion of its task, there may not be enough information in the frame to make a solution possible. (The method by which this is established is described in the next chapter where the solution types are discussed in detail.) When this is the case, the user is immediately so informed and, under certain circumstances, ALBERT permits user-mediated incorporation of additional information.

There are three classes of problem statement for which this situation occurs.

- a. The problem statement is deficient, i.e. it is not possible to solve the problem with the information given. When this happens, there is nothing that can be done to save the situation.
- b. The information is explicitly stated in the text but it is embodied in syntactic patterns which are not a part of ALBERT's repertoire. It will thus not be identified and incorporated into the frame.
- c. The information is not explicitly stated but may be inferred from the problem setting. In this case, the person solving the problem usually draws on knowledge which is outside of the specific domain of the problem. Since ALBERT does not incorporate world knowledge outside of the domain of 1-D kinematics, inferences of this kind are not possible.

ALBERT has been made to approach the second two problems in the following way. First, the problem statement is searched for a number with units which correspond to one of the empty slots in the frame. Consider for example the following problem (Cromer, 1974, page 82 number 15) which illustrates both points b) and c) above:

"When making a vertical jump, a grasshopper extends its legs 2.5 cm in 0.025 s. What is the acceleration of the grasshopper while extending its legs?"

After semantic processing is complete for this problem, the frame would contain information about the time taken and the question asked, viz., Time: 0.025 s; Question: acceleration. The phrase "extends its legs 2.5 cm" would be missed because its syntactic form does not commonly describe displacement in Physics problems. Stated another way, ALBERT does not know about the function of legs and that "extends its legs" is equivalent to "moves a distance of".

However, upon searching through the problem statement, ALBERT would discover that there is an occurrence of a number with the units of

displacement, viz., 2.5 cm and that this slot is vacant. ALBERT, having informed the user that there is insufficient information to solve the problem, will ask the user whether it is true that there is a displacement of 2.5 cm. If the user responds positively, the information will be added to the frame. This makes the assumption that the student has understood the problem statement correctly which is a limitation as mentioned earlier. However, it is felt that this approach is better than asking the student to rephrase the problem statement so that ALBERT will understand it.

The second fact which ALBERT would miss in the above problem is that a grasshopper making such a jump starts from rest. This is an important piece of knowledge about jumping in general which ALBERT does not have. This kind of implicit information which draws on world knowledge almost always relates to the fact that either the initial or the final velocity may be assumed to be zero. In view of this, if the check for sufficiency shows that only one more piece of information is required to make a solution possible and that it cannot be found explicitly stated by searching for it as described above, ALBERT will then hypothesize that it must be that either the initial velocity or the final velocity is zero.

In cases where the final velocity is known or if neither is known, ALBERT will ask the student whether it may be assumed that the initial velocity is zero. If the initial velocity is known, the student will be asked if the final velocity is zero. In the case of the grasshopper, the student would be required to confirm that the assumption about the initial velocity is valid.

If the user chooses not to or cannot confirm ALBERT's findings and hypotheses, ALBERT will ultimately conclude that the problem statement is deficient. In such a case the user is asked to type a new problem and to inform the course lecturer.

Figure 3-16 shows the interaction between ALBERT and a student for the "grasshopper" problem.

---

When making a vertical jump a grasshopper extends its legs 2.5 cm in 0.025 s. What is the acceleration of the grasshopper while extending its legs?

Is the displacement 0.025 m (y/n)? Ok.  
May we assume that the initial velocity is zero (y/n)?

**Figure 3-16: User participation in frame building**

---

ALBERT does not permit user participation in frame building in the case of questions. The question in the problem statement must be properly understood by ALBERT's natural language system. If ALBERT misses the question, the user is required to edit the problem statement or to type in a new problem.

### 3.6. Testing the natural language processor

The two characteristics of a natural language processor which are regarded as being the most important are its speed and its ability to handle a wide range of problems in the domain of interest without student intervention. The system has been tested thoroughly, using numerous problems taken from the textbooks and others contrived to test specific aspects of the system.

#### 3.6.1. Range of problems

Appendix C contains a collection of the problems which ALBERT is known to have understood without user intervention. These problems were drawn from the sources mentioned earlier. The list is open-ended. A representative selection of problems with the instantiated frames is shown at the end of this chapter in Figures 3-17 to 3-21.

It happens from time to time that ALBERT is unable to solve a problem because one or more words in the open lexical categories (nouns, verbs)

cannot be found in ALBERT's vocabulary. When this is the case, the words may easily be added to the appropriate category.

Occasionally a syntactic pattern is encountered which has not been seen before. For example, ALBERT does not provide for syntactic structures with embedded clauses, as in "The initial speed of the block which has a mass of 10 kg is 3 m/s." The initial speed would be missed in this case, although it could be incorporated with the help of the user. This sentence structure is rather unusual in problems of this kind. New patterns templates can easily be added to the database when deemed necessary.

The problems which give the most trouble are those in which assumptions are made about the students' broader world knowledge. These are generally the longer problems and do not occur frequently in elementary textbooks.

### 3.6.2. Speed of processing

The code in the iterative sections of the language processor has been written in such a way as to make it as fast as possible. It runs in PLATO "background" mode which is not normally recommended for instructional lessons. TUTOR programs executing in background mode obtain extra CPU time during each timeslice, if CPU time is available. In principle, a background program would not run at all on a "busy" PLATO system and its performance degrades linearly with the number of simultaneous users.

However, ALBERT only switches into background mode for short periods at a time, less than 1% of a student session. My experience with this kind of judicious use of the background facility on several PLATO installations in the United States and South Africa has been very favourable.

The system was tested for speed with four problems of increasing textual length. In each case, the time in the lexical analysis section and the time in the pattern matching and semantic section was recorded a large number of times. Because pattern matching and semantic processing are interwoven, separate timing of these two sections is not possible.

The results are shown in Table 3-2.

<p>Problem 1: (18 words; 2 lines)</p> <p>A block of mass 10 kg is subjected to a force of 5 N. What is its acceleration?</p> <p>Results:</p> <p><math>n = 100</math> ; <math>t_{lex} = 48</math> ms ; <math>t_{sem} = 320</math> ms ; <math>t_{lp} = 368</math> ms  <math>\sigma_m = 1.7</math> ms ; <math>\sigma_m = 4.2</math> ms</p>
<p>Problem 2: (26 words; 3 lines)</p> <p>A car starts from rest and experiences a constant acceleration of 3 m/s<sup>2</sup>. How far does it travel by the time its speed is 10 m/s?</p> <p>Results:</p> <p><math>n = 100</math> ; <math>t_{lex} = 76</math> ms ; <math>t_{sem} = 416</math> ms ; <math>t_{lp} = 492</math> ms  <math>\sigma_m = 1.2</math> ms ; <math>\sigma_m = 4.2</math> ms</p>
<p>Problem 3: (28 words; 3 lines)</p> <p>A 1000 kg car starts from rest and moves with constant acceleration for 10 s. If it travels 75 m in this time, what force was acting on it?</p> <p>Results:</p> <p><math>n = 100</math> ; <math>t_{lex} = 95</math> ms ; <math>t_{sem} = 474</math> ms ; <math>t_{lp} = 569</math> ms  <math>\sigma_m = 3.6</math> ms ; <math>\sigma_m = 10.3</math> ms</p>
<p>Problem 4: (47 words; 5 lines)</p> <p>A car which has a mass of 1.3 kg is moving with constant speed on a level road, when it suddenly experiences a constant force of 5 N for 12 seconds. After this its speed is 25 m/s. How far did it travel in the 12 second period?</p> <p>Results:</p> <p><math>n = 100</math> ; <math>t_{lex} = 161</math> ms ; <math>t_{sem} = 689</math> ms ; <math>t_{lp} = 850</math> ms  <math>\sigma_m = 5.0</math> ms ; <math>\sigma_m = 11.3</math> ms</p>
<p><math>n</math> = number of samples; <math>t_{lex}</math> = average time for lexical analysis;  <math>t_{sem}</math> = average time for pattern matching and semantic processing;  <math>t_{lp}</math> = average time for language processing = <math>t_{lex} + t_{sem}</math>;  <math>\sigma_m</math> = standard deviation of the mean (<math>\sigma_{n-1}/\sqrt{n}</math>).</p>

Table 3-2: Timing results for ALBERT's natural language processor

Since more than half of the problems on the student problem sheet contain 25 to 31 words, the language processor will take approximately 500 ms to understand the problem statement for most problems which students will type.

The results suggest that lexical analysis takes approximately 3.2 ms per word and that pattern matching and semantic processing takes approximately 18 ms per word. This figure could be used as a rule of thumb, but if a student should spread a 2-line problem over 8 lines by typing fewer words per line, the lexical analysis component would increase by about 12%. From the student's point of view, the language processing takes place along with clearing the screen. There is thus no noticeable delay in response time.

The speed of the system could be increased by optimizing the code further. Also, the syntactic patterns are grouped according to the semantic routines with which they are associated. They are then applied sequentially. If the order were changed to that of frequency of occurrence and if provision were made for terminating the processing when the frame is sufficiently instantiated to allow the problem to be solved, a substantial increase in speed could be achieved. Ultimately, the change will be made, but having the pattern templates grouped as they are is extremely useful for development and testing, and the increased speed is not needed.

### 3.7. Transferability to other domains

It should be possible to transfer this language processing system to other domains, both in Physics and in other subjects. The conversion process is facilitated by the fact that the vocabulary and the syntactic pattern templates are held as data. To make a transfer, the following operations would be necessary:

1. Problems in the new domain would have to be analysed and a new contextualized vocabulary would have to be designed and entered.
2. A new set of syntactic patterns would have to be entered.

3. An appropriate set of semantic routines would have to be written.

In principle, several of these systems could co-exist and a means could be provided for switching the processor from the data for one domain to those for another.

### 3.8. Discussion

In this chapter, I have described a natural language processing system devised for understanding 1-D kinematics problems. This system makes use of a novel approach which is intermediate between a keyword system and a formal natural language system, but which resides closer to the latter and is based on a cognitive rather than linguistic model of language processing.

The system has been shown to work well for a wide range of problems and is fast enough in a conventional programming environment to make its operation appear instantaneous to the user. For those cases where the language system fails, a means has been provided for user intervention to help it complete its task.

Because of the way it has been set up, the system can be converted to handle other domains or multiple domains.

A block of mass 10 kg experiences a force of 5 N.  
What is its acceleration?

(Took 495 ms.)

From the problem statement, we extract the following:

We are considering a moving block.

The acceleration\* is  $0.5 \text{ m.s}^{-2}$ . (a)

The mass is 10 kg. (m)

The force\* acting is 5 N. (F)

We are asked to determine the acceleration.

Answer:

\*(The scalar component of the vector in the chosen direction.)

Press NEXT to do another.

Press shift-DATA for tutorial mode.

Press shift-NEXT to repeat.

Press shift-HELP to edit the problem statement.

or press DATA to see how the problem was solved.

Figure 3-17: Problems which ALBERT understands, example 1

A stone is thrown vertically upwards with an initial  
velocity of 15 m/s. How long will it take to reach a  
height of 8 m?

(Took 438 ms.)

From the problem statement, we extract the following:

We are considering a moving stone.

The initial velocity\* is  $15 \text{ m.s}^{-1}$ . ( $v_g$ )

The displacement\* is 8 metres. (x)

The acceleration\* is  $-10 \text{ m.s}^{-2}$ . (a)

We are asked to determine the elapsed time.

Answer:

\*(The scalar component of the vector in the chosen direction.)

Figure 3-18: Problems which ALBERT understands, example 2

If the brakes of a car are applied when the car is 62 m from a tree and travelling at 18.5 m/s, how long will it take the car to stop, if it comes to rest just before hitting the tree?

(Took 595 ms.)

From the problem statement, we extract the following:

We are considering a moving car.

The initial velocity\* is 18.5 m.s<sup>-1</sup>. ( $v_0$ )

The final velocity\* is 0 m.s<sup>-1</sup>. ( $v_f$ )

The displacement\* is 62 metres. ( $x$ )

We are asked to determine the elapsed time.

Answer:

Figure 3-19: Problems which ALBERT understands, example 3

---

An airplane taking off from a landing field has a run of 370 m. If it starts from rest, moves with constant acceleration and makes the run in 30 sec, with what velocity did it take off?

(Took 542 ms.)

From the problem statement, we extract the following:

We are considering a moving airplane.

The initial velocity\* is 0 m.s<sup>-1</sup>. ( $v_0$ )

The displacement\* is 370 metres. ( $x$ )

The elapsed time is 30 seconds. ( $t$ )

We are asked to determine the final velocity.

Answer:

\* (The scalar component of the vector in the chosen direction.)

Figure 3-20: Problems which ALBERT understands, example 4

A car which has a mass of 1.3 kg is moving with constant speed on a level road when it suddenly experiences a constant force of 5 N for 12 seconds. After this its speed is 25 m/s. How far did it travel in the 12 second period?

(Took 781 ms.)

From the problem statement, we extract the following:

We are considering a moving car.

The final velocity\* is  $25 \text{ m.s}^{-1}$ . ( $v_f$ )

The elapsed time is 12 seconds. ( $t$ )

The mass is 1.3 kg. ( $m$ )

The force\* acting is 5 N. ( $F$ )

We are asked to determine the displacement.

Answer:

Figure 3-21: Problems which ALBERT understands, example 5

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## Chapter 4

### Computer-based Problem-Solving

#### 4.1. Introduction

In order to teach students how to solve problems in one-dimensional kinematics, ALBERT must be capable of solving problems of this kind. This chapter presents the development of two expert problem-solvers for use in ALBERT<sup>5</sup>.

The following are the requirements for a problem-solver in ALBERT.

- a. It must be able to solve the problem and write out a solution, showing the mathematical steps which would be followed by a human expert solving the same problem in that way.
- b. It must be able to monitor the student's progress in solving the problem, even when a different solution path is followed. For this, ALBERT need not check the appropriateness of the path as a whole, but it must be able to check the equations used and the numerical value of any quantity calculated by the student.
- c. If the student is unable to proceed with the solution at any stage, it must be possible to interrogate the expert in ALBERT to obtain a suggestion as to the most reasonable next step, based on the student's present state in the solution process.
- d. The expert in ALBERT should be able to explain why each step in the solution is taken, particularly when making suggestions to the student.

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5. This chapter is concerned with the numerical aspects of problem-solving. In tutoring students, a broader approach is necessary. This is discussed in the next chapter.

The problem-solvers implemented for ALBERT are not intended to be general purpose problem-solvers. They are best described in relation to general problem-solving techniques and work done on automated problem-solving in Physics.

#### 4.2. Problem-solving techniques

In general, problem-solving in artificial intelligence is regarded as a search process (Stefik et. al., 1982). One begins with an initial state and one must end up at a goal state. The most useful strategy for solving a particular type of problem depends on the properties of the problem and on the nature of what constitutes a solution. For example, in a game of chess, the solution is not uniquely defined; there may be many solutions. In Physics, there may be many different solution paths all leading to the same unique answer. Several authors (see for example Ritch, 1984) discuss the popular techniques.

Approaches to problem-solving may be classified by their control strategies and the search algorithms employed. The two major control strategies used are the depth-first search and the breadth-first search. In the depth-first search, a single solution path is followed until it either leads to a dead-end or results in a solution. In the event of failure, the system must backtrack and try another path. In a breadth-first search, all possible solution paths are explored simultaneously, resulting in a tree-like structure which grows rapidly, requires large amounts of memory and is computationally intensive.

Heuristics are frequently used to improve the efficiency of the search. Heuristic searching makes use of knowledge about the nature of a solution to guide the search for a solution. This can make the solution process more efficient by supplying knowledge which can assist in making a choice between paths which appear equally valid.

A search may be forward-directed from the initial states or backward-chaining from the desired final state. The latter approach is often referred to as goal-directed reasoning. The direction of the search is determined by the multiplicity of states at each end. If there is a single start state and many possible solution states, as would be the case

for a game of chess, then a forward directed-search is indicated. When there is a single goal state, as there would be for a Physics problem, and many initial states, a goal-directed search would be preferred. (The many initial states in a Physics problem arise due to the fact that there may be several physical principles each of which could be applied at the start.)

There are several general-purpose strategies of which the two most useful for solving Physics problems are hill-climbing and means-end analysis. In the hill-climbing approach, one picks a path and generates a possible solution. This is tested to see if it is a solution and if it is not, then it is used as the new start state. At each stage the path which shows the most promise is used in an attempt to make the search converge as quickly as possible.

In the means-end analysis approach, the difference between the present state and the goal state is examined and an operator must be found which will reduce that difference. When the operator cannot be applied directly to the current state, it may be necessary to set up a sub-problem which results in a state from which the operator can be applied to arrive at the goal state. Means-end analysis is goal-directed and is commonly used in solving Physics problems (Larkin, 1981a). For example, consider the problem:

"A block of mass 10 kg undergoes a change in velocity of 10 m/s in 5 s. What is the average force on it during this time?"

The means-end approach to this problem would suggest that application of the principle  $F=ma$  would lead us to the goal state. However, since this principle cannot be applied directly, one must first establish the sub-problem of calculating the acceleration. In this case, the definition of acceleration,  $a = \Delta v / \Delta t$ , may be used to achieve the goal state for the sub-problem from which the original goal state may be reached. It is interesting to note that Wickelgren (1974, p244) discusses the solution of a similar problem using a goal-directed hill-climbing approach. The mathematical steps in this case happen to be identical to the means-end approach although the reasoning is different.

The production system is a popular way of implementing a computer-based

problem-solver. A production system consists of three components (Davis and King, 1975), viz. a set of rules, a database, and an interpreter. When a production system is executing, the interpreter evaluates the rules in relation to the database. Each production rule consists of a condition part and an action part. When the condition part of a rule is met, the rule "fires", and its action part modifies the database. This process continues until the database contains a representation of a goal state. Rule-based systems provide a convenient way of modelling the decision making activities of human experts (O'Shea and Self, 1983).

In ALBERT, one of the problem-solvers operates on the basis of a means-end analysis approach, the other employs a forward-directed strategy driven by a limited number of heuristic rules.

#### 4.3. Automatic problem solving in Physics

Several workers, interested in modelling the process of solving Physics problems have produced computer-based problem-solvers. Four examples of such programs worth examining are GEORGE (Cornelius, Cabrol and Cachet, 1985), ABLE (Larkin, 1981a), MECHO (Luger, 1981) and NEWTON (De Kleer, 1977).

##### 4.3.1. GEORGE

GEORGE (Cornelius, Cabrol and Cachet, 1985) runs on an Apple II micro-computer and is intended for use by Chemistry students. However, since it solves problems dealing with mass, volume and the number of moles, it is useful for introductory Physics courses too. The program does not have a pre-stored set of formulae, but relies rather on a set of heuristic rules to solve the problems. GEORGE applies the techniques of dimensional analysis to the problems it is given.

An array is set up which represents the relationships between the fundamental quantities and other quantities which can be calculated, e.g. molar mass. The array includes information about the power to which each fundamental quantity must be raised to express the "desired" quantity or other quantities which can be calculated. GEORGE can thus figure out that the mass of a sample can be found by multiplying its volume by its

density.

GEORGE begins by checking to see whether the fundamental quantities in the desired quantity are also in the data given. If so, a solution is deemed possible and GEORGE tries to solve the problem by examining all possible pairs of quantities in the data given to see whether multiplication or division of any pair results in the desired quantity. This is a breadth-first approach. There is no guarantee that a solution will be found. If a solution is not found in a single step in this way, then all the intermediate results generated by the first step are included in the base of available data and the process is repeated.

In order to focus the search, only certain combinations are allowed to form intermediate results. Useful steps for this purpose are those in which units cancel during multiplication or division.

GEORGE is interesting because it dispenses with formal relationships between quantities and relies on a breadth-wise heuristic search to arrive at a solution to any given problem. Its biggest drawback is that it sometimes produces a solution path which contains redundant steps. Cornelius et. al. (op.cit.) cite at least one such example.

Since dimensional analysis on its own is not sufficient for the derivation of the kinematic equations, it does not seem the problem-solving strategy of GEORGE could be adapted to cope with problems of the kind which ALBERT understands.

#### 4.3.2. ABLE

ABLE (Larkin, 1981a), a program designed to solve elementary Physics problems, is a production system written in OPS, a production system language developed at Carnegie-Mellon University. Its knowledge is encoded as a collection of production rules and it can simulate learning by generalization and learning by proceduralization (Larkin and Simon, 1982). During the "learning" process, new production rules are built. ABLE has been used very successfully to model novice and expert problem solving.

Barely ABLE, the most primitive form of the system, begins the problem-solving process by searching for a physical principle which includes the desired quantity. Once a principle has been found, the elements of the problem statement are compared with the elements of the principle. If only a part of the principle does not match the problem, then this quantity is recognized as being desired and a new search can be initiated for a principle to establish that.

For example, ABLE can solve the problem (Larkin, 1979):

"A block of mass  $m$  starts from rest down a plane of length  $\ell$  inclined at an angle  $\theta$  to the horizontal. If the coefficient of friction between the block and the plane is  $\mu$ , what is the block's speed as it reaches the bottom of the plane?"

ABLE first selects the principle  $v = v_0 + at$ , because it contains  $v$ . Upon trying to match this principle to the problem and the known data,  $a$  and  $t$  will also be flagged as desired quantities, since, if they were known, the problem could be solved. This results in  $F = ma$  and  $x = v_0 t + (1/2)at^2$  being examined. ABLE does not calculate the numerical values of any quantity but merely flags the quantities as known when this is the case, and concludes that the problem has been solved when all the variables are known except the desired quantity.

When learning takes place in ABLE, two or more of the primitive productions are combined to form a new rule which is more specific. This models the ability to recognize a specific situation in which a particular principle can be applied. An example of a more specific rule which ABLE has "learned" is shown in Figure 4-1.

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IF	the goal is to find or justify an expression for pressure drop and there is a density associated with a fluid and there are two points in the fluid separated by a height, $h$
THEN	there is a pressure drop between the two points and its value is $\rho gh$ .

Figure 4-1: A production rule which ABLE has learned (Larkin and Simon, 1982)

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ABLE employs a goal-directed strategy which is essentially a means-end analysis approach. Its lack of algebraic ability and the fact that it cannot adjust its level of competence in both directions would limit its use in a tutorial program such as ALBERT. However, it was not designed for that purpose.

#### 4.3.3. MECHO

MECHO (Luger, 1981) is also designed to solve mechanics problems. It is written in the PROLOG language which is executed as a rule-based system and has become a popular language for the implementation of expert systems for this reason. PROLOG statements provide a convenient way of encoding facts, goals to be tested for truth, and inferences which can be used.

MECHO begins by instantiating a set of schemata (frames) with facts, inferences and default values. The schemata are used as a means of representing the semantics of the problem in a generalized way to allow the solution of a variety of problems of a particular type. (This is precisely the purpose of the natural language system and the frame representation in ALBERT.)

Once the schemata have been established, MECHO solves the problem by means of a goal-directed algorithm which searches back through equations which could be used until a set of equations sufficient to solve the problem is obtained. The search for equations is focussed by considering only those equations appropriate to the particular unknown of interest. The algorithm used produces a queue of equations for consideration and will establish intermediate unknowns when the primary goal cannot be calculated directly.

Like ABLE, MECHO employs a goal-directed means-end analysis strategy. MECHO has also been used to generate solutions for comparison with human problem-solvers.

#### 4.3.4. NEWTON

NEWTON (De Kleer, 1977) solves "roller-coaster" problems which de Kleer defines as "the kinematics of objects moving on surfaces". This program is particularly interesting because it uses qualitative reasoning in a forward-directed problem-solving strategy and resorts to the application of mathematical equations only when its qualitative reasoning can be developed no further. De Kleer developed the program to illustrate his theory of "envisionment" which describes the ability which experts exhibit of being able to say qualitatively how an object might move under a particular set of circumstances.

NEWTON generates a qualitative tree, the nodes of which represent possible positions of the object, and the arcs of which indicate an action which moves the object from one possible position to the next. The quantitative knowledge is stored in frames. Each frame holds a collection of equations which together can be used in one approach to solving problems of this kind. One of the difficulties of this approach is that of creating a viable interface between the two different representations, viz., the qualitative tree and the quantitative frames.

If the qualitative approach cannot be used to solve the problem directly, the tree generated is analysed and transformed into a frame representation. The result is a network of frames which is examined for possible solution paths. Symbolic mathematical techniques are then used to check the validity of the paths until one is found which works. This is characteristic of a "generate-and-test" strategy in problem-solving.

Larkin (1981b) has argued that NEWTON's qualitative reasoning ability is limited by the problem representation which is directly related to familiar objects and actions. Larkin suggests that, if one were to transform the problem into a physical representation when the earlier approach is no longer of use, further qualitative reasoning might be possible.

Both GEORGE and NEWTON employ a forward-directed approach to problem-solving; ABLE and MECHO use a goal-directed strategy. Larkin (1981a) suggests that the latter is more commonly used by human problem-solvers.

As is demonstrated by the systems described above, both techniques have proved useful in automated problem-solving to model human problem-solving activities. The usefulness of ABLE, MECHO and NEWTON in tutoring is limited, as they were not designed for this purpose.

#### 4.4. Solving 1-D kinematics problems

##### 4.4.1. Strategy taught

Generally, students are taught to solve problems of motion with constant acceleration by selecting an equation to use, with reference to the information given, and then putting numbers into the equation to obtain the correct answer. All too often, in this goal-directed means-end analysis approach, the underlying concepts are brushed aside, the emphasis being placed on the numerical answer and its interpretation in terms of outcomes such as the nature of the path, important in its own right.

Lin's work (1979) with students entering M.I.T. showed that many of those taking Physics regarded problem-solving as "mere formula-plugging". Mehl (1985) notes that almost all the students he interviewed attempted to solve problems of this kind by writing down one or more of the kinematic equations and attempting to substitute in the numerical data given in the problem statement. He makes the comment that

"It is apparent that the entire focus of attention is the equations and the numerical data. Once these are ascertained, the problem assumes an entirely mathematical nature with the problem (statement) only being re-read when the student cannot proceed further."

The students generally do not remember the derivations of the equations and also do not later attempt to relate the use of the equations to the fundamental concepts which form the basis of the terms which appear in them. In general, the equations are poorly understood.

To test this assertion, 38 students in the Physics 1s class at Rhodes University were asked to answer the two questions shown in Figure 4-2. (This is the first year class for students who wish to major in Physics. The total number of students in the class is approximately 45.)

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Please answer the following two questions about motion with constant acceleration.

1. The equation  $v = v_0 + at$  may be used to solve the following problem:

"How long does it take a car, moving with a constant acceleration of  $2 \text{ m/s}^2$ , to accelerate from an initial velocity of  $10 \text{ m/s}$  to a velocity of  $20 \text{ m/s}$ ?"

What is your interpretation of the term "at" in the above equation? (For example: Is it the distance travelled by the car?)

2. The equation  $x = v_0t + \frac{1}{2}at^2$  commonly used in problems of this kind may be factorized to give

$$x = (v_0 + \frac{1}{2}at)t.$$

What is your interpretation of the expression  $(v_0 + \frac{1}{2}at)$  in this equation?

**Figure 4-2: Questions about the kinematic equations**

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The results are summarized in Table 4-1.

For question 1, less than half the students mentioned change or increase in velocity when interpreting the term "at". The 6 who made a reference to velocity without qualifying what they meant used statements such as "it is the velocity of the car" and "'at' is velocity", which do not indicate the concept of change. The rest made it clear that they had no idea of what "at" meant. "It is the distance travelled due to the acceleration of the car" said one student; "its (sic) the velocity...after a certain time" maintained three others.

Of the 17 who correctly interpreted the term "at" in the first question, only 4 correctly associated the concept of average velocity with the expression  $(v_0 + \frac{1}{2}at)$ . Of the other 4 who answered correctly, 2 had answered "average velocity" for question 1, and the other two had said that "at" was the instantaneous velocity and the final velocity respectively. Two others, who used phrases such as "the velocity over the distance x" in their answers to question 2 might have come up with the correct answer upon further questioning.

Question 1: Interpretation of "at".	
Concept expressed	number of responses
distance/displacement	2
initial velocity	1
final velocity	3
average velocity	3
change in velocity	17
velocity (vaguely mentioned)	6
instantaneous velocity	1
acceleration	1
time	1
others (mostly described the symbols)	3
Total	38

Question 2: Interpretation of " $(v_0 + \frac{1}{2}at)$ ".	
Concept expressed	number of responses
distance/displacement	2
final velocity	4
average velocity	8
change in velocity	2
velocity (vaguely mentioned)	14
others (mostly described symbols)	6
no comment	2
Total	38

Table 4-1: The results of the "kinematic equations" questionnaire

Most of the students who answered question 2 by making a vague reference to velocity, showed that they came to this conclusion by noting that the expression given was equal to "x/t". (One student whose algebra was not up to this simply suggested that it was "displacement times time"!)

These results illustrate the confusions which students have about the terms in the kinematic equations. My experience, however, has been that students at this level have no difficulty selecting the correct equation to use with a problem such as the one stated in question 1 above. That problem would be regarded as "easy"; and problems of a similar standard are set at high school level<sup>6</sup>.

Reif and Heller (1982) make the following observation which may well explain this in part:

"In the quantitative sciences, a desire for precision often impels instructors and textbooks to overemphasize mathematical formalism at the expense of more qualitative modes of description."

The following examples of advice given to students demonstrate the emphasis on a numerical approach to problem-solving in 1-D kinematics.

Figure 4-3 shows the instructions given to tutors in the Department of Physics at Rhodes University by the member of staff teaching that section of the course (Baart, 1982). Baart notes that the weaker students rely heavily on this recipe whereas the better students are able to solve the problems more readily by applying the general principles they have been taught.

The second example (Figure 4-4) is taken from an Apple II program (Cross, 1982). The approach is very similar to that of Baart (1982). In this program, students are presented with the familiar table which must be completed and related to the usual set of equations.

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6. The problems in Appendix C taken from the SASSC curriculum (Control Data SA, 1982) are intended for High School students.

1. Identify the time period or periods during which the acceleration is constant.
2. For each such period found, construct a table of the information given (as shown) and mark the quantity to be found.

Table of information given:

x =	$v_0 =$	$v_f =$
a =	$t_0 =$	$t_f =$

3. Examine the table and the four kinematic equations and select the equation which contains the three knowns and the one unknown.
4. When the acceleration changes, the initial conditions in the second table correspond to the final conditions in the first.

Figure 4-3: Example 1, recommendations of a Physics lecturer (Baart, 1982)

AN OBJECT TRAVELLING AT 6 M/S IS GIVEN  
AN ACCELERATION OF +2 M/S<sup>2</sup>. HOW LONG  
DOES IT TAKE TO TRAVEL 40 METERS?

TRY TO FILL OUT THE CHART. PRESS

<RETURN> TO CHECK YOUR WORK.

	*INITIAL*	*FINAL*
x	0	40
t	0	
v	6	
A		+2

O.K> NOW LOOK AT THE EQUATIONS. WHICH  
ONE IS BEST FOR FINDING THE TIME?

Figure 4-4: Example 2, a 1-D kinematics Apple program (from Cross, 1982)

The LDEC Physics curriculum (CDC, 1983) includes a lesson which leads the student through a problem of this kind. After several pages dealing with the appropriate selection of an axis of reference and an estimation of the magnitude of the answer, the problem solving activity turns to the identification of the quantities specified in the problem statement and the selection of an appropriate equation which will allow the calculation of the unknown (Figure 4-5). As with the other examples cited, the physical interpretation of what is happening is glossed over at the critical stage.

The approach in the SASSC curriculum on PLATO (Control Data SA, 1982) is even more rudimentary and less formalized.

<p>A ball is thrown vertically upward. It rises to a maximum height of 25 m, and then it comes down. How fast was the ball initially thrown?</p>	C-20
$a = -9.8 \text{ m/s}^2 \quad y_0 = 0 \text{ m} \quad y_m = 25 \text{ m} \quad v_m = 0 \text{ m/s}$ <ol style="list-style-type: none"> <li>1) <math>v = v_0 + at</math></li> <li>2) <math>y = y_0 + v_0 t + \frac{1}{2}at^2</math></li> <li>3) <math>v^2 - v_0^2 = 2a(y - y_0)</math></li> </ol> <p>Using these three relations, look at which parameters you are given. Choose an equation to solve the problem.</p> <p style="text-align: center;">»</p> <p>Hint: You should try to choose an equation with only one quantity you do not know. The only value not known is <math>v_0</math>.</p>	

Figure 4-5: Example 3, a PLATO 1-D kinematics lesson from the LDEC curriculum

It is not difficult to find a textbook in which this approach is taught. The example in Figure 4-6 is taken from Fleming's (1978) section entitled "suggestions for solving problems". The message is clear; find an equation in which the given information can be used.

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► **Example 2.12** A bobsled accelerates in a straight line at a constant rate for 6.0 seconds, from rest to  $12 \text{ m s}^{-1}$ . (a) How far does it travel in 6.0 seconds? (b) How far has it traveled by the time its speed has reached  $20 \text{ m s}^{-1}$  if it maintains the same constant acceleration?

a) Given:

$$\begin{array}{ll} t = 6.0 \text{ s} & a = ? \\ v_0 = 0 & \bar{v} = ? \\ v = 12 \text{ m s}^{-1} & s = ? \end{array}$$

The expression for distance,  $s = \bar{v}t$ , involves the average velocity, which we do not know, and the expression

$$s = v_0t + \frac{1}{2}at^2$$

involves the acceleration, which we do not know. We can find the average velocity from

$$\bar{v} = \frac{v_0 + v}{2} = \frac{0 + 12 \text{ m s}^{-1}}{2} = 6 \text{ m s}^{-1}.$$

Then

$$s = \bar{v}t = 6 \text{ m s}^{-1} \times 6.0 \text{ s} = 36 \text{ m}.$$

Figure 4-6: A textbook approach (from Fleming, 1978)

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Since this is the way students are being taught to solve these problems, one might expect that they would employ a similar approach when attempting to solve them using ALBERT. ALBERT must therefore be capable of producing solutions based on the application of the kinematic equations.

#### 4.4.2. Solution types

There are a limited number of "different" problems which can be generated in terms of the quantities of interest here. (Two problems would be regarded as being "the same" if the same quantities are given in the problem statement and the question asked requires the calculation of the same quantity in each.) For each type of problem, the same equation could be selected every time and the same solution path generated. Table 4-2

lists the twenty possible problem types and shows which equations could be used to solve each. The problem types are grouped into classes according to the question asked.

In the standard approach to 1-D kinematics, the "fifth" kinematic equation is not normally derived. This equation relates  $x$ ,  $v_f$ ,  $a$  and  $t$ , i.e.,

$$x = v_f t - (1/2)at^2.$$

Thus, in cases where the initial velocity is not given, it must first be calculated, as there is no equation relating the other four quantities. Such solutions necessitate the use of two of the equations as indicated in Table 4-2.

As noted in Chapter 2, the acceleration is not given explicitly in some problems. Instead, information is given about the force and the mass, from which the acceleration may be calculated. Alternatively, a problem can be set in which the student is asked to calculate the force, assumed to be constant, from information about the displacement, the velocity etc. In these cases, the solution is very similar to that shown, except that Newton's Law,  $F = ma$  must be used to relate the force, the mass and the acceleration.

Table 4-2: Types of solution using the kinematic equations.

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The kinematic equations:

$$v_f = v_0 + at \quad \dots\dots\dots (1)$$

$$x = (v_f + v_0)t/2 \quad \dots\dots\dots (2)$$

$$x = v_0 t + \frac{1}{2}at^2 \quad \dots\dots\dots (3)$$

$$v_f^2 = v_0^2 + 2ax \quad \dots\dots\dots (4)$$

/ Table 4-2 continues.

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Class 1: find the initial velocity

$v_0$	$v_f$	x	t	a	equation/s	known
?	G	G	G		2	o36
?	G	G		G	4	o35
?	G		G	G	1	o33
?		G	G	G	3	o27

---

Class 2: find the final velocity

$v_0$	$v_f$	x	t	a	equation/s	known
G	?	G	G		2	o36
G	?	G		G	4	o35
G	?		G	G	1	o33
	?	G	G	G	3,1	o17

---

Class 3: find the displacement

$v_0$	$v_f$	x	t	a	equation/s	known
G	G	?	G		2	o36
G	G	?		G	4	o35
G		?	G	G	3	o27
	G	?	G	G	1,2	o17

---

Class 4: find the acceleration

$v_0$	$v_f$	x	t	a	equation/s	known
G	G	G		?	4	o35
G	G		G	?	1	o33
G		G	G	?	3	o27
	G	G	G	?	2,1	o17

---

/ Table 4-2 continues.

Class 5: find the elapsed time

$v_0$	$v_f$	$x$	$t$	$a$	equation/s	known
G	G	G	?		2	o36
G	G		?	G	1	o33
G		G	?	G	3	o27
	G	G	?	G	4,1	o17

G = information given ; ? = question asked ;

known = octal pattern of knowledge in the frame including the question

#### 4.4.3. Requirements for a solution to be possible

If a solution is to be possible at all in problems of this kind, a certain minimum amount of information must be given in the problem statement. The requirements for this may be stated as follows:

1. If one is asked to calculate the force, then one must be given either the mass and the acceleration, or the mass and any three of  $v_0$ ,  $v_f$ ,  $x$  and  $t$ .
2. If one is asked to calculate the mass, the rule is similar, except that mass and force are interchanged in 1. above.
3. If one is asked to calculate the acceleration, then either both mass and force must be given, or any three of  $v_0$ ,  $v_f$ ,  $x$  and  $t$  must be given.
4. If one is asked to calculate  $v_0$ ,  $v_f$ ,  $x$ , or  $t$ , then either  $a$  or both  $F$  and  $m$  must be given along with two other quantities, or all of the other three (not including  $a$ ) must be specified.

In ALBERT, a check is made, before attempting to solve the problem, to ensure that there is sufficient information in the frame to make a

solution possible. ALBERT does this by applying the rules stated above.

One of the slots in the frame is a 10-bit array of data which holds information about which quantities are known and whether or not a question has been asked. The data in the first seven bits are arranged as shown in Figure 4-7. If a quantity is known, its bit is set to "1", if it is not known, the bit remains "0".

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$v_0$	$v_f$	x	t		a		m	F
0	0	0	0		0		0	0
		A			B			C

Figure 4-7: Data in the "known" slot of the frame

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The use of this meta-knowledge about the frame serves two purposes. Firstly, it avoids the ambiguities of setting default values in the slots associated with each quantity, and secondly, of more importance here, it facilitates checking what is known and what is not.

Figure 4-8 shows how a simple logical expression may be derived for the sufficiency rules described above in terms of the information in the "known" slot. In the TUTOR language, the rules are implemented by bit-level manipulation of the data in "known".

If C1 or C2 or C3 is true, ALBERT will not attempt a solution. Instead, user-mediated frame-building is initiated as described in section 3.5.6. (ALBERT will also not attempt a solution if no question has been asked or if the answer is known because it is explicitly given in the problem statement.)

When ALBERT is satisfied that the problem can be solved, the problem-solving routines are called.

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1. Let  $P_1$  be the number of bits set in block A of "known".  
Let  $P_2$  be the number of bits set in block B of "known".  
Let  $P_3$  be the number of bits set in block C of "known".
  2. Let  $C_1$  be true if the question is in block B and  $P_3 < 2$  and  $P_1 < 2$ .  
Let  $C_2$  be true if the question is in block A and  $(P_1 + P_2) < 3$  and  $P_1 < 2$  or  $P_3 < 2$ .  
Let  $C_3$  be true if the question is in block C and  $(P_2 + P_3) < 2$  and  $P_1 < 3$  or  $P_3 < 1$ .
  3. If  $C_1$  or  $C_2$  or  $C_3$  is true, then there is not enough information to solve the problem.

Figure 4-8: Logical formulation of the sufficiency rules

---

#### 4.5. ALBERT's problem-solver type I

A problem-solving routine has been written for ALBERT which can solve 1-D kinematics problems using the approach described above. Figure 4-9 is a block diagram of this routine, the solver type I.

##### 4.5.1. Equation selection

The problem-solver is driven by the data in the "known" slot. Instead of checking each of the quantities explicitly and individually, as one would do in a conventional serial program, the pattern of bits in "known" is considered as a whole. From Table 4-2, it may be seen that for each given pattern of knowledge a unique selection of an equation can be made, with the exception of the case where the pattern corresponds to the octal number 17 (o17), in which case the goal is pushed onto a stack and a sub-goal is set for which an equation can be selected uniquely. For example, if the final velocity, the acceleration, and the time are given, and the initial velocity is required, the pattern in "known" is o33 and equation 1 can be used (see Table 4-2). In every case where these four quantities are involved, the pattern will be o33 and equation 1 will be selected.

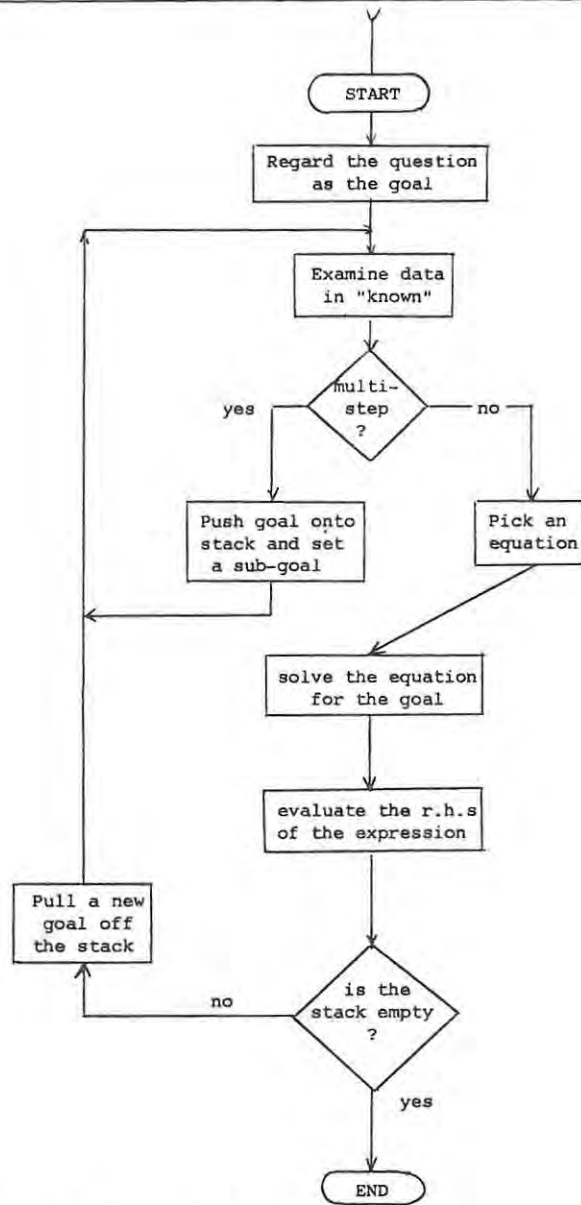


Figure 4-9: ALBERT's problem-solver type I

The pattern of knowledge represented by "known", including the bit corresponding to the desired quantity, is used to point to an equation. If the question is in block B or block C (Figure 4-7) and all three bits are set in those two blocks, i.e. a, m, and F then the problem requires a simple application of Newton's Law, equation 5. If a total of four bits are set in blocks A and B, and the question is in block A or block B, then the octal pattern of "known" is used as a pointer to one of the four kinematic equations.

If the pointer is 017, the question is pushed onto a stack and a sub-goal is set to calculate the initial velocity. If the question lies in block A or block B but there are three bits set in these blocks and two bits set in block C, then the question is pushed onto the stack and the acceleration is set as a sub-goal. In both cases, an equation can then be found to calculate the sub-goal and, upon retrieval of the original question, an equation can be found to calculate it. The goal stack is three levels deep, the maximum required in these problems.

#### 4.5.2. Formula manipulation

Once an equation has been selected, a routine is called which performs algebraic operations on the equation to make the goal the subject of the formula. The routine written for this purpose is adequate for the task at hand and probably for many other applications in Physics instruction, but it is limited by the following restrictions:

- the equation must include an equals sign;
- multiplication must be explicitly indicated by means of an operator;
- the goal must appear only once if the equation is linear;
- the goal may appear twice if the equation is quadratic.

The TUTOR `-search-`, `-pack-` and `-move-` commands are used to identify the terms and to juggle them around. Routines also are provided to remove unnecessary brackets and to perform square root operations. The routine returns as a string of text the righthand side of the equation, i.e., the part which needs to be evaluated.

#### 4.5.3. Answer Evaluation

PLATO provides a useful means of evaluating students' answers. If the variables used in the program are defined as "student" variables, then the student may use them when typing in an answer. The TUTOR command `-store-` will "evaluate" the student's input and store a number in any specified variable.

In ALBERT, I have defined the variables associated with the slots in the frame in a student define set and used symbols for them which correspond exactly with the symbols in the equations. The righthand side of the

equation is thus loaded as though it were a response typed in by a student and it is then evaluated by using the `-store-` command to save it into the desired slot of the frame. The routine which performs this operation is only seven lines of code, two of which are used to convert special symbols to compatible forms.

When the answer has been evaluated successfully, the corresponding bit in "known" is set to "1" to indicate that the quantity is now known and the stack is examined to see if there are any outstanding goals. If there are, an equation is sought for the new goal; if not, the solution is complete. For quadratic equations and square roots, where two answers are possible, both are generated (Figures 4-14 and 4-17).

Figures 4-12 to 4-17 at the end of this chapter show sample output from the type I problem-solver. In writing out these solutions, ALBERT does not modify the numerical values to show the correct number of significant figures. This defect should be remedied in due course, but in the discussion with students, a degree of flexibility is built in to allow for students who round their answers to the correct number of significant figures. One of the difficulties from ALBERT's point of view, is determining from the problem statement the most appropriate number of figures to use. For example, the elapsed time is often specified as a single digit, e.g., 5 seconds.

When the problem is over-specified (four quantities known in blocks A and B), ALBERT assumes that the information given is self-consistent and opts for the "easiest" solution path, making use of either equation 1 or equation 2 (Figure 4-25). These paths are believed to be easy because the equations are the least complex of the four and are the easiest to interpret in terms of the fundamental concepts expressed in their terms. ALBERT ignores redundant information.

#### 4.6. An alternative approach

It is also possible to solve problems of this type without the use of the kinematic equations. One may apply the following two facts:

1. Since the acceleration is constant, any change in velocity is equal to acceleration multiplied by the time interval, i.e.,  $\Delta v = at$ . This re-statement of kinematic equation 1 is easy to relate to the definition of acceleration.
  
2. Since the acceleration is constant, the velocity changes linearly with time and the displacement is equal to the average velocity multiplied by the time interval, i.e.,  $x = v_{av} t$ . This re-statement of equation 2 is easy to relate to the concepts of displacement, velocity and time.

The student is expected to know the definition of average velocity and should be aware that  $v_{av} = (v_f + v_0)/2$  in this case, because the velocity changes linearly with time since the acceleration is constant.

It is more difficult to find authors who advocate this approach to solving problems of this kind. Broad (1965), one who does, presents a series of worked examples on this topic and then notes that "all the above examples have been solved without the use of formulae and it is recommended that students in general adopt this method". Sherwood, in one of his PLATO lessons (1972), demonstrates that the use of this approach is not only more direct but is also mathematically easier.

#### 4.6.1. Solution types

The two facts quoted above together with Newton's Law can be used to solve any of the 1-D kinematic problems. For example, consider the problem:

"A car starts from rest and moves with a constant acceleration of  $3 \text{ m/s}^2$  for 5 seconds. What is its velocity after this time?"

Solution:

Since  $\Delta v = at$ ,  $\Delta v = 15 \text{ m/s}$ . Since the initial velocity is zero, the velocity after 5 seconds must be  $15 \text{ m/s}$ , in the direction of the acceleration.

The traditional approach to solving this problem would have been:

"Pick equation 1 because it contains the three quantities which are given, viz.  $t$ ,  $a$ , and  $v_0$ , and the quantity we are asked to find, viz.,  $v_f$ ." (Putting in the numbers yields the same answer.)

Although the two solutions use the same equation, the first approaches the problem by trying to understand what is happening and applies the definition of acceleration. I believe that this approach is preferable to the traditional one in that it helps students gain a better understanding of the Physics of 1-D kinematics.

Table 4-3 shows the form the solutions take when the alternative approach is used.

---

Type 1: Given three of  $v_0$ ,  $v_f$ ,  $t$  and  $a$ ,

a. find  $v_0$ .

There is a change in velocity  $\Delta v = at$  which can be calculated.

Since  $\Delta v = v_f - v_0$ ,  $v_0$  can be found.

b. find  $v_f$ . (As for finding  $v_0$ .)

c. find  $t$ .

We know that  $\Delta v = at$  and  $\Delta v = v_f - v_0$  which can be calculated.

Hence we can find  $t$ .

d. find  $a$ . (As for finding  $t$ .)

---

Type 2: Given three of  $v_0$ ,  $v_f$ ,  $x$ , and  $t$ ,

a. find  $v_0$ .

The displacement is  $x = v_{av}t$ . Hence we can find  $v_{av}$ .

Since  $v_{av} = (v_f + v_0)/2$ ,  $v_0$  can be found.

b. find  $v_f$ . (As for finding  $v_0$ .)

c. find  $x$ .

The displacement is  $v_{av}t$ . Since  $v_{av} = (v_f + v_0)/2$ ,  $v_{av}$  can be found and hence  $x$ .

d. find  $t$ . (As for  $x$ .)

---

Type 3: Given three of  $v_0$ ,  $x$ ,  $t$ , and  $a$

a. find  $v_0$ .

The displacement is  $x = v_{av} t$ . Hence we can find  $v_{av}$ .

$v_{av} = v_0 + \Delta v/2$ . Since  $\Delta v = at$ ,  $\Delta v$  can be found and hence  $v_0$ .

b. find  $x$ .

The displacement  $x = v_{av} t$ .  $v_{av} = v_0 + \Delta v/2$  and

$\Delta v = at$ , so  $v_{av}$  can be calculated and hence  $x$  can be found.

c. find  $t$ .

The displacement  $x = v_{av} t$ .  $v_{av} = v_0 + \Delta v/2$  and

$\Delta v = at$ , so by substituting back,  $x = v_0 t + at^2/2$  from which  $t$  can be found.

d. find  $a$ .

The displacement is  $x = v_{av} t$ . Hence we can find  $v_{av}$ .

$v_{av} = v_0 + \Delta v/2$ , from which we can find  $\Delta v$ . Since  $\Delta v = at$ ,  $a$  can be found.

---

Type 4: Given three of  $v_f$ ,  $x$ ,  $t$ , and  $a$ ,

a. find  $v_f$ .

The displacement is  $x = v_{av} t$ . Hence we can find  $v_{av}$ .

$v_{av} = v_f - \Delta v/2$ . Since  $\Delta v = at$ ,  $\Delta v$  can be found and hence  $v_f$ .

b. find  $x$ .

The displacement  $x = v_{av} t$ .  $v_{av} = v_f - \Delta v/2$  and

$\Delta v = at$ , so  $v_{av}$  can be calculated and hence  $x$  can be found.

c. find  $t$ .

The displacement  $x = v_{av} t$ .  $v_{av} = v_f - \Delta v/2$  and

$\Delta v = at$ , so by substituting back,  $x = v_f t - at^2/2$  from which  $t$  can be found.

d. find  $a$ .

The displacement is  $x = v_{av} t$ . Hence we can find  $v_{av}$ . We can find

$\Delta v$  from  $v_{av} = v_f - \Delta v/2$ , and since  $\Delta v = at$ ,  $a$  can be found.

---

Type 5: Given three of  $v_0$ ,  $v_f$ ,  $x$ , and  $a$

a. find  $v_0$ .

The displacement is  $x = v_{av} t$ .  $v_{av} = (v_f + v_0)/2$  and  
 $\Delta v = v_f - v_0 = at$ . By substituting back,  $x = (v_f^2 - v_0^2)/2a$   
from which  $v_0$  can be found.

b. find  $v_f$ . (As for  $v_0$ .)

c. find  $x$ .

The displacement  $x = v_{av} t$ .  $v_{av} = (v_f + v_0)/2$  from which  $v_{av}$   
can be found. Also  $\Delta v = at$  and  $\Delta v = v_f - v_0$  from which  $t$  can  
be found and hence  $x$ .

d. find  $a$ .

The displacement is  $x = v_{av} t$  from which we can find  $t$ .  $\Delta v = at$   
and since  $\Delta v = v_f - v_0$   $a$  can be found.

---

Table 4-3: Types of solution without using the kinematic equations.

---

This approach is forward-directed in that one begins by considering either the definition of acceleration,  $\Delta v = at$  or the relationship between displacement, velocity and time, and tries to find the unknown quantities while moving in the general direction of the goal. There are four solution paths which involve substituting back and in effect deriving two of the kinematic equations. In practice, this need not be confusing for the student and may be easier than remembering the equations or deciding which equation to use.

#### 4.6.2. ALBERT's problem-solver type II

The problem-solver implemented to solve 1-D kinematics problems in this way can be thought of as being rule-based. The following heuristic rules can be used to generate a solution.

- a. IF the displacement is NOT mentioned in the problem statement,  
THEN begin by selecting the equation  $\Delta v = at$ .
- b. IF the displacement is mentioned in the problem statement,  
THEN begin by selecting the equation  $x = v_{av} t$ .
- c. IF the time is NOT mentioned in the problem statement,  
THEN push the question onto the goal stack and set a sub-goal to find  
the time.
- d. IF the current sub-goal cannot be evaluated using the current  
equation,  
THEN pick a new equation.
- e. IF the current sub-goal cannot be calculated using the new equation,  
THEN set a new sub-goal.
- f. IF the current goal can be evaluated and there are more goals on the  
stack,  
THEN pull the next goal off the stack and try to substitute back.
- g. IF there are no more equations available which can be used to  
calculate the current sub-goal,  
THEN substitute back algebraically.

Figure 4-10 is a block diagram of the routine written to implement this problem-solver.

The problem-solver operates in the following way. First, an equation is selected in terms of the initial state of the problem. For this the first two rules, a and b above, are applied. The question is then set up as the primary goal. The data given are examined again and if necessary, the primary goal is pushed onto the primary goal stack and an intermediate primary goal is established. Three stacks are used, a primary goal stack (or question stack), a secondary goal (or sub-goal) stack and an equation stack. An intermediate primary goal is established in cases where rule c above requires that the elapsed time should be calculated first and in problems which are not purely kinematic or purely Newtonian as mentioned

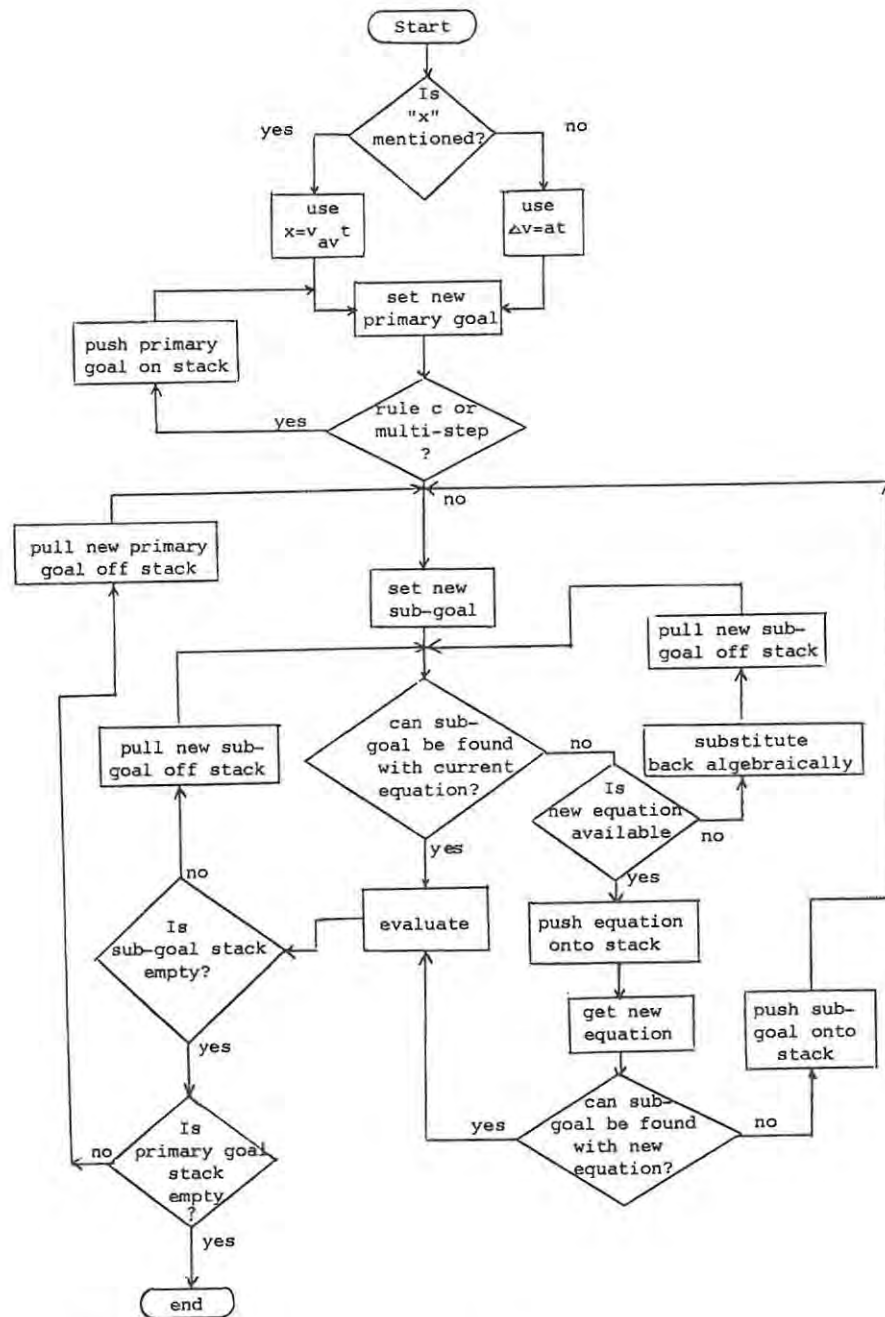


Figure 4-10: ALBERT's problem-solver type II

in section 4.4.2 above.

Once the primary goal has been established, a secondary goal is set up. Initially this would be the same as the primary goal. A check is then made to see whether the secondary goal can be calculated using the equation currently selected. If not, the current equation is pushed onto the equation stack and a new equation is selected using rule d above. If

the current secondary goal cannot be satisfied using the new equation, then the current secondary goal is pushed onto the secondary goal stack and a new secondary goal is established using rule e. This process repeats itself until one of the secondary goals can be satisfied in which case rule f applies or until one is forced to substitute back algebraically (rule g).

Once a secondary goal has been satisfied, a back-tracking process is initiated by pulling an earlier secondary goal and equation off their respective stacks. An attempt is then made to satisfy this secondary goal as described above. When the last secondary goal has been evaluated, the primary goal stack is examined. If it is not empty, then an earlier primary goal must be pulled off it and the process of finding that proceeds. When the last primary goal has been evaluated, the problem is solved.

#### 4.6.3. Equation and goal selection

As with the type I solver, this solver uses the pattern of bits ("known") which represents what is known about the problem. Because of the forward-directed nature of the solving process in this case, the path between certain equations is fixed. For example, if the equation which has just been used is  $v_{av} = v_0 + (1/2)\Delta v$ , then the next equation selected will always be  $\Delta v = at$ . In other cases, where the forward path is not uniquely defined, certain bits of information in "known" are used to point to the next equation.

This is a very different approach from the type I solver. In the type I solver, at each stage, an equation is selected on the basis of what is known and what is desired. This is the goal-directed emphasis. In the type II solver, the equation is selected on the basis of where one is and on what one has been doing. This is characteristic of a forward-directed approach.

If the current goal cannot be evaluated, a new secondary goal is set. Goal selection is always driven by the equation currently selected.

#### 4.6.4. Answer evaluation

The pattern of knowledge which corresponds to the equation selected (section 3.5.5.1, Figure 3-13) is used to determine whether the current goal can be evaluated with the equation currently selected. For this purpose, information about the current goal is included in "known" and the resulting bit pattern is compared bit-for-bit against the pattern of knowledge corresponding to the equation selected using the PLATO mask function. The number of bits matched indicates whether or not the equation can be used to calculate the goal. Figure 4-11 illustrates this.

Given  $v_f$  and  $v_0$ , and with a current goal to calculate  $v_{av}$ , the equation  $v_{av} = (v_f + v_0)/2$  has been selected.

	$v_f$	$v_0$	x	t	a	m	F	$v_{av}$	$\Delta v$
known:	1	1	0	0	0	0	0	0	0
known with goal included:	1	1	0	0	0	0	0	1	0
knowledge in equation (o602):	1	1	0	0	0	0	0	1	0

Number of bits matched in (2) and (3) is 3; goal can be evaluated using the equation selected.

Figure 4-11: Equation checking for possible goal evaluation

Once it is found that an equation can be used, the routines described in sections 4.5.2 and 4.5.3 are used to manipulate it algebraically and to evaluate it numerically. One additional routine had to be written for this solver, to provide the facility for algebraic substitution of one equation into another. This is also implemented using the PLATO -search-, -pack- and -move- commands and an appropriate pattern representing the "knowledge" in the new equation is constructed from the patterns for each of the constituent equations forming it.

The solver type II is set up so that it can perform a single step at a time and it may be called in that way from anywhere within ALBERT. This facilitates interrogation as its registers may be examined after each step

to obtain information about the current primary goal, the current secondary goal, the current equation, whether the equation can be evaluated for the secondary goal, whether to start back-tracking to earlier goals and equations, and whether or not to substitute back algebraically.

Figures 4-18 to 4-23 at the end of the chapter show typical output generated by the type II solver for the same problems used in Figures 4-12 to 4-17. This type of output is not shown to the student. It shows the current major goal at each stage, the current sub-goal and the equation being considered. When an answer is calculated, it is sometimes possible to backtrack (Figure 4-21) to an earlier sub-goal and equation and on occasions one must substitute back (Figure 4-20). Figure 4-24 shows an example of the application of the "time" rule (rule c).

Over-specification of the problem and redundant information is treated in the same way as for the type I solver, viz., it is assumed to be self-consistent and the "easiest" solution path is generated (Figure 4-25). However, due to the forward-directed nature of this solver, if there is a shortage of information, it can loop endlessly. However, the check that there is sufficient information to solve the problem, prevents this from happening in ALBERT.

#### 4.7. Testing ALBERT's problem-solvers

The two problem-solvers are both accurate and fast. They have been tested for every possible combination of given data and have not been known to crash or to produce an incorrect answer. They have solved correctly every example which the natural language system has been able to understand.

It should be noted that the solutions as written by the solvers and shown at the end of this chapter are not necessarily for student viewing, although students may request ALBERT to generate a model solution at the end of a session.

Table 4-4 shows the results of the speed tests for both solvers, using the problems shown in Figures 4-12 to 4-16.

Example 1 (Figure 4-12): (100 samples)

Time for solver type I =	70 ms	$\sigma_m =$	1.7 ms
Time for solver type II =	74 ms	$\sigma_m =$	1.9 ms

Example 2 (Figure 4-13): (100 samples)

Time for solver type I =	261 ms	$\sigma_m =$	2.5 ms
Time for solver type II =	265 ms	$\sigma_m =$	2.7 ms

Example 3 (Figure 4-14): (100 samples)

Time for solver type I =	181 ms	$\sigma_m =$	2.5 ms
Time for solver type II =	203 ms	$\sigma_m =$	2.0 ms

Example 4 (Figure 4-15): (100 samples)

Time for solver type I =	125 ms	$\sigma_m =$	2.1 ms
Time for solver type II =	222 ms	$\sigma_m =$	2.5 ms

Example 5 (Figure 4-16): (100 samples)

Time for solver type I =	177 ms	$\sigma_m =$	2.6 ms
Time for solver type II =	160 ms	$\sigma_m =$	3.0 ms

$\sigma_m =$  standard deviation of the mean ( $\sigma_{n-1}/\sqrt{n}$ )

Table 4-4: Results of speed tests for the problem-solvers

These results show that the type I solver is slightly faster in every case except example 5. This is partly because of the way the type II solver is set up with a single step approach in mind. However, in certain cases such as example 5, the type II solution is easier and hence marginally quicker than the type I solution. The time is of course not related to the number of words in the problem statement, but it is interesting to note that the time taken on example 5, a three-step solution, is less than that for example 2, a single-step solution.

The solvers are used to calculate the answer to the problem before the tutorial starts, i.e. immediately after the natural language processor has completed its task. This process thus adds approximately 300 ms on average to the delay between typing in the problem and the first screen of the tutorial. However, as has been noted already, this takes place along with a full screen erasure and a jumpout to the second lesson which contains the tutorial part of ALBERT. Both the erasure and the jumpout are slow. The natural language processor and the problem-solving routines do not introduce a noticeable delay in those operations.

#### 4.8. Discussion

In this chapter, I have described the two expert problem-solvers to which the ALBERT tutorial system has access. One of these is goal-directed in its approach. It solves kinematics problems in much the same way as students are generally encouraged to do. Its primary functions are in writing out model solutions and in performing rapid checks of student answers.

The second problem-solver operates in a forward-directed manner. It solves kinematics problems by considering the changes in velocity and the displacement. This problem-solver is designed as the basis for teaching a more fundamental approach to solving kinematics problems and can explain its solutions in a step-wise fashion. It has been set up in such a way that it can be interrogated from any point in ALBERT and is designed to provide help and suggestions during the problem-solving activity.

The most severe limitation of this problem-solver is that, while it is able to explain what it is doing, it cannot explain why it is doing it.

This gives it the ability to make suggestions to a student without being able to offer reasons as to why the suggestions are valid or good. It is in this area that programming languages such as LISP and PROLOG come into their own. However, it might be possible to find a way of incorporating the necessary knowledge into a problem-solver within a traditional environment such as this. For this, a system for separating the domain specific knowledge from the problem-solving operations would have to be devised.

Apart from this limitation, the two problem-solvers meet the requirements laid out in section 4.1 and both problem-solvers have been demonstrated to be completely reliable and fast enough for ALBERT. They are quite specific to the domain in which they operate, although the techniques employed could be applied elsewhere. The routines written to perform the algebraic operations are generally applicable and, in spite of their limitations, could probably be used without modification in almost any area of Physics.

The language system and the problem-solvers can be used independently of the rest of ALBERT and as a unit provide a useful environment for experimenting with kinematics problems. The quantities given can be changed quickly and their effects observed immediately.

---

A block which has a mass of 3 kg is subjected to a force of 6 N. What is its acceleration?

From the problem statement, we extract the following:  
We are considering a moving block.  
The mass is 3 kg. (m)  
The force\* acting is 6 N. (F)  
We are asked to determine the acceleration.

We use  $F=m \times a$ .  
We solve for a.  
This gives  $a = (F) \div m$   
Hence  $a = 2 \text{ m.s}^{-2}$ .  
This is the answer required.

Figure 4-12: ALBERT's problem-solver type I, example 1.

A motorcycle starts from rest and moves with constant acceleration for 30 seconds. If in this time it covers a distance of 250 m, what is its final velocity?

(Took 470 ms.)

From the problem statement, we extract the following:

We are considering a moving motorcycle.

The initial velocity\* is 0 m.s<sup>-1</sup>. ( $v_0$ )

The displacement\* is 250 metres. ( $x$ )

The elapsed time is 30 seconds. ( $t$ )

We are asked to determine the final velocity.

We use  $x = ((v_f + v_0) / 2) \times t$ .

We solve for  $v_f$ .

This gives  $v_f = (x/t) \times 2 - v_0$

Hence  $v_f = 16.67$  m.s<sup>-1</sup>.

This is the answer required.

Figure 4-13: ALBERT's problem-solver type I, example 2.

An automobile brakes to a stop in a distance of 75 m. If its deceleration is 2.5 m/s<sup>2</sup>, how long does it take to come to rest?

From the problem statement, we extract the following:

We are considering a moving automobile.

The final velocity\* is 0 m.s<sup>-1</sup>. ( $v_f$ )

The displacement\* is 75 metres. ( $x$ )

The acceleration\* is -2.5 m.s<sup>-2</sup>. ( $a$ )

We are asked to determine the elapsed time.

We use  $v_f^2 = v_0^2 + 2 \times a \times x$ .

We solve for  $v_0$ .

This gives  $v_0 = -\sqrt{v_f^2 - 2 \times a \times x}$

Hence  $v_0 = -19.36$  m.s<sup>-1</sup>.

We then make further use of this answer.

We use  $v_f = v_0 + a \times t$ .

We solve for  $t$ .

This gives  $t = (v_f - v_0) / a$

Hence  $t = -7.746$  seconds.

This is the answer required....there is another answer.

We use  $v_f^2 = v_0^2 + 2 \times a \times x$ .

We solve for  $v_0$ .

This gives  $v_0 = \sqrt{v_f^2 - 2 \times a \times x}$

Hence  $v_0 = 19.36$  m.s<sup>-1</sup>.

We then make further use of this answer.

We use  $v_f = v_0 + a \times t$ .

We solve for  $t$ .

This gives  $t = (v_f - v_0) / a$

Hence  $t = 7.746$  seconds.

This is the answer required.

Figure 4-14: ALBERT's problem-solver type I, example 3.

A car travelling at constant speed is given a constant acceleration of  $0.8 \text{ m/s}^2$  for the next  $10 \text{ sec}$ , during which time it travels  $200 \text{ m}$ . Find its speed at the end of the  $10 \text{ sec}$  interval.

From the problem statement, we extract the following:

We are considering a moving car.

The displacement\* is  $200 \text{ metres}$ . (x)

The elapsed time is  $10 \text{ seconds}$ . (t)

The acceleration\* is  $0.8 \text{ m.s}^{-2}$ . (a)

We are asked to determine the final velocity.

We use  $x = v_0 t + \frac{1}{2} a t^2$ .

We solve for  $v_0$ .

This gives  $v_0 = (x - \frac{1}{2} a t^2) \div t$

Hence  $v_0 = 16 \text{ m.s}^{-1}$ .

We then make further use of this answer.

We use  $v_f = v_0 + a t$ .

Hence  $v_f = 24 \text{ m.s}^{-1}$ .

This is the answer required.

Figure 4-15: ALBERT's problem-solver type I, example 4.

A toy train which has a mass of  $1.7 \text{ kg}$  is projected up an inclined track during which time it experiences a constant resultant force of  $0.5 \text{ N}$ . If after  $3 \text{ seconds}$  its speed is  $6 \text{ m/s}$ , how far did it travel in this time?

From the problem statement, we extract the following:

We are considering a moving train.

The final velocity\* is  $6 \text{ m.s}^{-1}$ . ( $v_f$ )

The elapsed time is  $3 \text{ seconds}$ . (t)

The mass is  $1.7 \text{ kg}$ . (m)

The force\* acting is  $0.5 \text{ N}$ . (F)

We are asked to determine the displacement.

We use  $F = m \times a$ .

We solve for a.

This gives  $a = (F) \div m$

Hence  $a = 0.2941 \text{ m.s}^{-2}$ .

We then make further use of this answer.

We use  $v_f = v_0 + a t$ .

We solve for  $v_0$ .

This gives  $v_0 = v_f - a t$

Hence  $v_0 = 5.118 \text{ m.s}^{-1}$ .

We then make further use of this answer.

We use  $x = ((v_f + v_0) \div 2) \times t$ .

Hence  $x = 16.68 \text{ metres}$ .

This is the answer required.

Figure 4-16: ALBERT's problem-solver type I, example 5.

A stone is thrown straight up into the air with an initial velocity of 15 m/s. How long does it take to reach a height of 8 m?

From the problem statement, we extract the following:  
 We are considering a moving stone.  
 The initial velocity\* is 15 m.s<sup>-1</sup>. (v<sub>0</sub>)  
 The displacement\* is 8 metres. (x)  
 The acceleration\* is -10 m.s<sup>-2</sup>. (a)  
 We are asked to determine the elapsed time.

We use  $x = v_0 t + \frac{1}{2} a t^2$ .  
 We solve for t.  
 This gives  $t = \frac{-v_0 \pm \sqrt{v_0^2 - 4 \times (\frac{1}{2} a) \times (-x)}}{2 \times (\frac{1}{2} a)}$   
 Hence t = 0.6938 seconds.  
 This is the answer required.....there is another answer..

We use  $x = v_0 t + \frac{1}{2} a t^2$ .  
 We solve for t.  
 This gives  $t = \frac{-v_0 \pm \sqrt{v_0^2 - 4 \times (\frac{1}{2} a) \times (-x)}}{2 \times (\frac{1}{2} a)}$   
 Hence t = 2.306 seconds.  
 This is the answer required.

Figure 4-17: ALBERT's problem-solver type I, example 6.

A block which has a mass of 3 kg is subjected to a force of 6 N. What is its acceleration?

From the problem statement, we extract the following:  
 We are considering a moving block.  
 The mass is 3 kg. (m)  
 The force\* acting is 6 N. (F)  
 We are asked to determine the acceleration.

major goal	sub-goal	subst	equation	evaluated	bktrk
a	a	no	F = m * a	2 m/s <sup>2</sup>	no

Figure 4-18: ALBERT's problem-solver type II, example 1.

A motorcycle starts from rest and moves with constant acceleration for 30 seconds. If in this time it covers a distance of 250 m, what is its final velocity?

From the problem statement, we extract the following:  
 We are considering a moving motorcycle.  
 The initial velocity\* is 0 m.s<sup>-1</sup>. ( $v_0$ )  
 The displacement\* is 250 metres. ( $x$ )  
 The elapsed time is 30 seconds. ( $t$ )  
 We are asked to determine the final velocity.

major goal	sub-goal	subst	equation	evaluated	bktrk
$v_f$	$v_f$	no	$x = v_{av} \cdot t$	no	no
$v_f$	$v_{av}$	no	$x = v_{av} \cdot t$	8.333 m/sno	
$v_f$	$v_f$	no	$v_{av} = \frac{1}{2} \times (v_f + v_0)$	16.67 m/sno	

Figure 4-19: ALBERT's problem-solver type II, example 2.

A automobile brakes to a stop in a distance of 75 m. If its deceleration is 2.5 m/s<sup>2</sup>, how long does it take to come to rest?

From the problem statement, we extract the following:  
 We are considering a moving automobile.  
 The final velocity\* is 0 m.s<sup>-1</sup>. ( $v_f$ )  
 The displacement\* is 75 metres. ( $x$ )  
 The acceleration\* is -2.5 m.s<sup>-2</sup>. ( $a$ )  
 We are asked to determine the elapsed time.

major goal	sub-goal	subst	equation	evaluated	bktrk
$t$	$t$	no	$x = v_{av} \cdot t$	no	no
$t$	$v_{av}$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	no	no
$t$	$\Delta v$	no	$\Delta v = a \cdot t$	no	no
$t$	$\Delta v$	yes	$v_{av} = v_f - \frac{1}{2} \times a \cdot t$	no	no
$t$	$v_{av}$	yes	$x = v_f \cdot t - \frac{1}{2} \times a \cdot t^2$	no	no
$t$	$t$	no	$x = v_f \cdot t - \frac{1}{2} \times a \cdot t^2$	-7.746 s	no
$t$		no		0	yes
$t$	$t$	no	$x = v_{av} \cdot t$	no	no
$t$	$v_{av}$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	no	no
$t$	$\Delta v$	no	$\Delta v = a \cdot t$	no	no
$t$	$\Delta v$	yes	$v_{av} = v_f - \frac{1}{2} \times a \cdot t$	no	no
$t$	$v_{av}$	yes	$x = v_f \cdot t - \frac{1}{2} \times a \cdot t^2$	no	no
$t$	$t$	no	$x = v_f \cdot t - \frac{1}{2} \times a \cdot t^2$	7.746 s	no

Figure 4-20: ALBERT's problem-solver type II, example 3.

A car travelling at constant speed is given a constant acceleration of  $0.8 \text{ m/s}^2$  for the next  $10 \text{ sec}$ , during which time it travels  $200 \text{ m}$ . Find its speed at the end of the  $10 \text{ sec}$  interval.

From the problem statement, we extract the following:

We are considering a moving car.

The displacement\* is  $200 \text{ metres}$ . (x)

The elapsed time is  $10 \text{ seconds}$ . (t)

The acceleration\* is  $0.8 \text{ m.s}^{-2}$ . (a)

We are asked to determine the final velocity.

major goal	sub-goal	subst	equation	evaluated	bktrk
$v_f$	$v_f$	no	$x = v_{av} \times t$	no	no
$v_f$	$v_{av}$	no	$x = v_{av} \times t$	$20 \text{ m/s}$	no
$v_f$	$v_f$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	no	no
$v_f$	$\Delta v$	no	$\Delta v = a \times t$	$8 \text{ m/s}$	yes
$v_f$	$v_f$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	$24 \text{ m/s}$	no

Figure 4-21: ALBERT's problem-solver type II, example 4.

A toy train which has a mass of  $1.7 \text{ kg}$  is projected up an inclined track during which time it experiences a constant resultant force of  $0.5 \text{ N}$ . If after  $3 \text{ seconds}$  its speed is  $6 \text{ m/s}$ , how far did it travel in this time?

From the problem statement, we extract the following:

We are considering a moving train.

The final velocity\* is  $6 \text{ m.s}^{-1}$ . ( $v_f$ )

The elapsed time is  $3 \text{ seconds}$ . (t)

The mass is  $1.7 \text{ kg}$ . (m)

The force\* acting is  $0.5 \text{ N}$ . (F)

We are asked to determine the displacement.

major goal	sub-goal	subst	equation	evaluated	bktrk
a	a	no	$F = m \times a$	$0.2941 \text{ m/s}^2$	
x	x	no	$x = v_{av} \times t$	no	no
x	$v_{av}$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	no	no
x	$\Delta v$	no	$\Delta v = a \times t$	$0.8824 \text{ m/s}$	yes
x	$v_{av}$	no	$v_{av} = v_f - \frac{1}{2} \times \Delta v$	$5.559 \text{ m/s}$	yes
x	x	no	$x = v_{av} \times t$	$16.68 \text{ m}$	no

Figure 4-22: ALBERT's problem-solver type II, example 5.

A stone is thrown straight up into the air with an initial velocity of 15 m/s. How long does it take to reach a height of 8 m?

From the problem statement, we extract the following:  
 We are considering a moving stone.  
 The initial velocity\* is 15 m.s<sup>-1</sup>. ( $v_0$ )  
 The displacement\* is 8 metres. ( $x$ )  
 The acceleration\* is -10 m.s<sup>-2</sup>. ( $a$ )  
 We are asked to determine the elapsed time.

major goal	sub-goal	subst	equation	evaluated	bktrk
t	t	no	$x = v_{av} \times t$	no	no
t	$v_{av}$	no	$v_{av} = v_0 + \frac{1}{2} \Delta v$	no	no
t	$\Delta v$	no	$\Delta v = a \times t$	no	no
t	$\Delta v$	yes	$v_{av} = v_0 + \frac{1}{2} a \times t$	no	no
t	$v_{av}$	yes	$x = v_0 \times t + \frac{1}{2} a \times t^2$	no	no
t	t	no	$x = v_0 \times t + \frac{1}{2} a \times t^2$	0.6938 s	no
t		no		0	yes
t	t	no	$x = v_{av} \times t$	no	no
t	$v_{av}$	no	$v_{av} = v_0 + \frac{1}{2} \Delta v$	no	no
t	$\Delta v$	no	$\Delta v = a \times t$	no	no
t	$\Delta v$	yes	$v_{av} = v_0 + \frac{1}{2} a \times t$	no	no
t	$v_{av}$	yes	$x = v_0 \times t + \frac{1}{2} a \times t^2$	no	no
t	t	no	$x = v_0 \times t + \frac{1}{2} a \times t^2$	2.386 s	no

Figure 4-23: ALBERT's problem-solver type II, example 6.

A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

From the problem statement, we extract the following:  
 We are considering a moving bullet.  
 The initial velocity\* is 100 m.s<sup>-1</sup>. ( $v_0$ )  
 The final velocity\* is 0 m.s<sup>-1</sup>. ( $v_f$ )  
 The acceleration\* is -10 m.s<sup>-2</sup>. ( $a$ )  
 We are asked to determine the displacement.

major goal	sub-goal	subst	equation	evaluated	bktrk
t	t	no	$\Delta v = a \times t$	no	no
t	$\Delta v$	no	$\Delta v = v_f - v_0$	-100 m/s	yes
t	t	no	$\Delta v = a \times t$	10 s	no
x	x	no	$x = v_{av} \times t$	no	no
x	$v_{av}$	no	$v_{av} = \frac{1}{2} \times (v_f + v_0)$	50 m/s	yes
x	x	no	$x = v_{av} \times t$	500 m	no

Figure 4-24: ALBERT's problem-solver type II, an example of "rule c".

A car starts from rest and moves with a constant acceleration of 0.8 m/s<sup>2</sup> for 30 seconds. If it travels 360 m in this time, what is its final speed?

From the problem statement, we extract the following:  
 We are considering a moving car.  
 The initial velocity\* is 0 m.s<sup>-1</sup>. ( $v_0$ )  
 The displacement\* is 360 metres. ( $x$ )  
 The elapsed time is 30 seconds. ( $t$ )  
 The acceleration\* is 0.8 m.s<sup>-2</sup>. ( $a$ )  
 We are asked to determine the final velocity.

We use  $v_f = v_0 + a \times t$ .  
 Hence  $v_f = 24$  m.s<sup>-1</sup>.  
 This is the answer required.

major goal	sub-goal	subst	equation	evaluated	bktrk
$v_f$	$v_f$	no	$\Delta v = a \times t$	no	no
$v_f$	$\Delta v$	no	$\Delta v = a \times t$	24 m/s	no
$v_f$	$v_f$	no	$\Delta v = v_f - v_0$	24 m/s	no

Figure 4-25: ALBERT's problem-solvers ignore redundant information.

## Chapter 5

### The design of ALBERT's tutoring system

#### 5.1. Introduction

ALBERT is intended to be a computer-based problem-solving monitor and coach. As such, it is intended that the system should model the behaviour of a human tutor dealing with students in a one-on-one teaching situation. In this chapter I shall review some of the work on teaching problem-solving in Physics and discuss several examples of computer-based problem-solving tutors. Finally, the design of ALBERT's tutoring system will be presented.

Small group and one-on-one teaching is recognized as an effective means of promoting creative thinking on the part of individual students (Bligh, 1971). In relation to problem-solving, Lin (1979) stresses the need for personal interaction in addressing the difficulties which students have. He also points out that it is only by one-to-one discussions that many of these difficulties will be exposed.

Although one-on-one tutoring has been shown to be effective (Bloom, 1984), the low student-to-teacher ratio makes the cost high. It is with this in mind that intelligent computer-based tutors are being developed in the hope that computers, through a one-on-one interaction with students, will be able to provide the kind of discussion which will help students to identify their individual difficulties and solve them efficiently.

#### 5.2. Teaching students to solve Physics problems

Reif, Larkin and Brackett (1976) observe that

"many students in an introductory Physics course approach problems in very haphazard and ineffectual ways. For example, many students simply proceed to calculate something from the information stated in a problem without ever asking themselves whether this calculation will get them closer to the desired answer. (Needless to say, often it does not.)"

This has been confirmed by others. For instance, Reif and Larkin (1979) showed that novice students experience difficulty in problem-solving because of their inability to describe the problems properly. Larkin and Reif ascribe this partly to an inadequately structured knowledge-base on the part of the students.

A major conclusion which Lin (1979) draws from his study of problem-solving in introductory Physics is that in general

"students do not learn new techniques of analysis or approaches to problem-solving from their introductory course."

Lin also suggests that the inappropriate techniques which students may be using are deeply ingrained and that they are only effectively identified through personal interviews with the students. He believes that some students may pass right through an introductory Physics course without modifying these approaches.

It is now widely agreed that students in introductory Physics courses need explicit instruction in how to set about solving Physics problems. However, as Reif (1981) notes, this is normally approached by showing students examples of solutions in class and then setting several homework practice problems. Reif and Heller (1982) point out that teaching students to solve problems by giving them a large set of examples to practice on is not guaranteed to be efficient or effective. Fuller (1982a) agrees. Reif and Heller (1982) confirm Lin's assertion that the problem-solving skills of novices, left to themselves, improve slowly.

Reif, Larkin and Brackett (1976), Lin (1979), Fuller (1982a), Reif and Heller (1982) and others strongly recommend that problem-solving techniques should be taught explicitly in introductory level Physics courses. How to do this most effectively, however, remains the subject of considerable debate. As a result, problem-solving skills and their acquisition have been the subject of several studies.

#### 5.2.1. Acquisition of problem-solving skills

One aspect of the work on how problem-solving skills are learned has

focused on problem representation. I have already discussed De Kleer's work on envisionment (1977) and the symbolic representation of a progression of scenes described in familiar terms (section 4.3.4). Larkin (1981b) expands upon this and suggests that students should be taught to represent problems using physical schemas. In subsequent work, Larkin (1982), examined the importance of spatial knowledge in solving Physics problems. She has demonstrated the link between spatial knowledge and the application of physical principles and hence the importance of a complete and accurate diagram. In Larkin's experiments, the less able subjects were generally those who tried to solve problems by the "blind application of algebraic expressions".

This work has highlighted the importance of both the ability to form a "clear mental picture" of the problem and the need to represent the problem on paper in the form of a sketch.

Theorists have also tried to determine the cognitive abilities necessary for problem-solving and the processes by which these are learned. Anderson, Greeno, Kline and Neves (1980), for example, studied problem-solving in Geometry. They considered the question of how knowledge, initially encoded as declarative knowledge, is later incorporated as procedural knowledge for problem-solving. Anderson et. al. discuss the compilation and optimisation of procedural knowledge in terms of such operations as prodecuralization, composition and generalization.

Some of these modes of learning have been demonstrated by Larkin and Simon (1982) by means of a computer simulation. Larkin (1979) earlier showed how primitive knowledge can be combined into automatic knowledge and thereby the problem-solving behaviour of a computer program changes from that observed in novices to that of an expert, the former being a means-end backward-chaining strategy, the latter being more forward-directed.

This work is generally representative of the information processing model of learning to solve Physics problems. Its supporters involve themselves in the detailed analysis of the process of problem-solving and a comparison of the expert's approach versus that of the novice. The work of Larkin, McDermott, Simon and Simon (1980), Anderson, Greeno, Kline and Neves (1980) and Chi, Feltovich and Glaser (1981) is typical of this

approach.

Fuller (1982b) identifies a second theoretical strain, namely that of constructivism which has its roots in the Piagetian theory of mental development. The constructivists have attempted to describe the way in which problem-solving strategies are constructed and how these mental structures are modified in the course of growth and learning. They have become concerned with what knowledge is, how it is represented and how a representation of it is built up during the process of learning.

Piagetians have long argued that the process of self-regulation stemming from controlled disequilibrium can be an effective means of learning problem-solving skills (Lawson and Wollman, 1975). Lawson and Wollman offer suggestions as to the type of homework problems which can be most effective in bringing about these conditions. Such problems may be easy from the point of view of achieving a numerical solution, but are designed to be thought provoking in their interpretation.

Another area of study important to problem-solving in Physics is that of the alternative conceptions which students have of some of the concepts in elementary Physics. Trowbridge and McDermott (1980), for example, showed that some students are unable to relate the concept of how fast an object is moving to the ratio of distance travelled upon time. They later investigated students' understanding of the concept of acceleration in one dimension (Trowbridge and McDermott, 1981) and again showed that students have difficulty relating everyday experiences to the concepts taught in elementary Physics.

Misconceptions have been studied by several other workers, for example Clement (1982), Helm (1980) and Hewson (1985). Helm administered tests to first-year students at Rhodes University and later tested school pupils and teachers. A wide range of misconceptions was revealed, not only in mechanics but also in other areas of Physics such as electricity and magnetism. The effect of these misconceptions has not been incorporated to any meaningful extent by the information processing theorists who study problem-solving strategies.

The constructivists would argue that misconceptions should ultimately be

eliminated by the process of self-regulation through the provision of appropriately designed learning activities. Hewson (1985) subscribes to this view and presents a model of conceptual change based on the constructivist notion of concept learning as an interaction between new and existing concepts.

### 5.2.2. Explicit problem-solving instruction

If one takes into account the results of studies such as those performed by Lin (1979 & 1982) and the knowledge of problem-solving skills and their acquisition gathered by the theoreticians, one must strive for an optimal instructional strategy by which students may be taught how to solve problems in Physics. There have been several suggestions with regard to explicit problem-solving instruction.

Wood (1985) presents students with the flow chart shown in Figure 5-1.

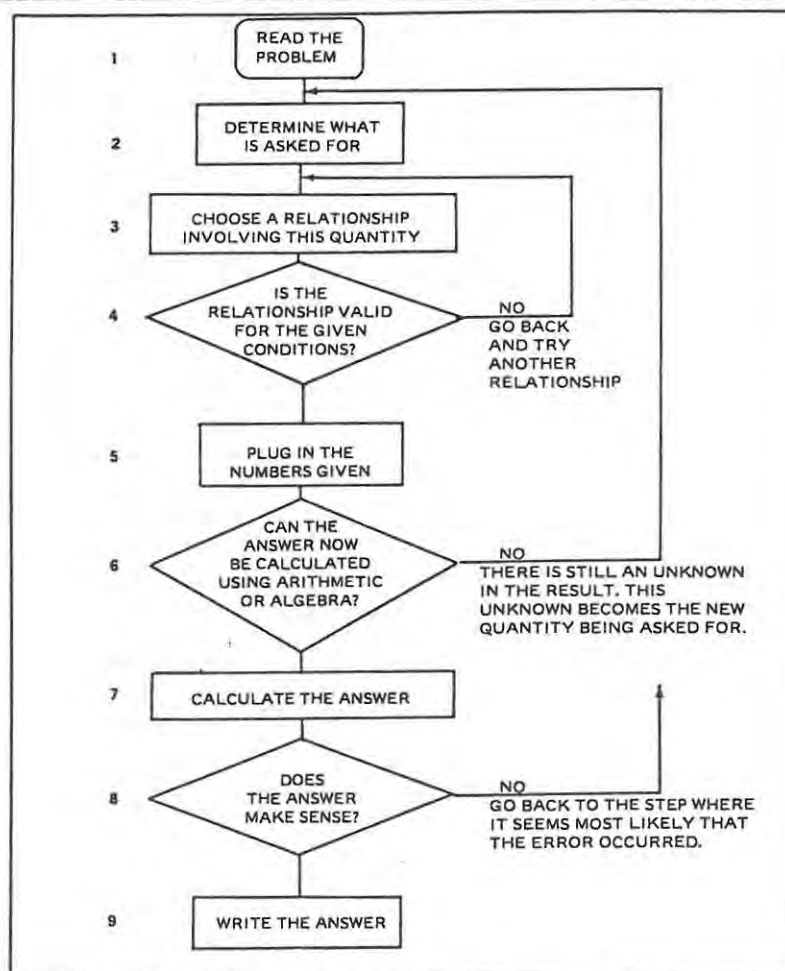


Figure 5-1: A flow chart for problem solving (from Wood, 1985)

Although Wood notes that it is desirable to make a sketch to help organize the information given, his approach encourages students to search for an appropriate equation and to plug numbers into it. The use of this flow chart would encourage students to adopt the undesirable approaches to problem-solving observed by Lin (1979) and Mehl (1985) which I discussed in the last chapter (section 4.4.1).

Reif, Larkin and Brackett (1976) implemented the four-point problem-solving strategy shown in Table 5-1. (These steps are similar to those suggested by Polya (1957) and Wickelgren (1974).) This strategy was explained and demonstrated to students who were later observed solving problems.

1. Description: List explicitly the given and desired information. Draw a diagram of the situation. (The result of this step should be a clear formulation of the problem.)
2. Planning: Select the basic relations pertinent for solving the problem and outline how they are to be used. (The result of this step should be a specific plan for finding the solution.)
3. Implementation: Execute the preceding plan by doing all the necessary calculations. (The result of this step should be a solution of the problem.)
4. Checking: Check that each of the preceding steps was valid and that the final answer makes sense. (The result of this step should be a trustworthy solution of the problem.)

**Table 5-1: An explicit problem-solving strategy (from Reif et. al., 1976)**

Reif et. al. (op. cit.) found that students who were taught this approach made better use of diagrams, showed evidence of more extensive planning and, even when they could not solve a problem, generated steps which were more relevant than those of other students who had not been taught the strategy.

In the above strategy, it is assumed that the student is able to relate the concepts expressed diagrammatically in the first step to the relations required in step 2. I believe that the work of Trowbridge and McDermott (1980 & 1981) suggests that this might not be the case, particularly if the diagram is cognitively linked to experience rather than the physical interpretation.

Reif (1981) later refined this by stating that the initial summary and description must be "augmented by a 'theoretical description'... in terms of the key concepts provided by the problem-solver's available knowledge about the problem domain". This addresses the problem just mentioned.

Reif (op. cit.) also draws attention to the need for an appropriately structured knowledge-base on the part of the problem-solver. Included in this would be "problem schemata" which hold knowledge about how to solve particular classes of problems. Reif advocates teaching such schemata directly to students. This is what Mehl (1985) set out to do by teaching students to recognize particular classes of problems and then to adopt an appropriate strategy in solving them.

Reif and Heller (1982) present a prescriptive model of problem-solving. The importance of the model is that it is reliable. It is not necessarily intended to mirror expert performance. Once again the need for a carefully structured knowledge base is stressed. The structure suggested is hierarchical and as such is in line with their recommended approach of successive refinements in the problem-solving activity, leading from the most general qualitative description of the problem to the most detailed analytic solution of its component sub-problems.

In the model, the problem-solving activity is divided into three distinct classes of activity, viz.,

- problem description and analysis;
- construction of a solution;
- assessment of the solution.

Reif and Heller note that students frequently have difficulty with problem-solving because they are incapable of describing the problem

adequately. Problem description and analysis consists of an initial basic description which amounts to a restatement of the problem, often in the form of a diagram, a theoretical description which relates the basic description to key concepts in the knowledge base and an attempt at simplifying the description by applying qualitative considerations, for example boundary conditions.

Constraint satisfaction and problem decomposition form the basis of the strategy suggested for the construction of a solution. Reif and Heller have captured the sentiment that the solution should grow out of the basic and theoretical descriptions of the first step and thus be related closely to the concepts in the knowledge base. The final step of assessing the solution would include checks for clarity, completeness, internal and external consistency and optimality.

The approach to problem-solving embodied in Reif and Heller's prescriptive model appears to be useful in that it helps students to make the important connection between the qualitative description of a problem and the relations which may be used to describe it mathematically. (For more complex and abstract problems than those of interest here, it does far more than this, of course.) The question in this case is how best and to what extent to incorporate these ideas into a computer-based learning environment.

### **5.2.3. Computer-based problem-solving instruction**

The use of the computer for problem-solving instruction makes it possible to engage the student in a personal dialogue, an approach believed to be very effective (Lin, 1979). Whether one is using a traditional CAI system, in which case the dialogue is largely predetermined by the author of the lesson, or whether one has access to an "intelligent" system, one must decide to what extent an approach to problem-solving will be taught explicitly.

Van Humbeeck, Boving and Broeckhoven (1982) implemented a computer-based program for teaching problem-solving in Applied Mathematics and basic Physics. They set out to teach their students the four general problem-solving steps (Polya, 1957; Reif et. al., 1976) set out in Table 5-1.

Students did not work on-line all the time. The computer was used to correct, to provide help and to evaluate their work.

Before the student started a problem, he was required to take a test on the computer to ensure that he had the necessary theoretical background to solve problems of this kind. If the student passed the pre-test and started working on a problem, the next interaction with the computer would be after the descriptive analysis and planning stages. The student then used the computer to compare his diagram with the one generated by the computer and was able to see whether his list of data extracted from the problem statement was complete. The computer also informed the student at this stage whether the laws and principles chosen for use in the solution were relevant and sufficient.

The student was then required to solve the problem away from the computer. In the next session with the computer, the student answered questions about his solution. The computer was programmed to check the student's answers, provide help when they were wrong and, "by means of a code", referred the student to a similar problem in a book. At any stage, a complete set of data was available on each student showing which problem he was currently working on and how far he had got with it. Apart from the necessity of these data in allowing the student to work discontinuously at the terminal, it provided a useful means of monitoring student progress.

This approach represents one way of providing individualized problem-solving instruction to a large number of students (340) with a minimum of computing equipment (6 terminals). This could be a cost-effective way of implementing the "problem clinics" suggested by Lawson and Wollman (1975). The biggest drawback of this kind of implementation is that it lays itself open to misuse on the part of the students. Students may engage in each interaction more than once, so, for example, they may sign on to see the diagram suggested by the computer, without giving it much thought themselves. However, if a generic program to provide a shell for this kind of problem-solving assistance could be made available, it could provide a very cost effective means of offering an individualized tutorial service to students.

A second program, designed to teach students how to solve Physics problems is described by Trowbridge and Chiocciariello (1985). These authors recognize the effectiveness of teaching through questioning as a means of identifying difficulties which students have and helping them to overcome these. They set out to implement a computer-based Socratic tutor which could "mimic some of the roles of a skilled tutor such as teaching through inquiry". Their dialogue was designed to teach motion with and without friction.

The program teaches the problem-solving steps shown in Table 5-2 by leading the student through the solution of a problem and asking questions designed to make him/her think about each of the steps in turn. Problem "skeletons" are provided which allow the program to generate many different problems. In addition, various routines have been written which allow mathematical manipulation of equations and answer judging.

This program is useful in that it maintains an interactive dialogue with the student while he/she is solving the problem. However, the biggest drawback of any program of this kind (viz., traditional CAI) is its relative inflexibility when compared with a person-to-person dialogue. It can lead a student through a problem and show him/her how to solve it in a particular way. However, it cannot observe the student solving the problem and decide whether the solution is valid. The system must maintain a tight control over the dialogue.

1. Classifying the problem.
2. Identifying the knowns and unknowns.
3. Identifying the appropriate mathematical tools.
4. Drawing a diagram.
5. Choosing a coordinate system.
6. Solving the equation for the unknown.
7. Substituting in the values of all the knowns.
8. Computing the answer.

Table 5-2: Problem-solving steps in elementary mechanics (from Trowbridge and Chiocciariello, 1985)

As the authors admit:

"A major purpose of the field testing was to establish whether the answers the design team **anticipated** actually matched those the learners gave. **The success of the learning experience depends on this match....**" (my emphasis)

What an indictment of traditional CAI! It should further be noted that the success of the learning experience depends on the student solving the problem in the way envisaged by the authors of the program. In a Socratic dialogue, the questioning can be used to funnel the student into a particular solution path, but a student who believes that he/she knows a different approach to the problem could be greatly frustrated by never being able to test his/her method. Student initiative is not catered for.

Also, while it is true that a program of this kind can generate a wide variety of problems, the student may not feel that any of those produced by the system are relevant to his/her particular needs.

The third (and final) example of a CAI program designed to teach problem-solving to which I wish to refer is one which is a part of the PLATO LDEC Physics curriculum (CDC, 1983). In Table 5-3, I have summarized the steps through which this program takes the student while teaching him/her how to solve a problem in one-dimensional kinematics. The steps are not taught explicitly, but rather form an integral part of the discussion about a particular problem. (The problem statement does not change.)

This is similar to the general problem-solving strategy of Polya (1957), used later by Reif et. al. (1976) and Van Humbeeck et. al. (1982). Steps 1 to 8 spell out a method of describing the problem; steps 9 and 10 form the planning stage; steps 11 and 12 execute the plan and step 13 is the assessment of the solution.

The descriptive stage is very thoroughly treated by this program, although, if one accepts the model of Anderson et. al. (1980) relating to schema-based problem-solving, one might suggest that the identification of the problem type should appear earlier in the procedure. The prediction

1. Understand what the problem statement tells you. Give a qualitative description of the situation and draw a diagram.
2. Make sure you understand the question, i.e. what are you asked to find?
3. Choose an axis of reference and note which quantities are changing, which are constant, and the directions of vectors.
4. Make a note of what you are given explicitly.
5. Make a note of implied values of quantities.
6. Draw rough graphs of position versus time, velocity versus time and acceleration versus time.
7. Relate symbols to the quantities given and draw up a table showing their respective values.
8. Estimate the answer and specify the sign, the number of significant figures and the units it will have.
9. Decide what type of problem it is and try to relate what you have been given to other problems of this kind.
10. Write down the equations which apply to problems of this kind.
11. Pick the one which contains the quantities you are given and the quantity you are required to find.
12. Calculate the answer.
13. Check that the answer fits in with your predictions.

Table 5-3: Summary of the LDEC (CDC, 1983) approach to problem-solving

of the sign of, approximate magnitude of, and number of significant figures in the final answer is an important step the value of which is often overlooked. However, as I pointed out in section 4.4.1, once the qualitative description has been completed, the activity focuses on selecting an equation and plugging in the numbers without relating these operations to what has gone before (in step 6, for example). It is clear from step 10, that a set of equations is selected on the basis of the problem type, rather than on theoretical grounds. This program fails to help the student build associations between the kinematic equations and the qualitative description of a problem.

The three computer programs described in this section have each attempted to provide a problem-solving environment within which students can learn a good general problem-solving strategy, either by explicit instruction or by observing the use of one in the solution of one or more specific problems. The biggest limitation of these programs and others like them, as pointed out in section 2.2.4, has been their inflexibility and in some cases such as the LDEC program, a problem-solving approach with built-in weaknesses.

In ALBERT, I have attempted to build upon this work by incorporating the general approach to problem-solving, while at the same time providing the flexibility and scope for student initiative which these conventional programs are lacking.

### 5.3. The design of ALBERT's problem-solving tutor

The general problem-solving strategy described in the previous section appears to have a wide base of acceptance and its validity has been demonstrated by Reif and Heller (1982), who refined the strategy in terms of the three stages:

- problem description and analysis;
- constructing a solution;
- assessment of the solution.

In ALBERT, I have incorporated this as the basis of the approach to problem-solving. Figure 5-2 shows the overall structure of the tutoring section of ALBERT, i.e., ALBERT as the student sees it. In the present

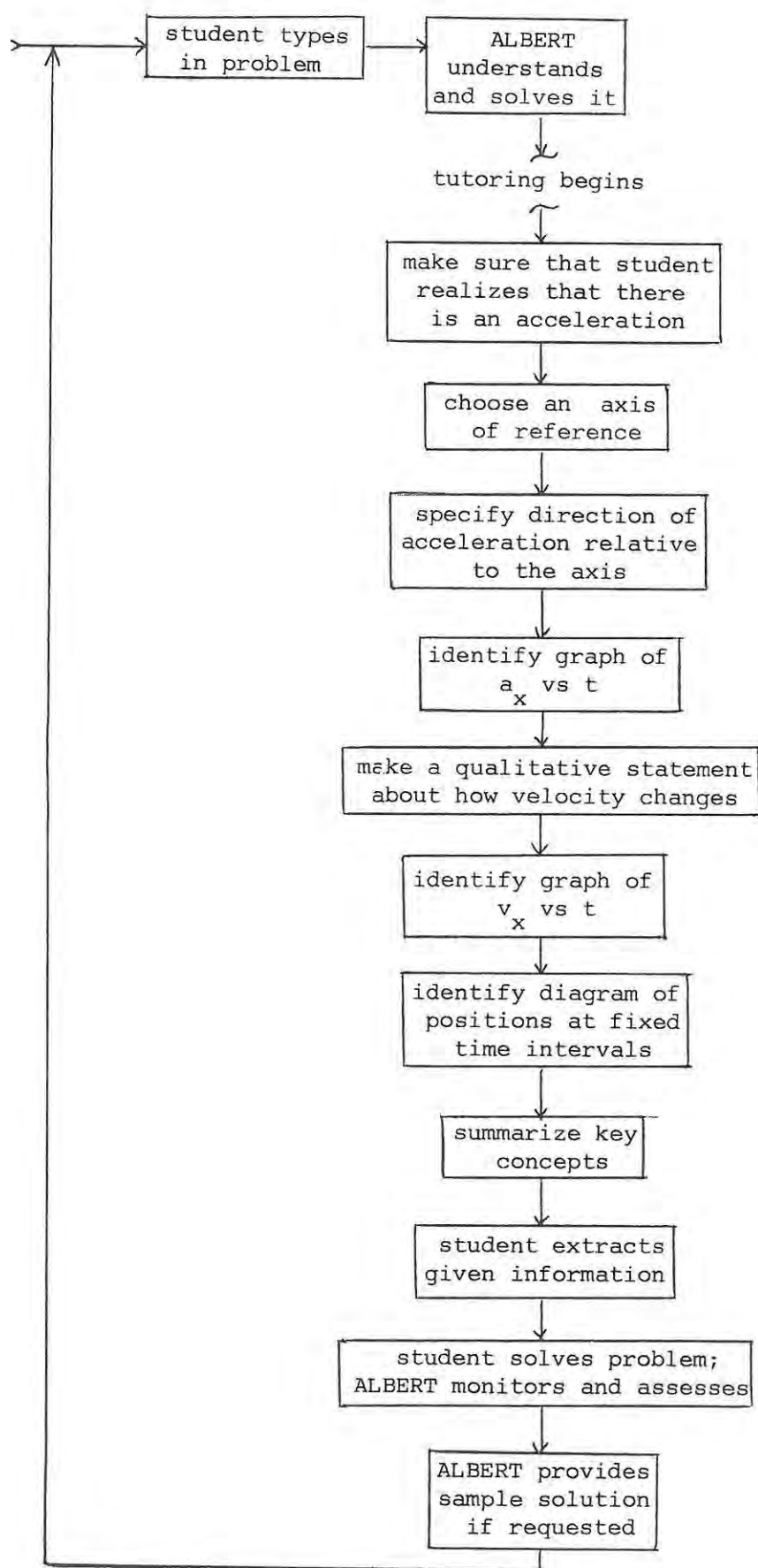


Figure 5-2: The structure of ALBERT's tutoring system

section, I shall present the philosophy of the instructional design of the tutoring system. The next chapter contains a technical description of the computer program used to implement it.

### 5.3.1. The Introduction

Any good book, seminar, lecture, or computer lesson should begin with an introduction which sets out the purpose, general objectives and overall structure of the activity (Alessi and Trollip, 1985). In ALBERT, the introduction is made up of the four pages shown in Figures 5-17 to 5-20 at the end of this chapter.

The first two pages explain the purpose of ALBERT and how to use it. The structure of the tutorial is made clear, viz., that there are three sections to the discussion, a qualitative section, a summary stage, and the numerical solution. The student is also told that ALBERT will allow him/her a good deal of flexibility in guiding the discussion.

The third page stresses the fact that one is working with vector quantities and that in this case, because the motion is linear, one may work with the components of the vectors in the chosen direction of reference. Throughout ALBERT the student is reminded that when we refer to "velocity", for example, we mean the scalar component of the velocity vector in the direction of interest.

This is a point which is often not made clear by the authors of books and computer lessons and in some cases it leads to confusion. For example, if one talks about "velocity" throughout a problem without making it clear that this is really the scalar component of the velocity vector, the student may become confused when the "velocity" takes on a negative sign. Many students will accept that "negative velocities" exist without trying to rationalize the concept of a negative vector. (One of the LDEC Physics lessons actually teaches and tests the concept of negative velocity!)

The final page of the introduction presents the symbols used to represent the physical quantities of interest in ALBERT. The textbooks use a variety of symbols for these quantities and the notation used in ALBERT was not based on any particular text. The symbols were chosen for clarity

and technical convenience. (This page is included at the back of the problem sheet handed to students who use ALBERT.)

Although it is only four pages long, students are not compelled to read the introduction each time they use ALBERT. There is a provision for skipping it once one is familiar with the program. After the introduction, the student is required to type in the problem statement which is then checked and understood by ALBERT as described in Chapter 3.

During the tutorial discussion, the problem statement is kept at the top of the screen and immediately below it several lines are reserved for ALBERT's use. This is where certain diagrams and graphs appear. Below this reserved space, the tutorial dialogue takes place. The dialogue rolls around in the space available as indicated in Figure 5-21 at the end of the chapter.

### 5.3.2. Problem description and analysis

This is the first stage of the discussion, the qualitative stage. It covers both the "basic" description and the "theoretical" description of Reif and Heller (1982). To some extent the student is required to describe the motion of the object in general every day terms to show that he/she has a feel for what is taking place. At the same time the student must show that he/she can relate this to the physical concepts and a graphical interpretation of the quantities involved. For the most part, the student is obliged to proceed linearly through the descriptive stage in the way determined by ALBERT.

It should be noted that the descriptive answers are not uniquely determined, but depend on the particular problem. ALBERT evaluates the student's response by consulting the expert's knowledge of the problem. Also, due to the flexibility of the dialogue system, the student may exhibit knowledge of a concept before ALBERT has checked it explicitly. In such cases, ALBERT is able to tailor the discussion accordingly. (The latter is explained more fully in section 6.8.1.)

First the student must show that he/she realizes that the velocity of the object is changing and that it is therefore accelerating (Figure 5-3).

---

Problem:

A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

---

albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

oberem: yes

albert: Ok. And that means.....

oberem: it is accelerating

albert: Right! There is an acceleration.

---

Figure 5-3: Problem description - a changing velocity

---

Next, an axis of reference must be chosen. When the student makes a suggestion about this, ALBERT draws it on the screen and asks the student to confirm that this is what he/she had in mind, before commenting on it (Figure 5-4). If the student makes an inappropriate choice, suitable feedback is provided.

---

Albert's workspace:



albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we shall need an axis of reference (x-axis).

In which direction would you choose the x-axis?

albert: (You can use FONT and w,d, etc. to get ↑↗↘↙↖↙.)

oberem: up

albert: Do you mean as shown above?

oberem: yes

albert: Good! I agree!

---

Figure 5-4: Choosing an axis of reference

---

Once the axis of reference has been agreed upon, the student is required to indicate the direction of the acceleration relative to the axis and then to show that he/she can identify correctly the graph of  $a_x$  versus time (Figure 5-5).

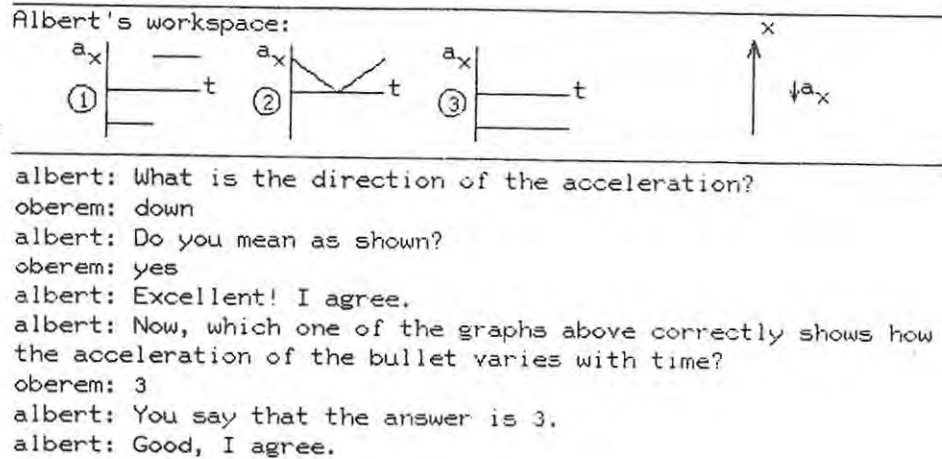


Figure 5-5: Checking the student's knowledge of acceleration

For any given problem, the student selects one of three graphs. ALBERT has a collection of graphs (Figure 5-6) and uses the three most appropriate for any given problem. The graphs used are designed to show up some of the common misconceptions which students have. For example, the bottom row of graphs in Figure 5-6 are the same as those used by Stanton (1986) in his misconceptions test. Stanton's test, conducted under the auspices of the Faculty of Education at the University of the Witwatersrand, was administered to a large number of school children in the Johannesburg area.

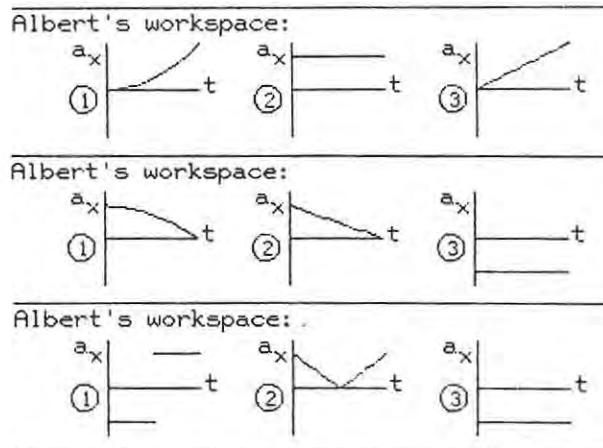


Figure 5-6: Acceleration versus time graphs in ALBERT

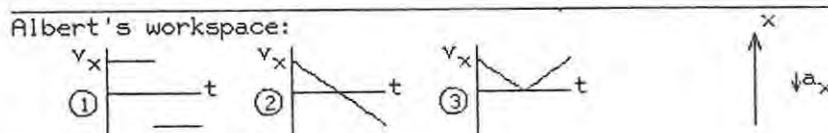
Many students choose the first graph because they hold to the mistaken belief that the acceleration changes direction at the top of the flight of an object thrown straight up into the air. For many of them, the acceleration (vector?) starts out being negative because the object is slowing down and later becomes positive when it is speeding up. This provides further confirmation of the need to fix an axis of reference and to stress the use of scalar components.

The graphs are presented in a random order on the screen so that, if the student does a problem with similar characteristics, at least the number associated with the correct answer will be different.

Once the student has demonstrated that he/she knows that the acceleration is constant and has identified correctly a graph of  $a_x$  versus time, he/she is asked to make a qualitative statement about the change in velocity (Figure 5-7). Again this qualitative assertion must be linked immediately to a graphical interpretation of the variation of velocity with time (Figure 5-8). As with acceleration, ALBERT has a collection of graphs from which to choose (Figure 5-9), the particular ones used being dependent upon the nature of the problem. Again, the graphs are designed to show up common difficulties which students have with these problems.

albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
 oberem: slowing down  
 albert: Good! I agree with that.

Figure 5-7: A qualitative statement about velocity



albert: You have said that the bullet is slowing down. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.  
 oberem: 2  
 albert: You say that the answer is 2.  
 albert: Good, I agree.

Figure 5-8: Student identifies velocity versus time graph

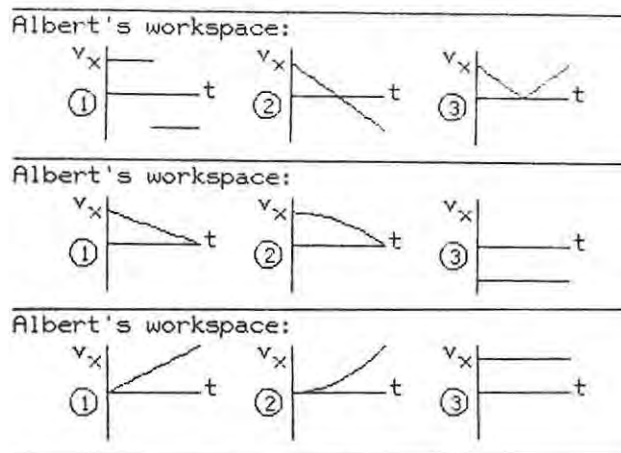


Figure 5-9: Velocity versus time graphs in ALBERT

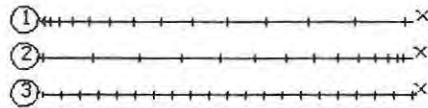
The last phase of the descriptive stage is to test the student's conception of how the displacement varies with time. A graph of displacement versus time is parabolic but this could be confusing for students because, in projectile motion, the shape of the path is parabolic. For this reason it was decided to make students select among a set of diagrams which show the positions of the object at equal time intervals. This performs an important check on the student's ability to associate the concept of slowing down with a decrease in the distance travelled in equal time intervals. As Trowbridge and McDermott (1980) have demonstrated, many students fail to do this adequately.

In ALBERT, students are presented with three diagrams, one depicting an increase in velocity, another showing a decrease in velocity and the third representing constant velocity. The student is required to identify the appropriate one for the problem at hand (Figure 5-10).

That completes the descriptive stage. By now, it is hoped that the student will have a clear picture of what is taking place in the problem and how the acceleration, velocity and displacement are changing with time. The student's intuitive feelings about the object speeding up or slowing down should by now have been "augmented by a 'theoretical description'... in terms of the key concepts provided by his/her knowledge of the domain (1D- kinematics)" (Reif, 1981).

---

Albert's workspace:



albert: The bullet in this problem moves in a straight line.

We may think of it as moving along the x-axis.

albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience.)

oberem: 2

albert: You say that the answer is 2.

albert: Good, I agree.

The distance travelled in a given time decreases.

albert: -----

Figure 5-10: Diagrams showing distance travelled in equal time intervals

---

It should be noted that when the student makes an incorrect response (not shown in the Figures presented so far), suitable corrective feedback is supplied and the student is required to make another attempt at the question. If the student is stuck, he/she may request help. ALBERT will begin by giving a hint. If the student requests more help, the answer will ultimately be given. Figure 5-11 illustrates the corrective feedback and the help given while a student is selecting a suitable reference direction.

---

we shall need an axis of reference (x-axis).

In which direction would you choose the x-axis?

albert: (You can use FONT and w,d, etc. to get ↑↗↘↙↖.)

oberem: angle up

albert: Do you mean as shown above? ↗

oberem: yes

albert: That is not a good choice. You will have to resolve vectors into their components unnecessarily.

oberem: help

albert: It is usually a good idea to choose the axis of reference in the direction of the velocity during the early part of the motion.

oberem: help

albert: In this case, the best choice would be vertically up. (Try it that way!)

oberem:

Figure 5-11: Corrective feedback and help in the descriptive stage

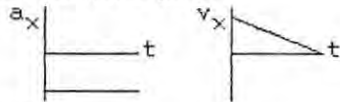
---

### 5.3.3. The summary stage

The descriptive stage is followed by a summary stage which is made up of two parts. First ALBERT summarizes the discussion of the descriptive stage, illustrating the points made by means of appropriate graphs of acceleration and velocity versus time (Figure 5-12).

---

Albert's workspace:



---

albert: So to sum up: We are considering a bullet which moves with constant acceleration.  
albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.  
albert: The x-component of velocity changes linearly with time.

Figure 5-12: ALBERT's summary of the descriptive stage

---

Ideally, an animation of the motion of the object should be provided as well to emphasize the nature of the path travelled. However, this has not been included yet for two reasons. The first is that animations on PLATO are rather unsatisfactory due to the fact that one is operating within a time-sharing mainframe environment. The second is that depicting a wide range of objects and spatial configurations such as one finds in problems of this kind will require considerable graphics design effort. While neither of these difficulties is insurmountable, I do not believe that the benefits warrant the effort at this stage in the development of the system.

In the second part of the summary stage, the student is required to show that he/she has extracted all the useful information from the problem statement and knows what he/she is being asked to calculate (Figure 5-13). ALBERT provides help when necessary. (In early versions of ALBERT, the system summarized the information given in the problem statement. It was later decided that it would be better to make the student do this.)

The student then begins the solution of the problem.

---

albert: So, what information is given in the problem statement?  
oberem: initial velocity is  $100\text{ m/s}$ ; final velocity is  $0\text{ m/s}$   
acceleration is  $-10\text{ m/s}^2$   
albert: You say that the initial velocity is  $100\text{ m/s}$ .  
albert: (That's the x-component of the initial velocity.)  
albert: Good, I agree.  
albert: You say that the final velocity is  $0\text{ m/s}$ .  
albert: (That's the x-component of the final velocity.)  
albert: Good, I agree.  
albert: You say that the acceleration is  $-10\text{ m/s}^2$ .  
albert: (That's the x-component of the acceleration.)  
albert: Good, I agree.  
albert: What are you asked to find?  
oberem: the maximum displacement  
albert: That's right!  
albert: That completes the descriptive part.

Press NEXT.

Figure 5-13: The student extracts the "given" information and the question

---

#### 5.3.4. The solution and assessment stage

The solution stage is the most flexible part of ALBERT, the idea being that the student should solve the problem in whatever way he chooses. In the words of Lin (1979):

".....what is most necessary is that he (the tutor) should be willing to listen and not be so quick to give the student a hint".

This idea here is to let the student lead the discussion while giving him/her just enough support to prevent his/her confidence failing.

The degree to which ALBERT controls the problem-solving activity depends on the degree to which the student allows or calls upon him to do so. (This will be demonstrated by example in the chapters which follow.) If ALBERT is allowed control, the general approach to solving the problem numerically is as shown in Figure 5-14.

First a goal must be established. This may be a secondary goal, required to be known before the question or primary goal can be evaluated. If the student begins by writing down an equation, ALBERT will not let him/her use it without clarifying its purpose (Figure 5-15).

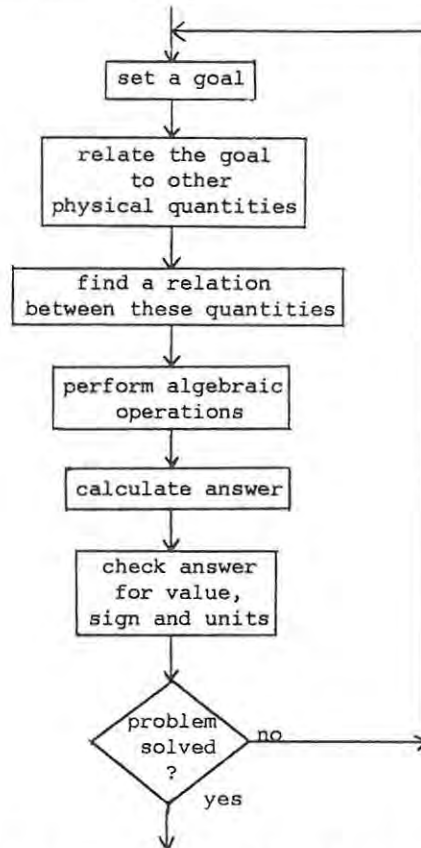


Figure 5-14: ALBERT's strategy for teaching the numerical solution

albert: How would you like to start?  
 oberem:  $F=ma$   
 albert: You want to use  $F=ma$ .  
 albert: What do you wish to calculate?  
 oberem:  $a$   
 albert: The value of  $a$  is given in the problem statement.  
 albert: What do you wish to calculate?  
 oberem:  $m$   
 albert: Ok. The current goal is to calculate  $m$ .  
 albert: You want to use  $F=ma$ .... Ok!  
 albert: You don't know  $F$ .  
 albert: What do you wish to do now?

Figure 5-15: Student clarifies a goal

Once a goal has been established, ALBERT will ask the student to relate it to other quantities of interest. For example, if the student wishes to calculate the displacement, the student must show that he/she knows that the displacement depends on the average velocity and the time, without requiring the student to demonstrate immediately that he/she knows the mathematical relationship between these three quantities (Figure 5-16).

---

albert: How would you like to start?  
oberem: I want to find the distance travelled  
albert: Distance is a scalar quantity. It is always positive.  
We must work with the x-component of the displacement.  
albert: Ok. The current goal is to calculate x.  
albert: On what does x depend or what quantities could be  
used to calculate it?  
oberem: velocity and time  
albert: You say it depends on the velocity.  
Please specify;  $v_i$ ,  $v_f$ ,  $\Delta v$ ,  $v_{av}$  or what?  
albert: You say it depends on the time. Good! I agree!  
albert: So x depends on t and what else?  
oberem:  $v_{av}$   
albert: You say it depends on the average velocity. Good! I agree!  
albert: Do you know a formula which relates t,  $v_{av}$ , and x?  
oberem:

(Note that the student is reminded of the vector nature of velocity when he refers to distance.)

Figure 5-16: Relating the goal to physical quantities

---

The importance of this approach is that it makes the student think first about the interdependence among the physical quantities. Only once the student has applied some intuition and given some thought to the Physics, is it necessary to think about the mathematical relationships between the quantities. Hopefully this provides an instructional means of bridging the gap between the qualitative description and the use of the equations, a deficiency in the LDEC lesson (CDC, 1983) which I described earlier. I believe that this operation corresponds to the planning stage of Reif et. al. (1976).

Once the student has selected a relationship to use, its appropriateness is checked by ALBERT and, when the student has calculated an answer, it too is assessed by ALBERT. For the latter, as Trowbridge and Chiocciariello (1985) recognize, the algebraic sign, the numerical value and the physical units are all important. ALBERT checks all of these and provides feedback and assistance where necessary. Although ALBERT does not check the number of significant figures, a range of tolerance is provided for in checking the student's answer to allow for rounding.

If the first quantity calculated is not the answer to the question, the

student may repeat this process until the desired solution has been achieved. The student is not constrained as to the order in which goals may be suggested, or which equations to use. However, if he/she is stuck and asks for help, ALBERT will come up with the best suggestion about how to proceed from that point.

In ALBERT, the solution and the assessment of the solution are interwoven. In addition, once the problem has been solved, the student may request ALBERT to write out his solution of it. In this case, a solution of the type described in section 4.5 is produced. After this, the student may return to the editor to type in a new problem or modify the existing one to answer a different question.

Figure 6-24 at the end of the next chapter is an example of a complete dialogue with ALBERT.

#### 5.4. Discussion

In this chapter, I have explained the basis of the tutoring model used in ALBERT. It is based on the work of the theorists, particularly those who advocate the information processing model, and it attempts to overcome some of the weaknesses identified in existing computer courseware.

Although it is not prescriptive with regard to the problem-solving strategy, the general approach which has developed out of the work of Polya (1957) and others is embodied in the tutoring model.

The tutorial comprises three broad sections. The first is a descriptive stage in which the student must demonstrate his/her understanding of the concepts of acceleration, velocity and displacement and his/her ability to apply them to the problem at hand. In ALBERT, this section is probably not as fully developed as that in some traditional lessons, for example, the LDEC lesson referred to in this chapter. This is partly due to the fact that ALBERT has to cope with a wide range of problems which he has not seen before, but it is also because ALBERT has been kept as brief as possible without detracting from its purpose so that students should not be deterred from using ALBERT because of the length of time it takes to work through a problem.

The second stage provides a summary of the qualitative discussion and requires the student to show that he/she has extracted all the useful information from the problem statement.

In the final stage, the student solves the problem. In this section the student is given opportunity to lead the discussion. However, ALBERT attempts to help the student to relate the qualitative discussion to the use of the equations by leading the student to consider the inter-relationships between quantities and encouraging him/her to work with the definition of acceleration and the relationship between displacement and average velocity rather than the standard kinematic equations. During this process the student is given as much flexibility as possible, while ALBERT acts as a monitor, assessor and coach.

ALBERT's problem-solving environment is radically different in two major respects from any existing Physics problem-solving program that I have encountered. First, it allows the student to specify the problem completely. For students, this means that they can work on problems which they feel to be relevant and at a level of difficulty which they feel to be appropriate. Secondly, ALBERT gives students a degree of control over the problem-solving process which no other computer lesson does. The student can solve the problem in whatever way he/she chooses. However, ALBERT will never desert the student who is stuck. Help is always available, but once a suggestion has been made, it is up to the student to continue.

ALBERT should provide a powerful means of individual assistance to students solving problems in 1D-kinematics in a manner which is currently not possible with human tutors due to the teacher-to-student ratio at most institutions.

---

## INTRODUCTION

ALBERT has been designed to help you solve Physics problems dealing with motion in a straight line with constant acceleration.

First, you must type in the problem from the textbook or your problem sheet. ALBERT will first check your typing. You will then have the opportunity to correct typing errors if there are any. Be sure to read the instructions to avoid retyping the whole problem.

ALBERT will then check to see that there is sufficient information to solve the problem. If not, he may ask you about it.

Figure 5-17: The introduction - page 1.

---

## INTRODUCTION (continued):

ALBERT will then discuss the solution of the problem with you. This discussion is split into three sections, namely

- the qualitative discussion,
- a problem summary,
- and - the numerical solution.

In the qualitative section, ALBERT will discuss the problem with you in general terms to make sure that you understand the Physics behind it.

After summarizing what is given and what you are asked to calculate, ALBERT will help you with the solution. In this section, you have the freedom to guide the discussion. You are not forced to answer ALBERT's questions, if you show that you know what you are doing.

If you get stuck, ask for help. ALBERT will make a suggestion about how to proceed.

After you have solved the problem, ALBERT will show you his solution.

Press NEXT.

Figure 5-18: The introduction - page 2

NOTATION:

Motion of any kind is best described by means of the displacement, velocity and acceleration vectors.

In this case, since the motion is along a particular direction, we may work with the components of the vectors in this direction, which ALBERT will refer to as the x-axis.

Therefore, if we talk about "velocity", we shall mean the x-component of the velocity, and similarly for the other vector quantities (not be confused with scalar quantities such as speed and distance).

Figure 5-19: The introduction - vector notation

---

## IMPORTANT

In different textbooks, one finds a wide variety of symbols used to represent physical quantities.

Albert uses the following notation:

x-component of displacement	-	x
x-component of initial velocity	-	$v_0$
x-component of final velocity	-	$v_f$
x-component of average velocity	-	$v_{av}$
x-component of change in velocity	-	$\Delta v$
x-component of acceleration	-	a
x-component of force	-	F
mass	-	m
time	-	t

You MUST use these symbols.

(Albert will not understand you if you don't.)

NOTE: To type  $\Delta$  hold down the shift key and press -.

Press NEXT to get started.

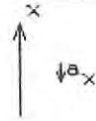
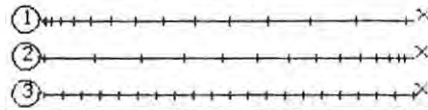
Figure 5-20: The introduction - symbols used

---

Problem:

A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

Albert's workspace:



albert: Good, I agree.  
oberem: The bullet in this problem moves in a straight line.  
We may think of it as moving along the x-axis.  
albert: Which one of the three diagrams above correctly shows  
the positions of the bullet along the x-axis  
which are equally spaced in time?  
(The x-axis has been drawn horizontally for convenience.)  
oberem: ← Current position in dialogue.  
  
Oldest point in dialogue.  
oberem: slowing down  
albert: Good! I agree with that.  
albert: You have said that the bullet is slowing down.  
Now please tell me which one of the graphs above correctly  
shows how the x-component of velocity changes with time.  
oberem: 3  
albert: You say that the answer is 3.

Figure 5-21: Format of the tutorial screen

## Chapter 6

### Implementation of ALBERT's tutoring system

#### 6.1. Introduction

ALBERT's dialogue system is designed to give the student as much flexibility and scope for initiative as possible. This represents a significant departure from the current concept of a CAI dialogue which is very much a one-way communication process in which the system presents information and the student answers questions.

In this chapter, I shall discuss the concept of an intelligent dialogue system and present a detailed discussion of the operation of the system devised for ALBERT.

#### 6.2. Tutorial dialogue systems

##### 6.2.1. CAI and the concept of an intelligent dialogue

In a conventional CAI environment, the pattern of the dialogue is entirely pre-determined by the author of the lesson, even in branching programs. Ideally, as Trowbridge and Chiocciariello (1985) acknowledge, every possible response that the student is likely to make at any particular point in the dialogue must be anticipated. Consider the program in Figure 6-1.

The first instruction which appears on the screen is "Name a vector quantity." If the student types "I know that mass is a scalar", the system will respond with "That's not a vector". It cannot acknowledge the correctness of the statement because it was not anticipated at that point. If the student then types "force", this will be accepted and the student will be asked to name a scalar quantity, when he/she has just shown that he/she knows that mass is a scalar.

While it is possible to write programs which overcome this difficulty in a limited way by anticipating responses of the kind illustrated, the root of the problem is twofold.

- i) The context within which responses are made is restricted to the immediate rather than being allowed to span the full duration of the dialogue. This means that the student's input is nearly always judged in isolation from earlier inputs which he/she might have made.
- ii) The knowledge which the program has about the subject under discussion is local and specific rather than global and general. For example, the answer to each question is usually coded in at the point in the program where the question is asked. The computer does not have access to this knowledge throughout the session with the student.

Furthermore, the assumption that the student's response must be "correct", before he may proceed is not necessarily a valid one. If both parties may

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*
at      1010                $$ sets screen location for printing
write   1. Name a vector quantity.
arrow   where+1            $$ accept student input
specs   okextra            $$ ignore extra words
answer  velocity, force, etc.  $$ list of anticipated responses
write   That's right!       $$ response for a correct answer
no                                     $$ anything else is wrong
write   That's not a vector.  $$ response for wrong answers
endarrow

*
at      1210                $$ sets new screen location
write   2. Name a scalar quantity.
arrow   where+1            $$ accept student input
specs   okextra            $$ ignore extra words
answer  mass, speed, etc.    $$ list of anticipated responses
write   That's right!       $$ response for a correct answer
no                                     $$ anything else is wrong
write   That's not a scalar.  $$ response for wrong answers
endarrow

*

```

Figure 6-1: Program for a conventional CAI dialogue

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exercise initiative in the dialogue, the student may choose to postpone answering a particular question while other issues are considered.

Student frustration with "correct" answers was illustrated in a study undertaken at Rhodes University among 660 students using the PLATO system in a wide variety of disciplines (Oberem, 1984). In this survey, approximately 40% of those who responded complained of being stuck on occasion because the computer would not accept an answer which they believed to be correct, while there was no way of telling what the computer was expecting<sup>7</sup>.

The problems described are inherent in present day CAI author languages and authoring systems. It is assumed that authors will want to localize the knowledge as screens of text or as answers to particular questions. The context within which responses can be made is very restricted and, as a result of the "right answer" obsession, there is very little scope for student initiative. I believe that this concept of the nature of a CAI dialogue is partly due to the way in which CAI has evolved out of the traditions of Skinner and the programmed learning texts where a small unit of information was presented at a time to the student who was then required to answer a very specific question about it.

Figure 6-2 suggests how the ICAI model presented in Chapter 2 could be used to structure the CAI lesson about vectors. In this approach, there is a knowledge-base which is global to the lesson and a rudimentary context model which allows the computer to make use of earlier input from the student. A rule-based tutorial model guides the discussion.

The computer would begin by asking the student to name a vector quantity. If the student responds by saying "I know that mass is a scalar", the computer could respond with "I agree. Mass is a scalar, but you have not

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7. Other negative feelings towards the use of PLATO were related to the speed of the computer and specific defects in particular lessons. In spite of the frustrations mentioned, the overall response of the students in this study was extremely positive and almost 70% felt that they would like to spend more time using PLATO.

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Knowledge base:

Vector quantities include force, velocity, etc.

Scalar quantities include speed, distance, etc.

Context model:

The student has named a vector.

The student has named a scalar.

Tutorial model:

If the student has not named a vector quantity, ask him/her to name one.

If the student has not named a scalar quantity, ask him/her to name one.

If the student has named both, terminate the dialogue.

**Figure 6-2: Intelligent model of the vector/scalar dialogue**

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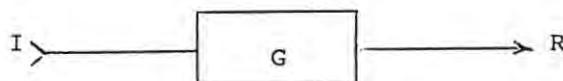
yet named a vector." At that point, the system already "knows" that the student can name a scalar quantity. If the student then correctly names a vector quantity, the dialogue will be terminated because the system knows from its context model that the student has named both a vector and a scalar. The second question will never be asked.

An important but subtle point here is that the dialogue would be terminated because the system "knew" that the student knew the answer, not because a particular string of text typed by the student was matched against the "correct" answer.

### 6.2.2. A systems approach

Any system may be represented in terms of its inputs and its outputs (Figure 6-3). For any input  $I$  to the system, the output  $R$  will be

$$R = G I, \quad \text{where } G \text{ is the system transfer function.}$$



**Figure 6-3: Systems analysis**

For a CAI system, the student types an input and the computer responds. We may represent this dialogue as

$$R(j) = G I(j)$$

where  $R(j)$  is the computer's response to the  $j$ th input,  $I(j)$ , from the student and  $G$  is the transfer function which relates  $R$  and  $I$ .

In a simple, traditional CAI system, the function  $G$  depends only on the most recent input from the student, i.e.,  $G = G(I(j))$ .

In a few of the more sophisticated CAI systems, it is possible to make use of the student's input which immediately preceded the present one. For example, if the student gets the answer wrong three times in a row, he may be given a hint or shown the correct answer. In this case,

$$G = G(I(j), p_1)$$

$$\text{where } p_1 = F(I(j-1), I(j-2), \dots, I(j-n))$$

The scope of function  $F$  is usually very limited. In most cases it merely counts the number of attempts at a question with " $n$ " typically less than 5.

The function  $G$  may thus be described as follows:

$$\begin{aligned} G(I(j), p_1) = & \text{"Well done!" for } I(j) \text{ matched and} \\ & \text{answer correct.} \\ & \text{"Wrong!" for } I(j) \text{ matched and} \\ & \text{answer incorrect and } p_1 < 3. \\ & \text{"Unknown." for } I(j) \text{ unanticipated and} \\ & p_1 < 3. \\ & \text{"The answer is.."} \text{ for } I(j) \text{ matched but wrong,} \\ & \text{or unanticipated, if } p_1 > 2. \end{aligned}$$

where  $p_1 := p_1 + 1$  if  $I(j)$  is wrong or unanticipated.

In this case,  $p_1 = F(I(j-1), I(j-2), I(j-3))$ .

In an intelligent dialogue system, the function G is expanded to handle student input in a more flexible manner and to embody the teaching strategy defined by the tutorial model.

In such a system, the response, R(j), would have two components, an acknowledgement that the input was understood, and a comment on it, pertinent to the instructional model. The latter will depend on the nature of the input. For example, if the student has just asked a question, then it must be answered. If the student has made an assertion, it must be checked and a comment provided which is relevant to the context and the goal of the discussion.

Thus we may write:

$$R(j) = R1(j) + R2(j)$$

where R1(j) = an "acknowledgement phrase" if the parsing  
was successful.  
an "input not recognized" phrase if the  
parsing fails.

R2(j) = F(Ic,g1,p1,p2,p3,.....pn) a comment  
for all successful parses.

0 if parsing fails.

where Ic = class of input, e.g. question, assertion, etc.  
g1 = current goal in the discussion  
and the pi are a collection of parameters which  
describe the current state of the dialogue context.

Figure 6-4 shows an example of this. In this case, the student makes an assertion which is acknowledged and confirmed by the computer.

The facility for mixed initiative is particularly important in a problem-solving dialogue, so that the students may have the freedom to solve the problem in whatever way they choose. This is not possible within the



discussion. Associated with the world is information about the concepts it contains and how they should be taught. This can be used to determine the teaching strategy. The student's state of understanding and history in the system are stored as a part of the data base.

At times, the system assumes full control and the student is not permitted to interrupt. However, at strategic points in the discourse, mixed initiative dialogue is allowed. This usually happens at the end of a "page" of subject matter. At this point, the student may ask questions, change the course of the discussion or leave it up to the system to determine what happens next.

Otsuki and Takeuchi (op. cit.) have shown the importance of the various parameters which are needed in the student model to make the student's initiative coexist with the teaching strategy of the BOOK system.

### 6.3.2. GUIDON

GUIDON (Clancey, 1979 & 1982) provides for a mixed initiative dialogue, although the language capabilities of the system are rather limited. At any point in the discussion, the student is able to state what he/she knows, what he/she would like to know more about, and what he/she wishes to ignore.

In GUIDON, the student model interacts dynamically with the tutoring rules to determine the flow of the dialogue. For example, the system decides, on the basis of the student model, when to interrupt the student and at what level of detail to discuss a particular concept with him/her. This is achieved through a set of "discourse procedures". A discourse procedure is a set of actions which the program can follow under a particular set of conditions governed by the complexity of the material under discussion, the student's understanding of the material and the current goals of the tutor.

In GUIDON, the information about the state of the discussion is held in two parts, viz., a record of inferences associated with each topic and whether or not they have been discussed, and a context. The latter contains information about topics which GUIDON thinks might be of interest

to the student and maintains a set of indices to remarks which have been made by the system, to allow unambiguous references back to them later and to avoid repetition.

Systems such as GUIDON and BOOK have demonstrated the complexities of implementing a tutoring system in which the initiative shifts dynamically from the computer to the student and back. The importance of the student model and a general dialogue context in achieving this has been amply demonstrated.

BOOK is designed to be able to teach a wide variety of topics. ALBERT's language capabilities are equivalent to one of the language world's in BOOK and ALBERT's knowledge would be represented by one of its knowledge worlds. In BOOK, the student may take the initiative only at certain points. In ALBERT, the discussion is controlled very tightly through the qualitative section, but ALBERT refuses to take the initiative during the solution phase. He will only interrupt at certain key places when the student gets stuck and will only offer advice when the student requests it.

GUIDON is an extremely well-developed system with in excess of 200 tutoring rules. ALBERT, although not as advanced, also makes use of a context model and a student model to guide the discussion. Like GUIDON, ALBERT keeps a record of what has been discussed for future reference and to avoid repetition.

#### **6.4. The structure of ALBERT's dialogue system**

##### **6.4.1. Overview**

The tutorial system in ALBERT has been implemented as an intelligent dialogue system. Its overall structure is shown in Figure 6-5.

The flow of control in the system is shown in Figure 6-6 and the general operation of the system is as follows. The tutorial management system examines the context model to determine the status of the discussion. The context model is comprised of a student model, a tutorial status model and a dynamic dialogue model and is used to focus the dialogue.

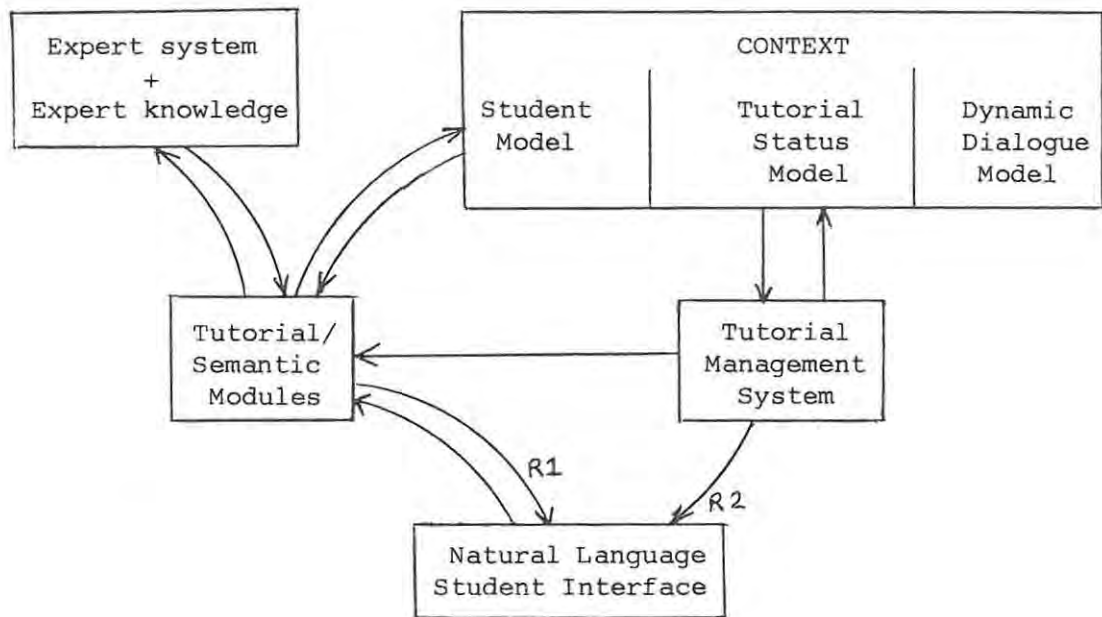


Figure 6-5: Overall structure of ALBERT's dialogue system

The student model holds information about what the student knows and what he has been doing with respect to solving the problem; the tutorial status model contains information about which aspects of the problem have been discussed and the current state of the solution process, and the dynamic dialogue model helps to maintain coherence by modelling the dynamics of the discussion.

Student input is made via a natural language interface which is a modified version of the natural language processor used for reading in the problem. The output from the natural language interface is directed to a particular tutorial module by the language system or tutorial management system, depending on the context. Semantic processing takes place in the tutorial modules which assess what the student has said; generate output to the screen and update the context model accordingly. This is the acknowledgement response, R1(j). If necessary, the tutorial modules may access the expert system to check the student's answers or assertions.

After a tutorial module has provided a specific response to the student's most recent input, control is returned to the tutorial management system

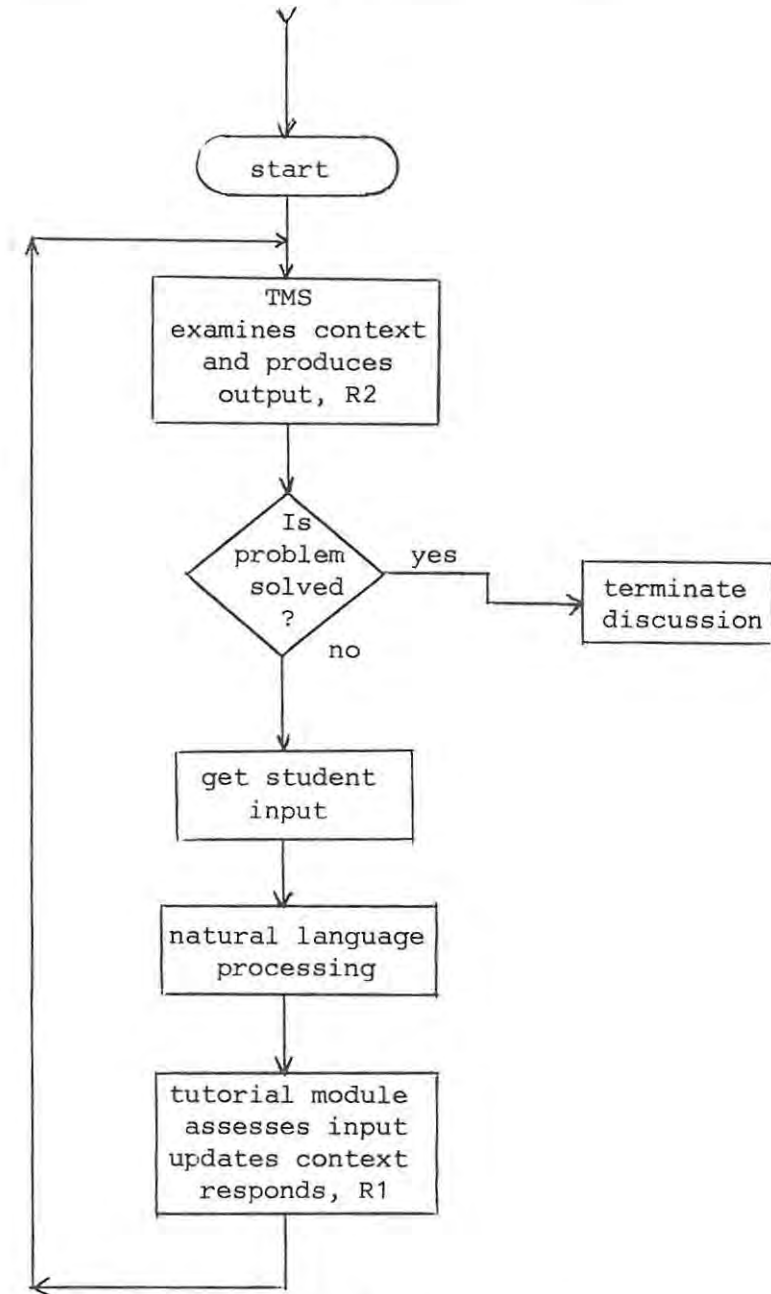


Figure 6-6: Flow of control in ALBERT's dialogue system

which may produce additional output,  $R2(j)$ , after consulting the tutorial status model in the context model. The system will then wait for further input from the student.

The use of the context with its student, tutorial status and dialogue models allows the kind of flexibility described earlier. When the

tutorial management system discovers that the student has finished solving the problem, the dialogue is appropriately terminated.

The natural language interface plays a key role in the operation of the system.

#### 6.4.2. The natural language interface (general considerations)

Natural language systems for use in dialogue situations have requirements which differ from those which are used for understanding complete passages of text. As Ritch (1983) points out, dialogue understanding is particularly difficult because it involves co-operation between the two parties on the basis of a shared set of assumptions about the nature of the conversation.

Bobrow, Kaplan, Kay, Norman, Thompson and Winograd (1977) discuss the problems of natural language dialogue in relation to their system, GUS, which was designed to simulate a travel agent making a flight reservation for a customer. In addition to the problem of providing mixed initiative, they identified four major difficulties which systems such as this need to overcome, viz.,

- indirect answers,
- resolving anaphora,
- sentence fragments, and
- conversational patterns.

The answer to a question in a dialogue is by no means always well defined. For example, the respondent may ask a further question for clarification or answer by supplying additional information in the hope that the questioner will then be able to figure out the answer. In principle, in a system like ALBERT, the question for clarification could be answered by an appropriate tutorial module which would refer to the expert system, or the additional information would update the context, possibly rendering the original question superfluous.

The parties in any dialogue legitimately assume that it is possible to refer economically, in terms of the number of words they use, to objects, ideas or concepts mentioned earlier. Keeping track of such references and

making the correct associations presents a severe problem. In systems like ALBERT, the context contains dynamic information about the current goal in the discussion. This helps to focus the dialogue and can aid the understanding of such references.

Part of the economical use of words in dialogues results in the participants using sentence fragments rather than syntactically complete utterances. This problem was recognized by the developers of SOPHIE, an electronics troubleshooting environment (Brown, Burton and Bell, 1975; Brown, Burton and De Kleer, 1982). They made use of the fact that certain concepts were always associated with particular syntactic categories and implemented a "fuzzy" parser using semantic grammar. Brown, Burton and De Kleer also note that the more experienced users of the system were less inclined to use complete sentences, and by a process of trial and error made themselves aware of the limits of the system. The fuzzy parser had the capability to skip words which were not in the dictionary and also ignored any input left over after a successful parse.

The latter could be problematic. Unlike the system ACE (Sleeman and Hendley, 1982), SOPHIE did not allow the expression of more than one concept in each input sentence. ACE was designed as a problem-solving monitor for students working on problems requiring the interpretation of nuclear magnetic resonance spectra. Sleeman and Hendley also note the need to skip syntactically invalid input and interpret semantically important phrases. In addition, their system accepts misspelled words and abbreviations.

Although ACE handles multiple concepts, it does so predictively, i.e., if concept A has been found, then concept B must follow. If a different concept, e.g., C, follows concept A, then the parser will fail. The interface has been specifically designed to cope with the presentation of a logical argument. The student builds up an argument by stating facts and making assertions and deductions to build up an explanation.

It was soon realized that ALBERT needed the ability to handle multiple concepts in a single input from a student. This feature, completely lacking in conventional CAI authoring languages and authoring systems, has been incorporated as a part of the dialogue natural language interface in

ALBERT.

The final point which Bobrow et. al. (1977) make is that conversations fit into predictable patterns. Within a particular context, the nature of the dialogue takes on a particular form. This is in accordance with Minsky's (1975) concept of stereotyped situations and has been noted by others (Lehmann and Bennett, 1985). Faught (1978) has studied conversational patterns in dialogues and has implemented a model of the recognition of situations and the performance of actions.

The natural language system devised for ALBERT is based on the assumption that the conversational patterns which arise in the discussion of Physics problems are highly specialized and fairly consistent, even for elementary students of the subject.

#### 6.5. The simulated ALBERT experiment

##### 6.5.1. Design

In order to investigate the nature of the dialogues further, it was decided to set up an experiment in which the role of ALBERT could be simulated by a human expert, while the learning environment for the student was kept as close as possible to its final form. The screen presentation was similar to that described in the previous chapter and illustrated in Figure 5-21.

The natural language system for reading in textbook problems and the problem-solvers had been completed, so it was decided to let the student use them, the human expert being substituted for the dialogue interface and tutorial guidance system. It was also decided to limit the discussion to the numerical solution of the problem, because of the difficulties associated with simulating the graphics of the qualitative discussion. The descriptive section is in any case less flexible than the solution part.

The program written to achieve this makes use of the fact that certain variables may be made common to any number of PLATO users working simultaneously. (In fact, a check was incorporated to ensure that only

one student used the program at a time!) A series of common flags was used to arbitrate input and output from the student and the expert, and a common response buffer was used so that neither party was aware of the other's typing. After each response, the buffer was written away, with timing information, to a PLATO student data file to allow later reconstruction and analysis of the dialogues.

Figure 6-7 illustrates the interaction between the two sections of the program.

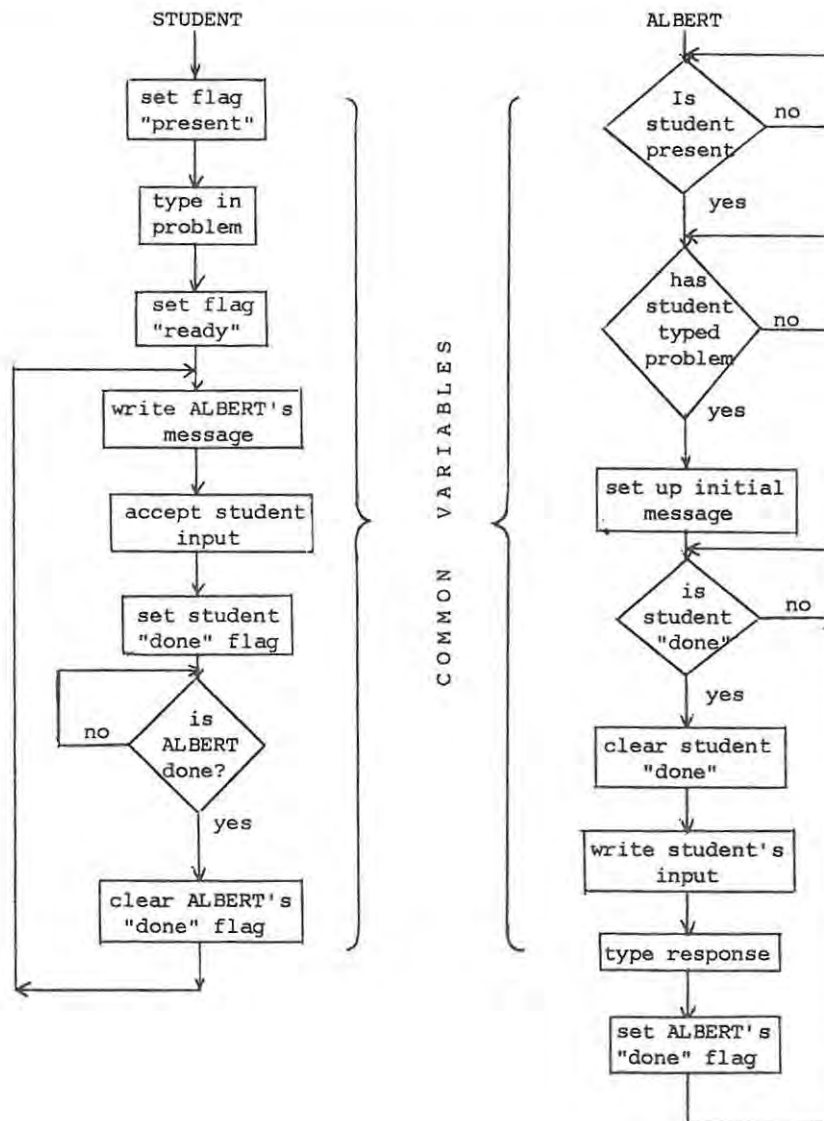


Figure 6-7: Interacting programs for simulation of ALBERT

### 6.5.2. Students and problems used

Seven students were picked at random from the Physics 1L class, a group of non-major Physics students, most of whom are studying the life sciences. As it turned out, there was a range of abilities from two very good students, who achieved a first class pass at the end of that year, to a student who failed to pass the course. The other three students achieved a third class pass at the end of the year. The typing ability of the group as a whole ranged from that of a trained touch typist to two finger hunting. Experience with computers varied from none (other than PLATO which they had all used earlier in the year) to slight. None of the students had taken a course in computer science.

Four problems were chosen for the experiment and are shown in Table 6-1. The problems were checked by experienced members of staff in the Department of Physics and Electronics at Rhodes University.

1. A bullet which has a mass of 0.020 kg experiences a force of 1025 N for a very short time at the start of its motion. Determine its acceleration during that time.
2. A motor car, initially moving with constant speed, undergoes a uniform acceleration of  $0.5 \text{ m/s}^2$  for 30 seconds. After this, its speed is 25 m/s. Calculate its initial speed.
3. A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it during its motion up the plane.
4. A stone is thrown vertically upwards with an initial speed of 15 m/s. How long will it take to reach a height of 8 m?

Table 6-1: Problems for the simulated ALBERT experiment

The first problem was intended to be very easy and was chosen to serve as an introduction to using ALBERT. The second problem can be solved by a straightforward application of the equation  $v_f = v_0 + at$ . It was intended to be easy and was selected as one for which it would not be too difficult for "ALBERT" to push the student into a solution by considering the definition of acceleration.

Problems 3 and 4 were chosen to be more difficult. In 3, a multi-step solution is called for. First one must calculate the acceleration using the equation  $v_f^2 = v_0^2 + 2ax$ , and then one may use the acceleration and the mass to calculate the force. Using ALBERT's approach, the acceleration can be found from  $\Delta v = at$ .  $\Delta v$  is known and the time,  $t = x/v_{av}$ .  $x$  is known and  $v_{av}$  can be calculated since both  $v_0$  and  $v_f$  are known.

The fourth problem is tricky because 8 m is not the maximum height reached by the stone. There are two answers and interpretation of the result is required. One has to use the equation  $x = v_0 t + (1/2)at^2$ . It is also an example of a problem in which ALBERT derives the equation just mentioned. This example was selected to see to what extent students could be persuaded to use ALBERT's method, in spite of the complexity of substituting back to derive the equation.

The purpose of the experiment was thus two-fold. Firstly, I wanted to investigate the patterns of natural language common to the discussion of Physics problems, taking into account the constraints of the medium, and secondly, I wanted to see to what extent students could be made to adopt the modified approach to solving problems of this kind.

The students were not told that they were interacting with a human, but they were told to expect a rather slow response from the program. This made co-ordination of the activities difficult, but it was felt worthwhile in the interests of making the simulation as realistic as possible. On one occasion, another lecturer was present during a session with a student, to give an independent assessment of the experiment and to participate in it.

### 6.5.3. Results

Four of the students were asked to solve all four problems. Only one student did not complete this assignment, missing out on the last problem, while one student chose to repeat a problem. A fifth student worked through two problems and two more students did one each. The students worked a total of 14.5 hours and in all 19 dialogues were collected. (One dialogue was lost due to technical problems.) The dialogues are shown in Appendix D.

#### 6.5.3.1. Problem 1: (4 dialogues collected)

As expected, the students found the first problem very easy. All knew Newton's second Law of motion and could rearrange the formula to calculate the acceleration. Two students began by writing down what they knew about the problem. Three students showed the tendency to go directly for an equation (Figure 6-8; response times are shown in seconds), while the other student allowed ALBERT to lead her to the equation by asking about the acceleration and its relationship to the force on the bullet.

---

Albert: How would you like to start?  
Swanepoel (212.1 s): which formula should i use ?

Albert: How would you like to start?  
Coombes (143.9 s): write the equations of motion

Albert: How would you like to start?  
Latre (39.8 s): Write an equation

Figure 6-8: Students choose an equation first

---

#### 6.5.3.2. Problem 2: (5 dialogues collected)

Again, several students began by trying to find an equation without saying why, or what it was that they wanted to calculate. It was not difficult, in this case, to compel the students to think about change in velocity and to get them to use  $\Delta v = at$ . Only one student resisted this very strongly and insisted on going directly (and legitimately) to the final answer in a single step (Figure 6-9).

---

Albert ( 24.4 s): How would you calculate the change in speed?  
Coombes (116.2 s): the final speed - the acceleration×the time  
that the car is accelerated

Figure 6-9: Student goes directly to the final answer

---

One student voluntarily came to see me the day after she had solved this problem with ALBERT to tell me that she had found the discussion very helpful and that she was excited because she felt that she had suddenly gained a new insight into the relationship between acceleration and change in velocity which she had never had before. I found this unsolicited comment most encouraging as it was indicative of the potential which ALBERT could have for making students feel that they had gained insight into some aspects of Physics.

#### 6.5.3.3. Problem 3: (7 dialogues collected)

Here it was also possible to get students to solve the problem using ALBERT's method. In each case, the student was made to calculate the elapsed time by considering the average velocity. This was then used with the change in velocity to calculate the acceleration and hence obtain the force. However, the students generally seemed unsure of average velocity. They tried to use initial velocity, final velocity and even change in velocity when they were supposed to use average velocity (Figure 6-10). One student even suggested that the acceleration,  $a = 1/2 \Delta v^2$ . As far as I can ascertain he was making a serious attempt (see dialogue DS-15 in the Appendix D).

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Donaldson ( 24.7 s): I also know that the car has travelled a distance of 0.3 m  
Albert ( 18.6 s): Excellent. How is the distance travelled related to the speed?  
Donaldson ( 55.4 s): distance = change of velocity/time  
Albert ( 31.4 s): Are you sure?  
Donaldson ( 96.6 s): No I think it should be  $\Delta v \times t = d$   
Albert ( 37.6 s): Do mean change is speed times time = distance travelled?

Figure 6-10: A student's knowledge of average velocity

In both problems 2 and 3, the technique of asking the student to state what it was that they wished to calculate and then making them relate that to other physical quantities and hence to a mathematical relationship appeared to work well.

#### 6.5.3.4. Problem 4: (3 dialogues collected)

This problem did not go as well as the other three. One of the students signed off mid'way through the problem and later claimed that she had run out of time. None of the students used ALBERT's method. The discussion of the solution of the quadratic equation was very clumsy due to the difficulty of representing the square roots on the screen.

Unfortunately, only one of the three dialogues was usable, so the results relating to the final problem were somewhat inconclusive.

#### 6.5.3.5. Overall impressions

The dialogues obtained from the simulated ALBERT experiment show that it is possible in a CAI environment to lead the student into thinking more deeply about a problem than they would otherwise be inclined to do. As suggested in the last chapter, making the student relate his current goal to other quantities, without thinking specifically about an equation appears to hold promise as a bridge between the qualitative description of a problem and its mathematical formulation.

It appears that many students will adapt readily to the use of ALBERT's approach to solving problems of this kind, and that in some cases this will lead to the student feeling more confident about the Physics involved.

The pressure of responding rapidly under the simulation conditions, did not always result in the best input from "ALBERT". Apart from directing the dialogue in haste, several spelling errors crept in and, in more than one case, the student's input was mis-read with minor confusion resulting. (Dialogue DS-11 in the Appendix shows an example of such an occurrence.)

### 6.5.3.6. Natural language considerations

Several points became clear with regard to the natural language interface required for ALBERT. Probably the most significant was that the students often expressed multiple concepts in a single input. Some of these are illustrated in Figure 6-11. At first, "ALBERT" rejected these, but later it was realized that they would have to be accepted as valid input.

---

Albert: How would you like to start?  
Student: Given mass= 0.020 kg ; force= 1025 N ; acc= ?  
Albert ( 22.3 s): Right. Do you know the distance travelled?  
Latre (144.6 s): Yes and the velocity. This would give the time  
as  
0.25 seconds. However this means we must assume that the car has  
a constant velocity.

Figure 6-11: Students express multiple concepts in a single input

---

Students frequently gave indirect answers to questions. They also assumed that ALBERT was aware of the context and, as expected, they frequently used sentence fragments rather than complete sentences. An interesting point about equations is that students tended to write them out in words from time to time, rather than using symbols. There are several examples of these types of input in the dialogues in Appendix D.

It was possible to identify several categories of response, such as questions, assertions etc., in the dialogues. The categorization of responses is fundamental to the operation of the natural language interface and is discussed in detail in the next section.

The simulation of ALBERT proved a fruitful testing ground for the approach to problem-solving and the dialogues produced were a valuable source of information for the design of the natural language interface. However, anyone contemplating an experiment of this kind should not underestimate the time required and the logistic difficulties of co-ordinating the activity.

## 6.6. The natural language interface

The dialogue natural language interface is a key component in ALBERT's tutorial system. As mentioned earlier, students become exceedingly frustrated when the computer does not understand their input.

### 6.6.1. A model of language processing in dialogues

In section 3.4, I proposed a model of language processing for the understanding of textbook problems. This may be modified as follows to describe language processing in dialogue situations.

1. The dialogue does not take place in isolation. As both speakers are aware, they are discussing a Physics problem about the linear motion with constant acceleration of some object. This is a stereotyped situation (Minsky, 1975). The context model which the parties to the dialogue use is a dynamic frame which is being instantiated as the dialogue progresses. One may thus expect to find a finite number of concepts discussed. The concepts correspond to the slots in the frame.
2. Associated with the stereotyped situation is a contextualized vocabulary, as described in section 3.4. For the dialogue, this would be a slightly modified version of the vocabulary used for the textbook problems, but it would still be of limited extent.
3. Understanding is expectation driven. Each participant knows what to look for in the utterances of the other.
4. Syntactic processing is normally not conscious. As with the problem statements, syntactic patterns associated with the frame are cues to the presence of important information. In a dialogue, the syntactic pattern may be a sentence fragment or, in the limiting case, a single word.
5. When a syntactic pattern is recognized, the process of understanding which follows comprises two steps. First the pattern is classified as to its type, e.g., question, assertion etc. (see below). Once the pattern type has been determined, semantic interpretation and the

formulation of a reply takes place. The pattern type points to the appropriate semantic processing and the nature of the reply required. Only those parts of the input which are identified as relevant syntactic patterns are processed at the deepest level of understanding.

The intermediate step of pattern classification is the most significant difference between the models of text processing and dialogue processing. The other difficulties associated with dialogues, such as resolving ambiguities due to references, form a part of the semantic interpretation. Recognizing multiple concepts in a dialogue input is no different from recognizing them in a portion of text.

The student-teacher dialogue in Figure 6-12, which is similar to portions of the dialogues obtained in the simulation, illustrates pattern identification and response formulation in a dialogue.

---

teacher: What do you wish to do now?

student: I know that the mass is 10 kg, so I want to use the equation  $F=ma$  to calculate the acceleration.

teacher: Ok, the mass is 10 kg, but you can't use  $F=ma$  to calculate the acceleration because you don't know the force.

**Figure 6-12: Sample dialogue to illustrate pattern identification**

---

In this example, there are three important syntactic patterns. The first is the assertion that "the mass is 10 kg". The assertion is checked to see if it is valid and the reply "Ok, the mass is 10 kg" is used to confirm that. The second pattern of interest is "use the equation  $F=ma$ ", which is a statement of intent. This brings the equation  $F=ma$  into the context frame. From this point on, both parties know that they are talking about  $F=ma$  until there is a change.

The third pattern is also a statement of intent, viz., "calculate the acceleration". This pattern establishes the current goal slot in the context frame. The second portion of the reply deals with both the statements of intent. First, it implies that the equation is acceptable

and secondly it comments on the attainability of the goal.

The natural language interface in ALBERT has been designed to work on the basis of this model and can perform in exactly the way illustrated above.

ALBERT's version of the same dialogue is shown in Figure 6-13.

---

albert: How would you like to start?  
oberem: I know that the mass is 10 kg so I want to use the  
equation  $F=ma$  and I want to calculate the acceleration.  
albert: You say that the mass is 10 kg.  
albert: Good, I agree. You want to use  $F=ma$ . Ok. The current goal  
is to calculate  $a$ .  
albert: You don't know  $F$ .  
albert: What do you wish to do now?

Figure 6-13: A dialogue extract from ALBERT

---

#### 6.6.2. Input classification

For the dialogue system, the dictionary used for the textbook problems was slightly extended. The same classification of words into groups was maintained, and two new categories were added for personal references such as "I" and interjections such as "help". The entire dictionary is used for both the textbook and the dialogue processors and is listed in Appendix A.

Analysis of the dialogues from the simulation and firsthand experience of this kind of teaching situation has allowed the identification of the seven classes of syntactic pattern shown in Table 6-2. Additional classes can easily be added at a later stage.

There are ambiguities among the categories. For example, an assertion is frequently expressed in the form of an equation, e.g.  $m = 10 \text{ kg}$ . Also the single word "right" could be an assertion about the direction of a vector or it could be an affirmation.

These difficulties must be resolved in terms of the context model during semantic processing.

1. Assertion with number, e.g. the mass is 10 kg.
2. Assertion without number, e.g. it depends on the mass.
3. Statement of intent, e.g., I want to find the acceleration.
4. Affirmation/negation, e.g., I agree/yes/no.
5. Equations, e.g.  $F=ma$  and force equals mass times acceleration.
6. Questions, e.g. why is the acceleration negative?
7. Requests for assistance, e.g. please help

Table 6-2: Semantic classes of syntactic patterns in dialogues

### 6.6.3. Overall structure of the dialogue NL interface

The overall structure of dialogue natural language interface is shown in Figure 6-14.

The student input is typed via a regular PLATO "arrow" structure. The student may type a maximum of 250 characters and whatever is typed is stored in an input buffer and judged "ok" in the PLATO sense of right and wrong. During the simulation, a buffer of the same length was used and on no occasion did a student attempt to type anything of this length. The input routine also removes spaces in equations, e.g.,  $F = m \times a$  becomes  $F=mx a$ , and converts words in equations to the appropriate symbols, e.g. change in velocity =  $a \times t$  becomes  $\Delta v = a \times t$ .

Then lexical analysis is initiated. This establishes the word boundaries, maps the input words into a large pseudo-array for later recovery during semantic processing and converts the input text into a bit pattern representing the classes of words used. This process has been described in detail in section 3.5.3. The only significant modification is that any

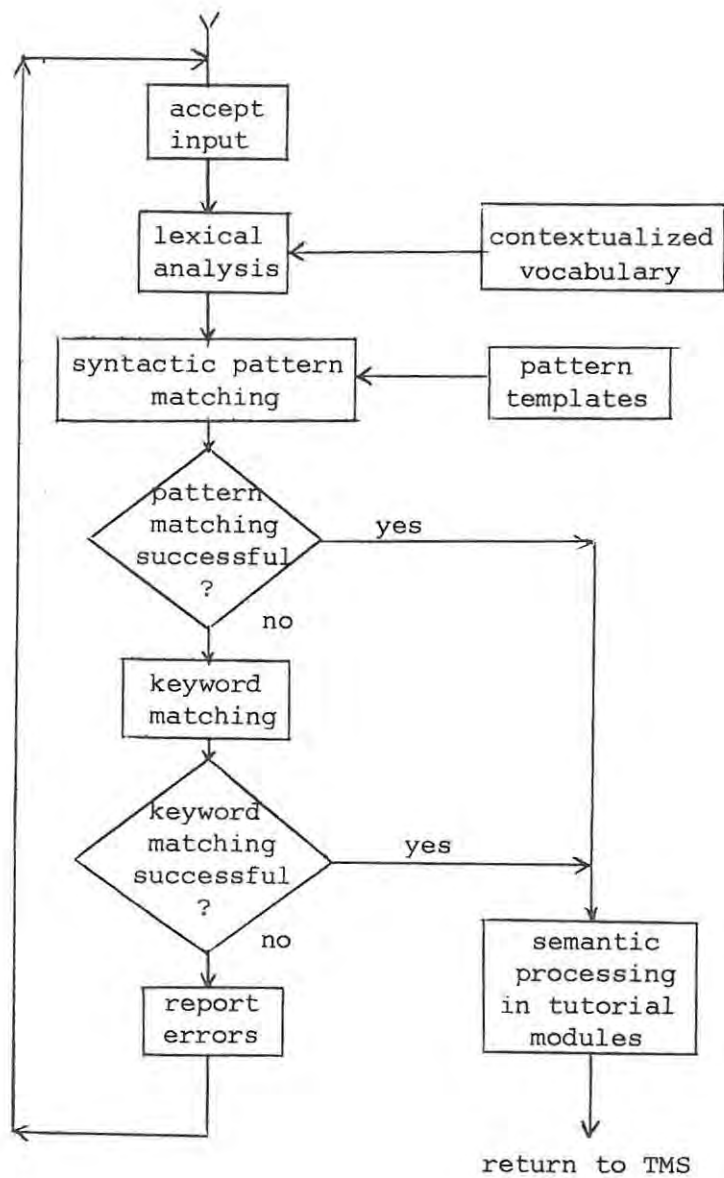


Figure 6-14: Structure of the dialogue natural language interface

words not in the dictionary are ignored at this stage and are only reported to the student if the rest of the parsing process fails. This type of "fuzzy" parse was used in SOPHIE and, as Brown, Burton and de Kleer (1982) point out, it can lead to misunderstandings.

Once the bit pattern representing the input text has been established, syntactic pattern matching is attempted as described in section 3.5.4. For the dialogue system, a different database of patterns is used. The list of patterns used in the dialogue interface is shown in Appendix E. The dialogue patterns were assembled by analysis of the dialogues from the simulation and were added to during the initial testing of the present version of ALBERT. The data format is identical to that described in Chapter 3 and illustrated in Figure 3-10. When a syntactic pattern is matched, semantic/tutorial processing follows immediately. The semantic processing takes place in the tutorial modules because it usually relates closely to the tutorial operations, e.g. checking the value of a quantity.

Any number of valid patterns in a single string of input text will be found. This allows the student to express multiple concepts in a single input. Syntactic pattern matching and semantic processing are interwoven and continue until no further patterns can be matched, at which point control is returned to the tutorial management system, as described in section 6.4.1.

If no syntactic patterns can be found, it could mean that the student has typed very few words or phrased the sentence badly. This is frequently the case in a dialogue, particularly when a reference is being made to a goal or an equation. In the simulated dialogues, it was apparent that students were more likely to abbreviate assertions in this way than statements of intent, questions or requests for assistance.

To allow for this, the language processor attempts keyword matching, when syntactic pattern matching fails. This is only done as a last resort. If a single syntactic pattern is matched, keyword processing will not be initiated. However, this means that if two ideas are expressed in a single input of which only one can be matched as a valid syntactic pattern the other will be ignored. Searching for keywords in this situation could lead to spurious interpretation of parts of the sentence already

processed.

The PLATO answer judging facility can be used to locate a keyword in a passage of text. However, it does not automatically indicate which word in the string of text was the one that was matched. On the other hand, this is important if one is to tie the semantic processing onto the keyword system. As a result, the keyword matching system is split into two sections. The first performs the classification of the input, while the second searches for words of a particular type in the text of the input. These would be words relevant to the interpretation of that class of input.

The keywords to be matched are grouped into classes as shown in Table 6-3.

1 = pure numbers	(checked by trying to store them as such)
2 =	(not used for technical reasons)
3 = equations	(when there is no equals sign)
4 = mathematical operations	(solve, rearrange, etc.)
5 = calculation	(related to setting a goal, intent)
6 = quantities	(mass, velocity, etc.)
7 = motion	(speeding up, slowing down, etc.)
8 = direction	(up, down, left, right, etc.)
9 = affirmation	(yes, etc.)
10 = negation	(no, not, etc.)
11 = unsure	(maybe, perhaps, etc.)
12 = questions	(why, what, etc.)
13 = don't know	(includes help, stuck, etc.)

**Table 6-3: Classes of keywords for the keyword matching routine**

Pure numbers are found by trying to store the numerical part of the input into a dummy variable using the PLATO `-store-` command. If this fails, there are no numbers in the input. The other groups of words are matched using successive `-answer-` commands and the class number is found in the PLATO system variable `-anscnt-`.

If a keyword match is found and more than one word was typed, the bit pattern formed from the input text is searched for a word of the type corresponding to the keyword matched. Its position in the input text is passed to the appropriate semantic routine as the location of the syntactic pattern would be. This allows the semantic routines to function normally, even when the syntactic pattern matching fails. If several similar keywords are used, they will each be found and processed independently. When all keywords have been processed, control is returned to the tutorial management system which determines the overall flow of the dialogue.

If keyword matching fails, then the natural language system has failed to understand the input. The student is so informed and asked to improve the input. At that point, words which are not recognized and words which are misspelled are pointed out to the user (Figure 6-15). The PLATO answer judging system includes a spelling correction algorithm (Nesbit, 1985) which is used to identify words which have been misspelled. The PLATO COPY and EDIT keys can be used for rapid correction of minor typographic errors.

---

```
albert: What do you wish to calculate?
oberem: accelertion
albert: Sorry, I do not recognise " accelertion".
       You have made a spelling mistake.
       (Use COPY to fix typing errors, or rephrase your sentence.)
oberem: the mountains are blue
albert: Sorry, I do not recognise " blue".
       (Use COPY to fix typing errors, or rephrase your sentence.)
```

**Figure 6-15: Unrecognized words**

---

Control remains with the language system until the student types an input which can be parsed either by syntactic pattern matching or by keyword matching. After that, the semantic/tutorial modules are used to assess the input and to respond to the student. Control then returns to the tutorial management system which may produce further output to the screen.

## 6.7. The context model

Another major component of the tutorial dialogue system is the context model. It is through the context that the dialogue is focussed, references are understood and the tutorial management system guides the discussion. The context model may be thought of as a meta-frame or schema. It has three components, a student model, a tutorial status model and a dynamic dialogue model. Figure 6-16 shows the structure of the context model.

### 6.7.1. The student model

The student model is an overlay model (Clancey, 1981b). In an overlay model the student's knowledge is considered to be a subset of that of the expert (O'Shea and Self, 1983). ALBERT's student model is made up of two parts, one representing the descriptive knowledge of the domain, the other representing quantitative knowledge about the problem. The descriptive part consists of a set of registers which indicate whether the student has made certain observations about the problem, e.g., that the acceleration is constant, and whether the student appreciates how certain quantities vary with time.

Initially, all these registers default to the "unknown" state. By the end of the qualitative discussion, they must indicate that the student has correctly interpreted the situation and shown some knowledge of the Physics. This kind of model does not try to make allowance for the misconceptions which the student might have. In the case of ALBERT, this is not required, as it is hoped that misconceptions will become apparent as the student expresses them in the dialogue.

The quantitative knowledge parallels that of the expert and is represented in the same way as the meta-knowledge about what the expert knows (Figure 4-7). The values of the quantities mentioned by the student are not stored. There is merely an indication of whether or not the student knows each quantity. If it has been ascertained that the student knows a quantity, then the value, units and direction would have been checked against the expert's knowledge and are assumed to be the same as that.

---

Student Model:

Descriptive knowledge:

has chosen an axis of reference

recognizes that the velocity is changing and how (increasing/decreasing)

recognizes that there is an acceleration

recognizes that the acceleration is constant

has indicated the direction of the acceleration relative to the axis

can identify correctly a graph of  $a_x$  versus time

can identify correctly a graph of  $v_x$  versus time

can identify correctly a diagram of  $x$  at constant  $t$

Quantitative knowledge:

knows the numerical values of:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$   $\Delta v$

associations between equations and goals

pattern of suggested relationships between quantities

-----

Tutorial status model:

qualitative section completed

summary and given information discussed

question established

a goal is under discussion

the quantities to which the goal is related have been made clear

an equation has been selected

the equation is in an appropriate algebraic form for answer evaluation

the answer has been evaluated

-----

/ Figure 6-16 continues.

Dynamic dialogue model:

current goal  
current equation  
direction of axis of reference  
most recent answer was right (used only in qualitative section)  
number of tries at current answer (used only in qualitative section)  
number of hints given  
student has been reminded about vector nature of velocity/displacement  
number of related quantities mentioned  
negation expressed  
yes/no expected next

-----  
**Figure 6-16: The context model**

---

Knowledge about which equations the student knows is not incorporated into the model. However, a dynamic record is kept of which equations the student has attempted to use to obtain particular goals. This gives the system the ability to "remember" plans formulated by the student, as illustrated in Figure 6-17. There is also a pattern of bits representing associations which the student has made between quantities without reference to a goal. (This is discussed more fully in section 6.9.1.)

#### 6.7.2. The tutorial status model

The tutorial status model is used by the tutorial management system to guide the tutorial as a whole in terms of the model presented in section 5.3. The first three registers in this section are used to ensure that the descriptive and summary stages are completed before the student attempts a numerical solution. They are also used by the tutorial modules in interpreting input from the student.

The next five registers have been set up to model the actions depicted in Figure 5-14. They are used by the tutorial management system as a default approach to the solution of the problem. This approach is suppressed if

---

albert: How would you like to start?  
oberem: let's find the acceleration  
albert: Ok. The current goal is to calculate a.  
albert: On what does a depend or what quantities could be used to calculate it?  
oberem:  $F=ma$   
albert: You want to use  $F=ma$ . Ok!  
albert: You need to rearrange the formula.  
oberem: let's rather find the time taken first  
albert: Ok. The current goal is to calculate t.  
albert: You want to use  $F=ma$ ....  
albert:  $F=ma$  does not contain t.  
albert: On what does t depend or what quantities could be used to calculate it?  
oberem:  $\Delta v=at$   
albert: You want to use  $\Delta v=at$ . Ok!  
albert: You don't know a.  
albert: You don't know  $\Delta v$ .  
albert: What do you wish to do now?  
oberem: Ok let's go back and find the acceleration  
albert: Ok. The current goal is to calculate a.  
albert: Do you wish to use  $F=m \times a$  to calculate a?  
oberem: no  
albert: Checking....  
albert: Type in a new formula.

Figure 6-17: ALBERT remembers associations between equations and goals

---

the student exercises initiative in solving the problem without going through all these steps, but the tutorial management system will force the student to make his goals clear in what he is doing. In the dialogue of Figure 6-17 the student did not allow ALBERT to constrain him to the model.

### 6.7.3. The dynamic dialogue model

The dynamic portion of the context model is used to make sense of references to goals, equations and quantities being discussed. It helps maintain general coherence in the discussion. This is mostly used by the tutorial modules. One of its functions is to keep track of the current goal and equation. The dialogue in Figure 6-18 shows how this information is used.

In the second line, the student supplies an equation. There is no goal at that stage, but the equation is placed in the dynamic dialogue model. As

---

albert: How would you like to start?  
 oberem: I want to use  $F=ma$   
 albert: You want to use  $F=ma$ .  
 albert: What do you wish to calculate?  
 A oberem: initial velocity  
 albert: Ok. The current goal is to calculate  $v_{\text{initial}}$ .  
 albert: You want to use  $F=ma$ ....  
 albert:  $F=ma$  does not contain  $v_{\text{initial}}$ .  
 albert: On what does  $v_{\text{initial}}$  depend or what quantities could be used to calculate it?  
 B oberem: initial velocity  
 albert: You say it depends on the initial velocity. No!  
 albert: On what does  $v_{\text{initial}}$  depend?  
 C oberem: 10 m/s  
 albert: You say that the initial velocity is 10 m/s.

Figure 6-18: Dialogue illustrating the role of the dynamic dialogue model

---

soon as the goal is established, the current equation is checked against it and the association is recorded in the student model. Also, at A and B the student makes two identical responses. In the first case, ALBERT concludes from the context that a goal is being stated. At B the context has changed and ALBERT reacts accordingly. At C the student quotes a number and units. ALBERT takes this to be a reference to the current goal.

Once a goal has been established, ALBERT assumes that comments which the student makes refer to that goal unless it has been made clear that they do not. Similarly, ALBERT assumes that the student is using the current equation unless it is made clear that this is not the case. The direction of the frame of reference is also held in the dynamic dialogue model for global reference.

Other registers in the dynamic dialogue model keep track of how much difficulty the student is having. If the student is unable to proceed but seems reluctant to ask for help, ALBERT may decide to give a hint. If the hint is insufficient, the student may eventually be given the answer. The "hints" register keeps track of the level of help given. The "related quantities" register is used to determine when to offer help without being

asked to do so and the "vector" quantities register is used to assess the level of reminder to provide for the student when he/she forgets the vector nature of a quantity.

The "negation" and "yes/no" registers were introduced to cater for specific expectations in the dialogue when they occur. For example, in certain cases, the student is asked the question "Do you mean as shown above?", referring to a diagram. The answer "yes" or "no" is meaningful in this context although not required. The "yes/no" register is used to indicate when this type of input is meaningful. An arbitrary "yes" will be rejected.

The "negation" register comes into play when the student makes a negative statement and is used to invert the logic of the meaning. However, as it has been found that students seldom use negative sentence structures, this aspect has not been fully developed at this point.

Unlike the registers in the student model and those in the tutorial status model, the registers in the dynamic dialogue model are continually changing. It is at this level, that the difficulties of references and initiative are addressed. For the moment, the model in ALBERT has been kept as simple as possible, while at the same time providing a reasonable level of coherence and intelligibility.

A better appreciation of the role of the context model can be gained by considering the operation of the tutorial management system.

## **6.8. The tutorial management system**

It is the task of the tutorial management system to implement the tutorial model described in Chapter 5. The tutorial management system has three components corresponding to the three phases of the discussion, viz., the descriptive part, the summary part, and the numerical solution part.

### **6.8.1. Descriptive tutoring**

Management of the qualitative discussion proceeds by examination of the student model. The descriptive tutoring model is embodied in the rules

shown in Table 6-4. These rules are applied sequentially by examining the context model and, if the condition part of the rule is matched, then an appropriate tutoring module is activated.

In practice, the student will proceed sequentially through these tutoring modules, although slight modifications are possible if the student shows knowledge of the Physics without being asked. For example, a student being asked whether the velocity is changing (rule 1) may show immediately that he knows that there is an acceleration and that the acceleration is

1. IF the student has NOT shown that he knows that the velocity is changing, THEN explore this idea with him.
2. IF the student has NOT shown that he knows that there is an acceleration, then explore this idea with him.
3. IF the student has NOT chosen a reference direction, THEN make him choose one.
4. IF the student has NOT indicated the direction of the acceleration relative to the axis of reference, THEN make him do so.
5. IF the student has NOT identified a graph of  $a_x$  versus  $t$ , THEN make him do so.
6. IF the student has NOT indicated in general terms how the velocity changes with time, THEN make him do so.
7. IF the student has NOT identified a graph of  $v_x$  versus  $t$ , THEN make him do so.
8. IF the student has NOT identified a diagram of the positions of the object at constant time intervals, THEN make him do so.

Table 6-4: Rules for descriptive tutoring

---

albert: So, this problem is about a train which moves.  
Does its velocity change during the period of interest?  
oberem: yes. It is accelerating and the acceleration is  
constant  
albert: Good! There is an acceleration. And it is a constant  
acceleration.  
\*\*\*\*\* Dialogue continues.....  
albert: You said earlier that the acceleration remains constant  
Now, which one of the graphs above correctly shows how  
the acceleration of the train varies with time?

Figure 6-19: Descriptive tutoring

---

constant. This will cause rule 2 to be skipped and modify the operation of rule 6 as demonstrated by the example in Figure 6-19.

The tutoring modules associated with these rules are mini-tutorial management systems in their own right and are not to be confused with the semantic/tutorial modules associated of the language interface. The general structure of a tutoring module is shown in Figure 6-20.

A tutoring module begins by generating output to the screen and initializing the context model. The initial output to the screen would usually take the form of a direct question. For example, the question "Is the velocity changing?" is used for the module associated with rule 1. Initialization of the context model includes the establishment of a goal, if necessary, and setting of default values for the number of tries, hints and the yes/no register. In the case of rule 1, since velocity is to be discussed, it is established as the current goal.

The student then types in some input via the language processing system. The input is parsed by the language interface and the semantic/tutorial modules update the context model and possibly generate output to the screen.

The tutoring module then examines the context and either returns control to the main tutorial management system or generates further output to the screen. This output depends on the context model for its level of help, if the student's input did not show his knowledge of the concept being

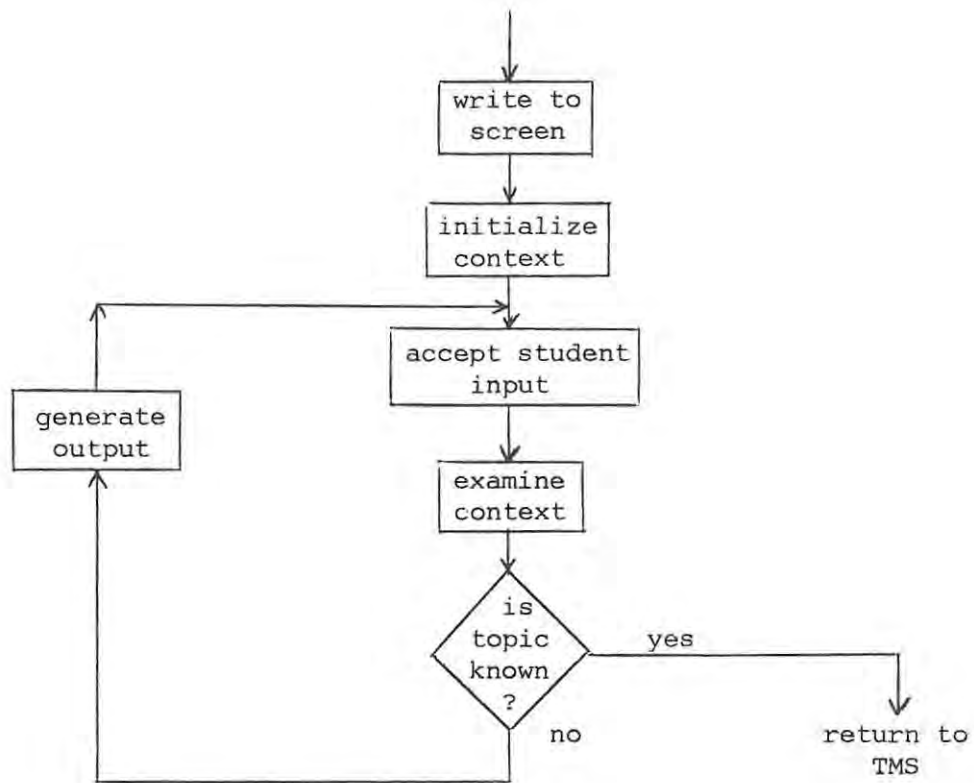


Figure 6-20: Descriptive tutoring module structure

---

explored. The cycle repeats itself until the student either demonstrates knowledge of the concept or is given the answer.

The tutorial management system leads the student through the qualitative discussion by applying the rules in Table 6-4 and using the associated tutoring modules as required.

Several special purpose routines were written to go along with the tutoring modules. For example, there is a routine to plot the graphs of  $a_x$  and  $v_x$  versus  $t$ . The position of the graphs on the screen depends on the length of the problem statement which is displayed at the top of the screen. Their order and hence the number corresponding to the correct answer is random and the characteristics of the set of graphs drawn depends on the nature of the problem.

The parameters of all the graphs are held in an array and a set of three

graphs is chosen for any particular problem. The right answer is put into the context model and checked against the student's input at the appropriate time.

Other routines were written to plot the reference axis and draw an acceleration vector relative to it, and to provide specific help with matters such as how to choose an axis of reference.

### **6.8.2. The summary stage**

The summary stage is a sequence of three tutoring modules. The first module summarizes the main points of the qualitative discussion and does not require any input from the student. The other two modules are constructed along the same lines as the descriptive tutoring modules described above.

The first of these two requires the student to show that he/she can extract all the useful information from the problem statement. The student may quote the information in any order and may specify all of it in a single string of input text, since the natural language interface can cope with multiple concepts. The semantic/tutorial modules update the context model and, when this tutoring module finds that the student has stated all the given information, it returns control to the tutorial management system.

The last tutoring module in the summary stage is designed to check that the student knows what the question is. Again, an appropriate semantic/tutorial module updates the context and control returns to the tutorial management system once the student has shown his knowledge of the question. Once the summary stage has been successfully completed, the student is permitted to proceed with the numerical solution.

### **6.8.3. The numerical solution**

During the numerical solution, the tutorial management system operates in the same way as the tutoring modules used for descriptive tutoring (Figure 6-20). ALBERT always begins this section with the question "How would you like to start?". The student types his input via the language interface

and the tutorial/semantic modules update the context model. The tutorial management system examines the context model and, if the student has solved the problem, the discussion is terminated. Thus, in the extreme case, the student could respond to the initial question with "xyz=123" and, if that were the right answer to the problem, that would be the end of the discussion.

However, this does not often happen, so the tutorial management system has to generate further output to the screen. The tutorial model for this section is embodied in the rules shown in Table 6-5. The tutorial management system uses these rules to evaluate the context model when generating output to the student. This allows a great deal of flexibility.

1. IF the student has NOT stated a goal, THEN make him do so.
2. IF the student has stated a goal but has not suggested an equation, THEN ask him to relate the goal to other quantities of interest.
3. IF the student has stated a goal and related it to quantities of interest but has NOT stated an equation, THEN find out if he knows the equation.
4. IF an equation has been stated but algebraic rearrangement is required, THEN advise the student to do this.
5. IF the equation is in a form where the goal may be evaluated, THEN ask the student to type in the numerical answer.
6. IF the problem is solved, THEN terminate the dialogue.
7. IF the problem is not solved, THEN reinitialize the context and continue.

Table 6-5: Rules for tutoring the numerical solution

ALBERT will generally try to get the student to state his goals. If the student begins by stating an equation, which is common, rule 1 applies and the student will be asked what he wishes to calculate. ALBERT remembers the equation and then assesses the usefulness of it once the goal has been stated (See Figure 6-18).

Figure 6-23 (at the end of this chapter) shows three examples of students solving the same problem. In the first case, the student is very passive and obediently answers ALBERT's questions, as he would have to do in a conventional CAI program. In the second example, the student takes a few short cuts. The final extract shows the trivial case in which the student merely states the answer.

If the student states a goal, but does not suggest an equation, he is asked what other quantities are related to the goal or could be used to calculate it. As discussed earlier, this is done in an attempt to make the student relate the current goal to other quantities without first trying to recall an equation. The student is not forced to show that he/she can make the necessary associations and many students type in an equation at this point which is acceptable as it demonstrates a knowledge of the relationship between the quantities anyway. If the student cannot answer the question in three attempts, ALBERT will interrupt the student and supply the answer.

When the student has chosen an equation which is recognized by ALBERT, he may be advised to rearrange it and then he will be asked to type in the numerical value of the goal on which he was working. The value of the goal is checked by one of the semantic/tutorial modules which also provides feedback to the student. When the tutorial management system finds, by inspecting the context model, that the student knows the answer to the problem, the dialogue is terminated.

The tutorial management system is concerned with the overall model of the tutorial discussion. It does not become involved in the specifics of tutoring, such as which equations to use or checking the student's answers. The latter is the job of the semantic/tutorial modules. This means that the instructional model can be augmented or entirely changed at

a global level by modifying the tutoring rules of Tables 6-4 and 6-5.

### **6.9. The tutorial modules**

The semantic/tutorial modules handle the specifics of what the student is saying. They judge his answers, give specific help and feedback, and update the context model. The modules correspond to the categories of semantic pattern identified by the language processor (Table 6-2).

When a syntactic pattern is identified by the pattern matching routine, a data element associated with the pattern template is used to point to the semantic routine needed. Similarly, when a keyword of the appropriate type is found by the keyword matching system, the corresponding semantic module is called as a subroutine.

There are eight entry points into the semantic/tutorial modules from the pattern matching program and several more from the keyword matching system. The semantic/tutorial modules deal with assertions, equations, affirmations, negations, statements of intent, questions, requests for help, and statements about the directions of vectors.

#### **6.9.1. Assertions**

Assertions occur in the two general forms indicated in Table 6-2, viz. with a numerical reference to some quantity or without. A parameter passed to the module which handles assertions indicates whether or not a number is present. Either way, it must first be established about what the assertion is being made. This is done by identifying the quantity mentioned. If no quantity was mentioned by name, as in "10 m", or if a reference was used, such as "it is 10 m", then it is assumed that the reference is to the current goal under discussion.

When a number is involved, its position in the pattern is passed to the assertion module as a parameter from the pattern matching routine. The number, along with its units, is stored in a temporary location, after the quantity being referred to has been identified. A routine is then called which checks the student's value against the expert's knowledge of the problem.

The units which the student has used are checked using the technique described in section 3.5.5.3. A feedback message is generated to provide the student with an assessment of his assertion. The dynamic dialogue model is used to determine the level of help to give, when that is required, and to see whether a reminder about the vector nature of a quantity is necessary.

Assertions about numbers come in a variety of forms ranging from "the acceleration is  $3 \text{ m/s}^2$ " to simply "3", the latter being a reference to one of three graphs displayed during the qualitative discussion. Students are also inconsistent about whether or not they leave spaces after the number and before the units. Special precautions have been taken to locate the units and combine them with the number for the correct operation of the -storeu- command. The routine written to check student answers is flexible enough to cope with all these variations.

The second class of assertion is the one which does not include a number. Examples of this type assertion are "it is speeding up" and "it depends on the mass and the force". Again it is necessary to identify the quantity being referred to and then to look for a modifier. In the first example, the student is indicating that the speed is increasing. In the second, the student is trying to relate the current goal to other quantities.

With this type of assertion, the context model has to be used to clarify the references. The first example above results in the student model being updated to show that he/she thinks that the velocity is increasing. In the second case, the student is making an assertion about quantities which may be used to calculate the current goal.

When a goal has been established ALBERT asks the student which quantities could be used to calculate it. A bit pattern is then set up which has elements corresponding to each of the quantities which the student could mention. The value of each element determines its relevance and hence the type of feedback given. When the student makes a valid association, a bit is set in a corresponding pattern in the student model. When the required number of bits is set in the student model, the tutorial management system knows that the student has mentioned all the relevant quantities.

If the student talks about deceleration, ALBERT ignores it and insists on using the term acceleration. Strictly, an additional comment should be added for this case to point out the dangers associated with the word deceleration and the concept of a negative acceleration.

### 6.9.2. Equations

First, it is necessary to distinguish between equations which are assertions and equations which are formulas. For example,  $x=3m$  is an assertion about the displacement whereas  $x=v_{av}t$  is a formula. In some cases, the distinction between an equation and an assertion may be subtle. For example,  $F=2ma$  must be assumed to be a formula but  $F=2m$  must be an assertion.  $F=2ma$  would be rejected as an unknown formula.  $F=2m$  would be rejected on the grounds that the units are incorrect, regardless of the significance of the number.

Upon recognizing that the input is in the form of an equation, ALBERT's first task is to determine whether the equation is an assertion or a formula. This is done by attempting to store the righthand side of the equation into a dummy variable using the `-storen-` command. Since all the symbols in legitimate equations are defined in a student define set, the attempt will succeed for a formula and fail for an assertion. However, there is one exception. The symbol for mass,  $m$ , is also used as an abbreviation for the units of length. This ambiguity is resolved by making the assumption that, if  $m$  is the only symbol on the righthand side of an equation, it is the unit of length and hence an assertion, otherwise it is assumed to be the symbol for mass. Generally this works well.

When an assertion is found, the input text is passed across to the module which handles assertions for processing as described above (6.9.1).

An additional complicating factor in recognizing equations is that the student should be free to perform algebraic operations on the equation before presenting it to ALBERT. It is not feasible to try to store every possible permutation and combination of each equation which the student might wish to use. Only those equations listed in Table 6-6 are stored in ALBERT.

---

$v_f = v_0 + a \times t$ $x = ((v_f + v_0) \div 2) \times t$ $x = v_0 \times t + \frac{1}{2} \times a \times t^2$ $v_f^2 = v_0^2 + 2 \times a \times x$ $F = m \times a$	$x = v_{av} \times t$ $v_{av} = v_0 + \frac{1}{2} \times \Delta v$ $v_{av} = v_f - \frac{1}{2} \times \Delta v$ $v_{av} = \frac{1}{2} \times (v_f + v_0)$
--	---

---

**Table 6-6: Equations stored in ALBERT**

Leibowitz (1985) discusses the judging of complex expressions in a PLATO program. In her case, she needed to recognize chemical formulas. A prime number was assigned to each term in the correct expression which was then evaluated to a number. The same values were used to "evaluate" the student's expression. If the two answers were within 1%, they were taken to be the same. Leibowitz actually wrote PLATO code to do the evaluation.

I have used a similar approach, except that I have made use of the fact that variables defined in a student define set can be evaluated by the system. To recognize an equation, all the variables are changed using a series of `-putd-` statements. The new variables hold a set of prime numbers. The student's equation is then loaded into the PLATO answer judging buffer and treated as though it were an algebraic expression. It is matched against all the known equations using the PLATO `-ansv-` command. This technique is extremely fast and very effective (Figure 6-21). A similar approach was used by Sherwood (1972) who did not use prime numbers. Instead, Sherwood used two sets of numbers and agreement had to be obtained for both.

The routine which recognizes equations first checks to see that the goal is present in the equation typed. If the equation does not contain the

goal, it is rejected on the basis of that. If the goal is present and the formula has already been rearranged to make the goal the subject of it, ALBERT will first manipulate each formula before trying to match it

---

Equation stored:  $v_f^2 = v_0^2 + 2 a x$

Equation recognized:  $x = (v_f + v_0) (1/(2a)) (v_f - v_0)$

Figure 6-21: An example of equation matching in ALBERT

---

against the one typed by the student. The routines mentioned in section 4.5.2 are used to rearrange equations.

Once an equation has been recognized, a pointer to it is held in the context model, but the form which the student used is retained for discussion. If ALBERT's form of the equation were used, confusion on the part of the student could result, if he has used the equation in a different form.

### 6.9.3. Affirmations/negations

Affirmations and negations mostly occur as a single word of input from the student. For example, students presented with questions like "do you know how to calculate the average speed?" or "do you mean as shown above?", usually respond with the single word "yes" or "no". Sometimes the question is ignored entirely. In the above example, the student may show that he knows how to calculate the average velocity by doing so.

Affirmations and negations are mostly handled by means of keyword matching. Also, the words "yes" or "no" are not permitted in isolation. They must follow in response to a request for confirmation by one of the parties to the dialogue. The "yes/no" register in the dynamic context model is used to keep track of this and affirmations or negations out of context are rejected.

A different type of negation is one in which a negative sentence structure has been used. For example, "It does not go up." This form of sentence structure was not found in the simulated dialogues and has not been observed in the testing of ALBERT. Provision has been made for its inclusion, but it has not been developed to any extent yet. When a negative sentence structure is detected, a flag will be set to denote the use of negative logic. The sentence will then be interpreted in the normal way but upon completion, the logic of the assertion will be inverted. This structure will be incorporated if students start trying to use it.

#### 6.9.4. Statements of intent

A statement of intent generally sets a goal. For example, "I want to calculate the acceleration now". Statements of intent may also refer to equations as in "I want to use  $F=ma$ ". In the latter case, a pointer to the appropriate part of the input text is set and control is passed to the module with the routines for identifying equations.

When the statement of intent refers to a goal, the quantity to be calculated is identified and the context model is set accordingly. If an equation has been mentioned prior to the goal being stated, the usefulness of the equation is automatically assessed when the goal is established.

Sometimes the goal is given as a single word of input from the student, e.g. "mass". When this is so, the context is used to determine that this is a statement of intent rather than an assertion without a number.

#### 6.9.5. Questions

Early testing of ALBERT and the simulated ALBERT has shown that students generally tend not to ask questions in this environment. This is perhaps because they do not realize the capabilities of a system such as ALBERT. ALBERT has the ability to answer direct questions such as "what is the value of the initial velocity?" However, this has not been developed yet. It will be when students start trying to use it.

A type of question which will be very difficult to answer with ALBERT in

its present form is a request for an explanation. The problem-solving expert in ALBERT can give advice about which equation to use or which goal to calculate next but, because of the way the problem-solvers are set up, knowledge about why these decisions are taken cannot easily be included.

From the students' point of view, this failing on the part of ALBERT has not proved to be a serious limitation thus far. The students have not questioned ALBERT's suggestions. The only direct question asked by a student so far was highly specific and beyond ALBERT's domain of knowledge. However, this is no justification for ignoring the problem.

#### 6.9.6. Requests for help

When a student presses the PLATO HELP key or states that he is stuck and is in need of help, the language system passes control to the help module. At this level, the context model is used to determine precisely where the student is and then appropriate help is offered.

In many cases, various levels of help are provided. The student is normally not given the answer right away. First, a hint is given or the student is simply encouraged to make an attempt at the question being asked by the tutorial management system (Figure 6-22).

When necessary the help routines consult the expert problem-solver. For example, if the student needs to establish a goal but does not know what he should do next, the help routine passes the student's current state of knowledge about the problem to the expert and examines the next step the expert would make on this basis. The knowledge passed to the expert for this purpose includes equations which have been used. As shown in Figure 6-22, the expert may suggest back tracking or substituting back. The expert can suggest an equation and when necessary can show how to rearrange it.

The limitation mentioned with regard to questions applies here too. When ALBERT advises the student to use a particular equation or set a certain goal, it cannot provide a reason along with the suggestion. As mentioned, this is due to the fact that the expert knows how but not why.

---

oberem: help  
albert: It is usually a good idea to choose the axis of reference in the direction of the velocity during the early part of the motion.  
oberem: I'm still stuck!  
albert: In this case, the best choice would be vertically up. (Try it that way!)

---

albert: How would you like to start?  
oberem: help  
albert: You should try to find  $t$  now.  
albert: On what does  $t$  depend or what quantities could be used to calculate it?  
oberem:  $\Delta v = at$   
albert: You want to use  $\Delta v = at$ . Ok!  
albert: You don't know  $\Delta v$ .  
albert: What do you wish to do now?  
oberem: help  
albert: You should try to find  $\Delta v$  now.  
albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
oberem:  $\Delta v = -100 \text{ m/s}$   
albert: You say that the change in velocity is  $-100 \text{ m/s}$ .  
albert: (That's the x-component of the change in velocity.)  
albert: Good, I agree.  
albert: What do you wish to do now?  
oberem: help  
albert: You should try to find  $t$  now by substituting back.  
albert: Do you wish to use  $\Delta v = at$  to calculate  $t$ ?

Figure 6-22: Requests for help

---

### 6.9.7. Directions

The final semantic/tutorial module deals with statements about directions. Statements about directions are usually assertions, but a separate module has been used because of the special requirements.

There are two ways of specifying directions, viz. absolute and relative. Absolute directions are left, right, up, down, or at some angle to the horizontal. They are screen orientated. Relative descriptions of directions include negative, positive, backwards, forwards and "the same". Relative directions are only meaningful once an axis of reference has been

established. The routines written to understand what students say about directions check this by consulting the context model to see if an axis of reference has been agreed upon.

In order to make it easy for students to indicate directions, the arrow keys on "a,q,w,e,d,c,x,z" may be used. ALBERT translates these into words as the student's input is stored in the input buffer.

Throughout the semantic/tutorial modules and the tutorial management system, text is generated by combining pre-stored phrases modified by the specifics of the problem statement and the current state of the context model.

#### 6.10. Capturing the dialogue

PLATO makes provision for capturing student data in a PLATO student data file. This can be done automatically while any lesson is running. However, there is no provision for storing the text which PLATO generates. Normally a number corresponding to the answer judging structure is stored in the data file and, since there is only one question and set of answers at that point, one may work out what the question was.

In ALBERT, it is not feasible to work out what statement or question was generated by the system at each point. For this reason, an unusual scheme was adopted for writing text to the screen. All text written to the screen is packed into a reply buffer using the PLATO `-pack-` command and written to the screen via a central routine which also writes the reply buffer to the student data file.

When the student completes his/her input, the input buffer is also written to the data file. This allows later complete reconstruction of the dialogue. (At present, the graphics is not reconstructed, but information could be written to the data file to permit this.)

#### 6.11. Overall operation

The annotated dialogue in Figure 6-23 at the end of this chapter which was reconstructed from data captured as described above gives a good overall

impression of the operation of the tutorial system as a whole.

#### 6.12. Initial testing

Every aspect of the tutoring system was thoroughly tested before the first students were asked to test it. The dialogue system typically responds in less than 100 ms. If a very long input is typed, with several concepts in it, the response time does increase, but it would rarely exceed 500 ms.

It should be noted that the language system and the semantic/tutorial modules run in "background". This could result in ALBERT running very slowly on a system with a lot of users. (On the four PLATO systems which I have used, I have never noticed a degradation in the performance of background lessons.) Also, ALBERT does not spend much time in background. Most of the time in the lesson is spent waiting for the student to type his/her input.

As more students use the system, one might expect to find sentence structures and syntactic patterns used which had not been allowed for. It is a relatively simple matter to incorporate these.

#### 6.13. Discussion

In this chapter I have described the tutorial system developed for ALBERT. ALBERT's dialogue system has been designed to provide a degree of flexibility in the problem-solving environment which is lacking in most conventional CAI programs. This system has the facility to conduct a mixed initiative natural language dialogue with a student.

The natural language interface makes provision for syntactic pattern matching to identify important sections of the input text. When the pattern matching system fails, the natural language processor has recourse to a keyword matching system. Generally this two-tier approach should result in a fairly robust language system and the implementation in ALBERT should transfer readily to other domains by modification of the pattern templates and keyword lists.

The dialogue is driven by a tutorial management system which is used to apply the tutorial model. A simple context model is used which consists of a student model, a tutorial status model and a dynamic dialogue model. The use of a context model introduces a new concept in student answer assessment rather than specific answer judging.

As the tutorial management system does not handle the specifics of tutoring, e.g., checking the students' answers, it can be modified to accommodate a different tutorial model without having to change the tutorial modules. Similarly, the tutorial modules may be changed or new ones added, e.g, to remedy common misconceptions which might be found, without the need for extensive modifications to the rest of the system.

The biggest limitation of the existing implementation is that it lacks the ability to offer explanations along with its suggestions. This is due to the fact that the expert system knows how to solve the problems but it has no knowledge of why particular equations are chosen or why particular goals are set when they are. Although this limitation has not proved serious in initial testing with students, from a tutoring point of view it is undesirable and needs to be improved upon. However this will probably necessitate major design changes to the expert problem-solving routines.

Problem:

A block of mass 10 kg experiences a force of 5 N.  
What is its acceleration?

---

albert: How would you like to start?

oberem: find a

albert: Ok. The current goal is to calculate a.

albert: On what does a depend or what quantities could be used to calculate it?

oberem: F and m

albert: You say it depends on the force. Good! I agree!

albert: You say it depends on the mass. Good! I agree!

albert: Do you know a formula which relates m, F, and a?

oberem:  $F=ma$

albert: You want to use  $F=ma$ . Ok!

albert: You need to rearrange the formula.

oberem:  $a=F/m$

albert: You want to use  $a=F/m$ . Fine!

albert: Type in the value you get for a.

oberem:  $a=0.5\text{m/s}^2$

albert: You say that the acceleration is  $0.5\text{m/s}^2$ .

albert: (That's the x-component of the acceleration.)

albert: Good, I agree.

albert: Well done! You have solved the problem.

---

albert: How would you like to start?

oberem: Given  $m=10\text{kg}$  and  $F=5\text{N}$  use  $F=ma$

albert: You say that the mass is 10 kg.

albert: Good, I agree.

albert: You say that the force is 5 N.

albert: (That's the x-component of the force.)

albert: Good, I agree. You want to use  $F=ma$ .

albert: What do you wish to calculate?

oberem: acceleration

albert: Ok. The current goal is to calculate a.

albert: You want to use  $F=ma$ ... Ok!

albert: You need to rearrange the formula.

oberem:  $a=F/m$  so  $a=0.5\text{m/s}^2$

albert: You want to use  $a=F/m$ . Fine!

albert: You say that the acceleration is  $0.5\text{m/s}^2$ .

albert: (That's the x-component of the acceleration.)

albert: Good, I agree.

albert: Well done! You have solved the problem.

---

albert: How would you like to start?

oberem: the answer is  $a=0.5\text{m/s}^2$

albert: You say that the acceleration is  $0.5\text{m/s}^2$ .

albert: (That's the x-component of the acceleration.)

albert: Good, I agree.

albert: Well done! You have solved the problem.

Figure 6-23: Examples of student initiative in dialogues

This is the reconstructed dialogue of a demonstration session with ALBERT. It should be noted that the format of the text in the reconstructed dialogue is not necessarily the same as the student would see on the screen, in that the reconstruction program begins a new line with "ALBERT:" for every new record of data. On the screen, several records may be written for one response from ALBERT. The numbers in parenthesis next to the student's name indicate how long, in seconds, it took him to type his input.

Oberem typing time: 26.4 s 09/30/86  
Oberem(28): A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?  
Albert: It is always useful to consider a problem qualitatively first.....  
Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.  
Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)  
Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

\*\*\*\*\* The tutorial management system examines the tutorial status model in the context and starts by applying rule 1 in Table 6-3.

Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

Oberem(24): yes it is slowing down

Albert: Sure, it is slowing down.

\*\*\*\*\* Here the student has done more than just answer the question given. The student model will record that he knows that the velocity is changing and that he knows that the bullet is slowing down.

Albert: And that means.....

Oberem(12): it is accelerating

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we shall need an axis of reference (x-axis). In which direction would you choose the x-axis?

Albert: (You can use FONT and w,d, etc. to get ↑→↘↙←↗.)

Oberem(27): at an angle

Albert: Do you mean as shown above?

\*\*\*\*\* With directions, ALBERT always draws a vector to show its interpretation of what was said and asks the student to confirm that it is correct.

Oberem(8): right

Albert: That is not a good choice. You will have to resolve vectors into their components unnecessarily.

\*\*\*\*\* The word "right" here is taken as a confirmation not as a direction. To resolve the possible ambiguity, the semantic/tutorial module made use of the dynamic dialogue model in the context.

Oberem(19): vertically up

Albert: Do you mean as shown above?

Oberem(4): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Oberem(7): opposite

Albert: Do you mean as shown?

Oberem(4): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?

Oberem(22): 2

Albert: You say that the answer is 2.

Albert: Sorry, I do not agree with that.

Albert: Think! Does the acceleration vary?  
Oberem(4): 3  
Albert: You say that the answer is 3.  
Albert: Good, I agree.  
Albert: You have said that the bullet is slowing down.  
\*\*\*\* Here the tutorial management system decided to skip rule 7 in Table 6-3 because it found that the student had already shown his knowledge of what was happening.  
Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.  
Oberem(14): 3  
Albert: You say that the answer is 3.  
Albert: Good, I agree.  
Albert: The bullet in this problem moves in a straight line. We may think of it as moving along the x-axis.  
Albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?  
(The x-axis has been drawn horizontally for conv  
Oberem(15): 1  
Albert: You say that the answer is 1.  
Albert: Sorry, I do not agree with that.  
Albert: In that one, the distance travelled in a given time increases. That would mean it is speeding up.  
So which one is it?  
Oberem(6): 2  
Albert: You say that the answer is 2.  
Albert: Good, I agree.  
Albert:  
The distance travelled in a given time decreases.  
Albert: -----  
\*\*\*\* The tutorial management system continues to apply the rules in Table 6-3 until at this point, the tutorial status model indicates that the qualitative discussion is complete.  
Albert: Now for a summary of what we know.....  
Press NEXT.  
Albert: So to sum up: We are considering a bullet which moves with constant acceleration.  
Albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.  
Albert: The x-component of velocity changes linearly with time.  
Albert: -----  
Albert: For any problem of this kind, it is important to extract all the useful information from the problem statement.....  
Albert: So, what information is given in the problem statement?  
Oberem(24): initial velocity and acceleration  
Albert: What is its value?  
Albert: There is still some given information which you haven't mentioned.  
Oberem(25):  $v_0=100\text{m/s}$  and acceleration= $-10\text{m/s}^2$   
Albert: You say that the initial velocity is  $100\text{ m/s}$ .  
Albert: (That's the x-component of the initial velocity.)  
Albert: Good, I agree.  
Albert: There is still some given information which you haven't mentioned.  
\*\*\*\* Although the student stated two concepts, one was ignored due to the misspelling.  
Oberem(9):  $a=-10\text{m/s}^2$   
Albert: You say that the acceleration is  $-10\text{ m/s}^2$ .  
Albert: (That's the x-component of the acceleration.)  
Albert: Good, I agree.

Albert: There is still some given information which you haven't mentioned.

Oberem(9):  $v_f = 0 \text{ m/s}$

Albert: You say that the final velocity is  $0 \text{ m/s}$ .

Albert: (That's the x-component of the final velocity.)

Albert: Good, I agree.

Albert: What are you asked to find?

Oberem(6): displacement

Albert:

Albert: That's right!

Albert: That completes the descriptive part.

Press NEXT.

Albert: -----

Albert: Now to the solution of the problem.....

(Remember, symbols used are:  $v_g$ ,  $v_f$ ,  $x$ ,  $t$ ,  $a$ ,  $m$ ,  $F$ ,  $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?

Oberem(5): help

\*\*\*\*\* The student activates a help module. The help tutorial modules in this case examine the tutorial status model and determine that the student needs to set a goal. The student's "known" information is then passed to the expert problem-solver which comes up with the suggestion to calculate the elapsed time.

Albert: You should try to find  $t$  now.

Albert: On what does  $t$  depend or what quantities could be used to calculate it?

Oberem(19): change in velocity

Albert: You say it depends on the change in velocity.

Albert: Good! I agree!

Albert: So  $t$  depends on  $\Delta v$  and what else?

Oberem(8):  $x$

Albert: You say it depends on the displacement.

Albert:

Yes, but that's not much use here. -

Albert: So  $t$  depends on  $\Delta v$  and what else?

Oberem(6):  $v$

Albert: You say it depends on the velocity.

Albert:

Please specify;  $v_g$ ,  $v_f$ ,  $\Delta v$ ,  $v_{av}$  or what?

\*\*\*\*\* At this point, ALBERT finds (from the dynamic dialogue model) that the student is getting nowhere and decides to interrupt and tell him the answer.

Albert: You can use the acceleration  $v_f$ ,  $\Delta v$ ,

Albert: and the change in velocity

Albert: to calculate the time.

Albert: Do you know a formula which relates  $a$ ,  $\Delta v$ , and  $t$ ?

Oberem(11): no

Albert: Checking....

Albert: Type a formula or ask for help.

Oberem(2): help

Albert: You could use  $\Delta v = a \cdot t$ .

Albert: Do you wish to use  $\Delta v = a \cdot t$  to calculate  $t$ ?

Oberem(4): yes

Albert: Checking....

Albert: You don't know  $\Delta v$ .

Albert: What do you wish to do now?

Oberem(3): help

Albert: You should try to find  $\Delta v$  now.

Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?

Oberem(13):  $v_f$  and  $v_g$   
 Albert: You say it depends on the final velocity.  
 Albert: Good! I agree!  
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 \*\*\*\*\* ALBERT recognized the multiple concepts expressed as keywords here.  
 Albert: Do you know a formula which relates  $v_g$ ,  $v_f$ , and  $\Delta v$ ?  
 Oberem(26):  $\Delta v = -100 \text{ m/s}$   
 \*\*\*\*\* Here the student chose to ignore ALBERT's question.  
 Albert: You say that the change in velocity is  $-100 \text{ m/s}$ .  
 Albert: (That's the x-component of the change in velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Oberem(18): find t  
 Albert: Ok. The current goal is to calculate t.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 \*\*\*\*\* ALBERT remembers that the student had earlier wanted to use this equation to calculate the elapsed time. These associations are part of the student model.  
 Oberem(14): yes t=10s  
 \*\*\*\*\* Here the student also makes two statements in one input.  
 Albert: You say that the time is 10 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Oberem(13): find the distance travelled  
 Albert: Distance is a scalar quantity. It is always positive. We must work with the x-component of the displacement.  
 \*\*\*\*\* From the context, ALBERT sees that the student needs to be reminded about the fact that distance is a scalar. If the student makes this mistake again, the reminder will be different because ALBERT knows that the student has been told before.  
 Albert: Ok. The current goal is to calculate x.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Oberem(18): help  
 \*\*\*\*\* The student remembers that he was given the answer before, so he asks for help. However, ALBERT forces the student to attempt an answer.  
 Albert: Please try to answer.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Oberem(8):  $x = v_{av} t$   
 Albert: You want to use  $x = v_{av} t$ .  
 Albert: Ok!  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?  
 Oberem(10):  $v_{av} = 50 \text{ m/s}$   
 \*\*\*\*\* The student makes an assertion about a quantity and thereby cuts the discussion short.  
 Albert: You say that the average velocity is  $50 \text{ m/s}$ .  
 Albert: (That's the x-component of the average velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Oberem(12): calculate x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: Do you wish to use  $x = v_{av} t$  to calculate x?  
 \*\*\*\*\* ALBERT remembers another equation which the student has used before.  
 Oberem(4): yes  
 Albert: Checking....  
 Albert: Fine!

Albert: Type in the value you get for x.  
Oberem(4): 500m  
Albert: You say that the displacement is 500 m.  
Albert: (That's the x-component of the displacement.)  
Albert: Good, I agree.  
Albert: Well done! You have solved the problem.  
Albert: Press NEXT to do another problem,  
          or DATA to see ALBERT solve this one.  
\*\*\*\*\* When the problem has been solved, ALBERT offers to show the student  
the solution.

Figure 6-24: A demonstration dialogue with ALBERT

## Chapter 7

### ALBERT and the students

ALBERT was designed to be used by students. It is therefore important to answer the following two questions.

- a. Can ALBERT conduct a sensible and coherent dialogue with a real student and thereby lead him/her through the solution of a particular 1-D kinematics problem?
- b. How do the students feel about ALBERT? Do they see ALBERT as something which is fundamentally different from other CAI lessons which they have used and do they think that ALBERT is potentially useful to them?

The question of whether or not a system of this kind can be effective in bringing about an improvement in a student's understanding of the Physics or his ability to solve problems of this kind is important, but it is beyond the scope of the present work and depends to a large extent on the findings with regard to the first two questions.

In addition to the question of what students think about ALBERT, it is also important to test expert opinion of the system. After all, it will be through the interest of academics who teach elementary Physics that the tutorial model will be refined.

Finally, ALBERT records students' thoughts and utterances about elementary Physics in a non-threatening environment where the students should feel a large degree of freedom to express their personal views of the subject. This should provide an ideal setting in which to study students' misconceptions of elementary Physics.

In this chapter, I present the results of student interactions with ALBERT and the opinions of students about the system. In addition, the views of two expert Physicists who worked through a problem using ALBERT are presented. Some indications are given as to how ALBERT might be used to identify and remedy common misconceptions which students have about this

area of Physics.

### 7.1. Student use of ALBERT

It was decided that the testing of ALBERT should progress through the following phases.

1. A limited number of students would attempt a single problem, carefully chosen to put ALBERT through his paces. This would show up any bugs in the program and draw attention to particular features with which the students may have difficulty.
2. A limited number of students would attempt four selected problems. This would take place after ALBERT had been modified in accordance with the findings of the first phase. Hopefully this phase would confirm ALBERT's readiness for general release.
3. A larger group of students would use ALBERT to solve the same set of problems and this would lead into the general release of the program. By the time the third phase was under way, there would be a clear indication of how well ALBERT would be able to cope with the real dialogue situation.

In practice, it was difficult to constrain the use of ALBERT as suggested above, because some of the students involved in the first phase of testing requested additional problems and, during the mid-year examinations, several students, not previously involved, asked to use ALBERT.

To date, approximately 25 students have used ALBERT in the various stages of testing and a total of 84 dialogues have been collected. A representative selection of dialogues including those referred to in this chapter may be found in Appendix F. The dialogues are numbered in approximate chronological sequence. Unfortunately, none of the students who participated in the simulated ALBERT experiment was available to test the final version of the system.

It should be noted that ALBERT's performance was monitored regularly and that minor adjustments were made to overcome some of the shortcomings

which the students exposed. A major modification was made between dialogues D-19 and D-20 to make ALBERT talk more consistently about vectors and their components. This is because many people talk about speed when they should refer to the component of velocity in some direction and about distance when they mean a component of displacement. The kinematic equations require the use of the scalar components of the vectors, whereas distance and speed are scalars and are always positive. From dialogue D-20 onwards, ALBERT talks only about velocity and displacement, and reminds students about the vector nature of these quantities when they talk about distance and speed.

A second major change was implemented after dialogue D-44. This forces students to demonstrate that they are able to extract the information which is given in the problem statement, whereas prior to this, ALBERT merely told them what was given, as a part of the problem summary.

#### 7.1.1. Initial testing

##### 7.1.1.1. Problem used

For the initial tests, stage 1 above, the problem shown in Figure 7-1 was used.

---

Problem: A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

Figure 7-1: A problem for initial testing

---

This problem was chosen because it is not difficult to solve using either the traditional method or ALBERT's approach. Using the regular approach, one would pick the equation  $v_f^2 = v_0^2 + 2ax$  because  $v_f$ ,  $v_0$ , and  $a$  are known. The maximum height is easily calculated from the equation.

Using ALBERT's method, one notes that the maximum height is  $x = v_{av} t$ .  $v_{av}$  is easily found as both  $v_f$  and  $v_0$  are known and  $t$  can be calculated since  $\Delta v = at$  and both  $\Delta v$  and  $a$  are known.

However, the problem was also used because the axis of reference is best chosen vertically upwards rather than in the horizontal direction and because of the negative signs associated with the components of some of the vectors. The students were more likely to have difficulty with the qualitative description in this problem than one in which the axis was chosen horizontally and the component of acceleration was positive. It was felt that the discussion of this problem was likely to put ALBERT through his paces.

#### 7.1.1.2. Results of initial testing

Nine students were picked at random from the Physics 1L class, a group of non-major students predominantly studying Pharmacy and the Life Sciences. They were asked to solve the bullet problem. One very weak student generated seven dialogues by restarting when things did not go well. A few others worked through it twice. In all, 19 dialogues were collected (D-1 to D-19).

Before ALBERT was ready for the next phase of testing, some of the students who participated in the initial testing and a few others who had got to hear about ALBERT requested permission to use it while they were preparing for the mid-year examinations. For this, a sheet of 25 problems was prepared and supplied to the students. This resulted in a further 24 dialogues (D-21 to D-44) which were regarded as an extension of the initial testing stage.

In terms of its overall operation, ALBERT has worked as it was expected to from the start. This was very encouraging, bearing in mind the unusual program structure and flow control, particularly in the numerical solution part. In the dialogue D-5, for example, ALBERT handled the student in a very satisfactory manner, apart from two spurious comments. The dialogue D-9 is another example of a successful interaction between a student and ALBERT which was collected in the early stages of testing. These dialogues were successful in that ALBERT understood everything that the students said and responded in a sensible manner throughout.

In both of the cases just cited, the students opted to use the kinematic

Mcbean(41): find x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Mcbean(79): x depends on a,  $v_0$ , t  
 Albert: You say it depends on the initial speed.  
 Albert: Do you know a formula which relates these quantities?  
 Mcbean(39): yes  
 Albert: Checking....  
 Albert: Please type in the formula you want to use.  
 Mcbean(45):  $v_f^2 = v_0^2 + 2ax$   
 Albert: You want to use  $v_f^2 = v_0^2 + 2ax$ .  
 Albert: Ok!  
 Albert: You need to rearrange the formula.  
 Mcbean(66):  $(v_f^2 - v_0^2) / 2a = x$   
 Albert: You want to use  $(v_f^2 - v_0^2) / 2a = x$ .  
 Albert: Fine!  
 Albert: Type in the value you get for x.  
 Mcbean(17): 500 m  
 Albert: You say that the distance is 500 m.  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.

---

Albert: How would you like to start?  
 Genney(30):  $v_f = v_0 + at$   
 Albert: You want to use  $v_f = v_0 + at$ .  
 Albert: What do you wish to calculate?  
 Genney(7):  $v_f$   
 Albert: The value of  $v_f$  is given in the problem statement.  
 Albert: What do you wish to calculate?  
 Genney(13):  $v_0$   
 Albert: The value of  $v_0$  is given in the problem statement.  
 Albert: What do you wish to calculate?  
 Genney(9): t  
 Albert: Ok. The current goal is to calculate t.  
 Albert: You need to rearrange the formula.  
 Genney(21):  $t = (v_f - v_0) / a$   
 Albert: You want to use  $t = (v_f - v_0) / a$ .  
 Albert: Fine!  
 Albert: Type in the value you get for t.  
 Genney(14): 10 seconds  
 Albert: You say that the time is 10 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Genney(58):  $x = t * [(v_f + v_0) / 2]$   
 Albert: You want to use  $x = t * [(v_f + v_0) / 2]$ .  
 Albert: What do you wish to calculate?  
 Genney(6): x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: Ok!  
 Albert: Type in the value you get for x.  
 Genney(8): 500m  
 Albert: You say that the distance is 500 m.  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see Albert solve this one.

Figure 7-2: Students successfully solved the problem in different ways

equations and did not give ALBERT the opportunity to suggest his method. This is not always the case, and Figure 7-2 shows how two students solved the bullet problem in very different ways. It is interesting to note that Genney in effect used ALBERT's method. He first used the change in velocity to calculate the elapsed time and then used the average speed and the time to calculate the displacement. McBean on the other hand ignored ALBERT's suggestion that the displacement depends on the average velocity and the elapsed time and picked the equation  $v_f^2 = v_0^2 + 2ax$  which she used successfully.

However, in many of the early dialogues, ALBERT had trouble understanding some of the student input and this resulted in a fair amount of frustration on the part of the students. It is interesting to note that it was mostly the keyword system which gave trouble due to omissions.

In general, the qualitative discussion worked well from the beginning. The only part of this which gave trouble fairly consistently was the specification of directions. In several dialogues, students had trouble making ALBERT understand the sense of direction of the axis of reference and the direction of the acceleration relative to it. Some examples of this are shown in Figure 7-3.

In Example 1, ALBERT did not recognize the word "vertical". The word had not been included in the list of keywords for directions due to the ambiguity associated with it. It was included at that stage and trapped in the tutorial module which checks statements about directions. Example 2 shows how ALBERT deals with it now. This is still a popular response and appears in several later dialogues, suitably clarified by the student after ALBERT's question.

Example 3 shows a case where ALBERT was in the right. The terms "positive" and "negative" are only meaningful once a reference direction has been established. This is not an isolated instance of this inadequate description. Examples 4 and 5 illustrate some of the other difficulties which students had while trying to express their ideas about the direction of the reference axis.

---

Example 1 (from D-1):

Cayzer(41): the axis should be vertical  
Albert: Sorry, I do not understand that.  
(Use COPY to fix typing errors, or rephrase your sentence.)  
Cayzer(13): help

Example 2 (from D-7):

Albert: Your axis is at right angles to the direction of motion.  
That is not a good choice.  
Blackie(60): then let it be vertical  
Albert: Up or down?  
Blackie(8): up  
Albert: Do you mean as shown above?

Example 3 (from D-3):

Sellers(62): positive  
Albert: That only makes sense relative to an axis.  
Sellers(16): help

Example 4 (from D-26):

Hobson(23): in the direction of-x  
Hobson(14): help  
Hobson(23): in the direction of velocity  
Hobson(4): help

Example 5 (from D-20):

Genney(7): sideways  
Albert: Sorry, I do not recognise " sideways".

Figure 7-3: Student difficulties with specification of directions

---

After a while it was realized that part of the difficulty here was that in a person-to-person discussion or even an examination question, the student would be more likely to draw a reference axis than to describe it verbally. It was therefore decided to let the student use the PLATO arrow keys to show directions. In ALBERT the keys are activated by pressing the FONT key and then "d", "w", "x", etc. These keys have arrows marked on them and, for example, FONT-d draws an arrow to the right. (This was considered easier for the student than the standard PLATO key presses of MICRO-shift-d, etc.) Students still have the option to type in words and this seems to have solved the problem at this point.

Spelling was a problem for some students (Figure 7-4). However, there is a system variable in PLATO which indicates when a word typed in is close

enough to a word in the dictionary to be classified as a misspelling of the dictionary word. It was thus decided to put that information to use as shown in the final example in Figure 7-4.

---

```
Van heerd(20): verticle
Albert: Sorry, I do not recognise " verticle".
      (Use COPY to fix typing errors, or rephrase your sentence.)
Van heerd(30): hirizontal
Albert: Sorry, I do not recognise " hirizontal".
      (Use COPY to fix typing errors, or rephrase your sentence.)
Van heerd(34): horizontal

graham: hirizintal
albert: Sorry, I do not recognise " hirizintal".
        You have made a spelling mistake.
        (Use COPY to fix typing errors, or rephrase your sentence.)
```

Figure 7-4: Misspellings in student input

---

In the numerical section, students had a lot of difficulty remembering the symbols used by ALBERT. Because of the way in which equations are checked, ALBERT regards them as numerical expressions. If an unrecognized symbol is used, the equation is classified as an invalid numerical expression. If the equation contains only known symbols, but is not recognized, then the student may have performed invalid algebraic operations on the equation. The PLATO system variable -formok- was incorporated to good effect here (Figure 7-5).

---

```
Albert: You want to use  $v_f^2 = v_g^2 + 2as \dots$ 
Albert: Sorry, I do not recognise that equation.
      (There is an unrecognised symbol in your equation.)

albert: You want to use  $a=F(m, No)$ .
        Check your number of "(" and ")".

Nel (129):  $a = (v_f - v_g) \div t$ 
Albert: You want to use  $a = (v_f - v_g) \div t$ .
Albert: Please make  $v_g$  the subject of the formula.
```

Figure 7-5: Feedback about formulas typed in by students

---

After putting various reminders about the symbols used by ALBERT into the program itself, the problem of unrecognized symbols was eventually solved by including a list of symbols on the problem sheet. (Although this strategy may seem obvious to some, the use of written instructions accompanying a CAI lesson has unfortunately been overlooked by many lesson writers.)

A related problem which students had was that many of them (surprisingly) did not know how to type a " $\Delta$ ". As a result some students typed "change in velocity" in words and thus mixed words and symbols in equations (Figure 7-6). ALBERT was modified to cope with this and instructions about how to type a " $\Delta$ " were included on the problem sheet. One student accidentally found that FONT-d produced a " $\Delta$ " and confused ALBERT no end, as FONT-d was at that stage being used as an internal representation of the sign for technical reasons. The internal representation was moved to a less obvious key.

---

```
Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
Cayzer (8): yes  
Albert: Checking...  
Albert: Sorry, I don't recognise that.  
Albert: You need to rearrange the formula.  
Cayzer (153): t=change in speed+a
```

Figure 7-6: Students mix words and symbols in equations

---

A less serious defect was ALBERT's inability, at times, to recognize all the quantities being specified in a student's input. This happened when the symbols were used and was due to the fact the "a" could be an indefinite article or the symbol for acceleration and "m" could be the unit of length or the symbol for mass. As a result, these words were being given an inappropriate classification by the pattern recognition system and then being missed by the keyword system.

To improve on this, the classification routine was modified to include a check on these two words. If "m" is preceded by a number, then it is regarded as the unit of length, otherwise it is taken to be a symbol. "a" is taken to be a symbol in every case as it does not effect the operation

of the pattern matching routine and has never been used as an indefinite article in a sentence fragment which would be matched by the keyword system.

It is also worth mentioning that the "help" system appeared to be working satisfactorily. Several students asked for help at various points in the discussion and ALBERT offered sound advice in every case. At least one student went right through a discussion with ALBERT successfully by asking for help whenever possible.

Of the 45 dialogues collected in this phase of testing, only 5 ended in confusion. Of the 5, one could be attributed to the student not knowing how to type a " $\Delta$ "; two more occurred when insufficient information was given in the problem statement and the checking routine had been accidentally left turned off. The other two could have been avoided if the students had asked for help. A high proportion of the dialogues were incomplete (approximately one third), but in many cases there was evidence to suggest that the students ran out of time. In a few cases, the students restarted when they made a mistake, e.g., typing in a symbol which was not recognized. In most cases, the dialogue was going well when it was terminated.

#### 7.1.2. Further testing

On the basis of the results of the initial testing various modifications and improvements were incorporated into ALBERT. (Most of these have been described already.) For the second phase of testing, four students who participated in the initial testing were asked to work through a set of four problems each. The problems used are listed in Table 7-1.

Three of the four problems were used during the simulated ALBERT experiment. The reasons for their selection were explained in section 6.5.2. Problem 2 is the only new one and was put in as it is representative of the fourth kinematic equation. In this case, ALBERT's method is almost identical to the "kinematic equations" method, since displacement is average velocity times time which, written in mathematical form, is exactly the kinematic equation most likely to be picked by the students.

1. A motor car, initially moving with constant speed, undergoes a uniform acceleration of  $0.5 \text{ m/s}^2$  for 30 seconds. After this its speed is 25 m/s. Calculate its initial speed.
2. A fast car accelerates from rest to 27 m/s in 7.5 s. Assuming the acceleration to be uniform, how far does it travel in this time?
3. A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it during its motion up the plane.
4. A stone is thrown vertically upwards with an initial speed of 15 m/s. How long will it take to reach a height of 8 m?

Table 7-1: Problems used in the second stage of testing

All four students completed this task very successfully, although several other students became involved before this phase had been completed. The dialogues in the range D-45 to D-58 and D-64 to D-66 in Appendix F are examples of ALBERT's performance during the second phase of testing. All 16 dialogues were almost perfect and more than one of the students commented that ALBERT had improved greatly since they had last used it several months earlier.

As noted earlier, students solve these problems in many different ways. For example, in problem 2, Blackie (D-52) first used the equation  $v_f = v_0 + at$  to calculate the acceleration and then used  $v_f^2 = v_0^2 + 2ax$  to calculate the displacement. Hobson's method (D-65) was similar in that he also began by using the equation  $v_f = v_0 + at$  to calculate the acceleration. However, he then chose to use the equation  $x = v_0t + \frac{1}{2}at^2$  to calculate  $x$ . McBean (D-55) allowed ALBERT more control and ended up using his method. She first calculated the average velocity and

then used  $x = v_{av} t$  to find  $x$ . Genney's method (D-47) is similar to Hobson's but differed conceptually at the start in that Genney used the definition of acceleration, viz.  $\Delta v = at$  to find  $a$ .

A similar effect was found in problem 3 where Blackie (D-53) again used the appropriate equation and solved the problem very quickly, while Mcbean (D-56) used ALBERT's method.

There were only a few minor problems. For example, one student uncovered a point at which the dynamic dialogue model was not being correctly updated (Figure 7-7). The yes/no register was being left set to expect "yes" or "no", so the student's input "right" was taken as an affirmation. This defect only affected the operation of the keyword system. The student eventually used a more complete sentence which was understood by the pattern matching system and thereby overcame the problem.

---

Albert: What is the direction of the acceleration?  
Blackie(23): left  
Albert: Do you mean as shown?  
Blackie(6): yes  
Albert: I do not agree. Think again.  
Blackie(16): right  
Albert: I do not agree. Think again.  
Blackie(42): right  
Albert: I do not agree. Think again.  
Blackie(77): help  
Albert: If it is slowing down, the direction of the acceleration will be opposite to that of the axis. If it is speeding up, the directions will be the same.  
Blackie(48): the direction will be right  
Albert: Do you mean as shown?  
Blackie(5): yes  
Albert: That's right!

Figure 7-7: A defect in the context

---

The problems of resolving the ambiguities associated with the symbols for mass and acceleration, and the unit of length and the indefinite article respectively had not yet been remedied at the start of this phase of testing, so they appear in some of the dialogues. Their effect is never serious and the condition was removed after D-57.

On the basis of the results of this phase of testing, which was thought to be highly successful, it was decided that ALBERT was ready for a wider audience.

### 7.1.3. General use of ALBERT

After the second phase of testing, approximately 20 students, picked at random from the first year Physics classes, were asked to try the problems in Table 7-1. A sheet of additional problems was made available to anyone wishing to make further use of ALBERT. ALBERT was also advertised to all first year students shortly before the final examinations.

As a result a wider group of students has now used ALBERT and several more dialogues have been collected bringing ALBERT's total number of sessions with students to 84. On the whole, ALBERT dealt satisfactorily with all of these students. The dialogues from D-67 onwards are typical examples taken from this period of operation. It was interesting to note that most first-time users of ALBERT now have almost had no trouble at all.

A few high school children use the PLATO system at Rhodes University. They are generally students having difficulty with mathematics or science. One of these students agreed to try ALBERT. She completed two problems and it was clear from the dialogues that her knowledge of Physics was defective. However, both problems were completed successfully with ALBERT's help. D-74 shows her first attempt.

However, there were times when ALBERT did not cope too well. I am only aware of two cases in which students gave up on ALBERT because they were unable to type in a problem. The first of these two students had never used a keyboard before and was incapable of transcribing the problem into the computer from the typed sheet. He randomly neglected to leave spaces between words, could not distinguish between "m/s" and "m\s" and modified the punctuation on the problem sheet in an arbitrary way, although the latter would not have made any difference. The second student was a girl who did not read the instructions and did not press the help key. She omitted spaces between the numbers and the units in the problem statement.

Another student ran into difficulty with ALBERT by attempting to solve a

problem using a graphical method. He had used ALBERT successfully before and admitted later that he had wanted to see if ALBERT could solve problems in this way. He tried to find the distance travelled in problem 2 (Table 7-1) by calculating the area under the  $v_x$  versus  $t$  graph. Of course, this is a valid approach but ALBERT has no knowledge of it and was totally uncooperative. After a few lines in which ALBERT denied any knowledge of graphs and areas, the student gave up and solved the problem in a more standard way.

Occasionally a student will type in a partially substituted equation, e.g., " $v_f=15\text{m/s}$  and so  $v_0=15-at$ ". ALBERT cannot recognize these equations. However, this has not been a major problem for those students who have tried it as such equations are often rejected on other grounds, such as not containing the goal. A similar problem exists with equations containing two equals signs, e.g.  $F=ma=10\text{N}$ . ALBERT can easily be modified to consider only the second part, i.e.  $F=10\text{N}$  in the example given.

Overall, ALBERT appears to work satisfactorily. Occasionally students do type things which ALBERT cannot understand, but generally this does not lead to confusion. The student is usually able to rephrase his or her input in such a way that it is accepted on the second attempt.

It should be noted that many of the students who used ALBERT claimed that they did not find the problems difficult. In fact, some of the students who were asked to try ALBERT had solved the problems in advance and had brought written solutions with them. To some extent this defeats the object of the program, since it is designed to be used by students having difficulty with Physics problems. If the student already knows how to solve the problem, there is not much point using ALBERT. As a result, the students who had not solved the problem in advance were more likely to end up using ALBERT's method. Similarly, the students who genuinely did not know how to solve the problem and asked for help also ended up using ALBERT's method.

## 7.2. The potential for educational research

The dialogues captured by ALBERT provide a wealth of data for those who wish to study problem-solving in elementary Physics.

It has already been noted that students solve the same problem in several different ways. It should be possible, for example, to modify the tutorial management system to make ALBERT ask the student why he wishes to use a particular equation. Perhaps ALBERT should be able to suggest an alternative route to the student, when the student's method is clearly more difficult. The student's path through ALBERT is probably related to the way in which 1-D kinematics is taught in particular textbooks or what is being done in class. The dialogues could thus play a useful diagnostic feedback role in this regard for the course lecturer.

It is also apparent from the dialogues that many students are unable to identify correctly graphs of  $v_x$  versus time and  $a_x$  versus time for problems of this kind. (This result is not unexpected, as these graphs have been used by others in misconceptions tests (Stanton, 1986).) In the first 70 dialogues, students chose an incorrect acceleration graph 13 times and an incorrect velocity graph 11 times. Unfortunately, at this stage, ALBERT does not store data about which graph was chosen as it has not been my intention to investigate the misconceptions which students have about these graphs. However, it would be possible to store this information so that it could be related to particular problems.

It should also be possible to modify the tutorial management system to intercept students who demonstrate that they have particular misconceptions about acceleration and velocity and then to lead them through a short discussion about the concept in question. However, this could make the discussion of a problem significantly longer.

It should thus be possible to use ALBERT as a research tool, either as it stands or with some minor modifications. Data obtained in this way should augment protocols from personal interviews with students and provide useful information about the students' approaches to problem-solving and their misconceptions about elementary Physics.

### 7.3. Student opinion of ALBERT

At Rhodes University, it has never been our intention to try to measure achievement gains due to the use of CAI. There are numerous studies

reported in the literature, and Kulik et. al. (1980), for example, provide a meta-analysis of over 600 such studies which shows that achievement gains are possible for students using CAI materials in place of conventional instruction.

For several reasons, it would be exceedingly difficult for us to replicate these studies, let alone improve upon them. Firstly, our equipment is very limited; for the first two years, 10 PLATO terminals served the whole University of 3600 students. Secondly, the number of students in first year Physics courses is very limited; there are normally approximately 50 students in the first year Physics major class and approximately 110 in the ancillary course for the Life Sciences.

In the area of Physics, Jones, Kane, Sherwood and Avner (1983) have studied achievement gains among students who used PLATO in place of lectures for an introductory mechanics course. Even with much larger numbers of students than we have and a study which spanned several years, their results are somewhat inconclusive.

At Rhodes University, we have monitored student and staff attitudes towards the use of PLATO regularly, and, while these continue to be favourable, we shall continue to use the system.

For ALBERT, the measurement of learning gains at this stage would be premature. ALBERT is designed to provide help to students in a manner and at a level which is not practical with human teachers. ALBERT is not designed to replace any existing form of instruction. It provides tuition where tuition is not currently available. It is thus important to determine whether students believe that a system of this kind could be useful to them and whether or not they perceive it to be any different from other CAI programs which they have used.

#### **7.3.1. General student attitudes towards CAI in Physics**

Generally, it has been found that students react positively towards the instructional use of the computer (Kulik et. al., 1980), but the quality of the instructional materials is a major factor in this.

At Rhodes University, CAI in Physics has always been used as an additional learning resource and has not replaced the traditional methods of instruction. During the PLATO evaluation at Rhodes University, Physics students responded very favourably to the use of PLATO (Oberem,1984). They maintained that it made them feel more confident about their work and they indicated that they would like to use PLATO more often and that they would like to see it used more in their other subjects.

During the first quarter of 1986, students in Physics were given access, as usual, to a series of PLATO lessons on introductory mechanics. These lessons have been carefully selected for their quality and accuracy, and are all taken from the PLATO published courseware library. Many of them were written at the University of Illinois and have been described elsewhere (Kane and Sherwood, 1980). A few lessons were taken from the newer LDEC curriculum (Control Data, 1983).

Towards the end of the first term, just before ALBERT was available for initial testing, a survey was conducted among students in the Physics 1L class to determine their attitudes towards CAI and the Physics lessons. The survey was conducted by means of informal interviews with students, during their practical classes. Students who had not used PLATO were also interviewed.

The following questions were used as a basis for the interview:

- a. What is the PLATO system? Try to describe in your own words what it is and what it does.
- b. What did you like most about PLATO?
- c. What did you like least about PLATO?
- d. Which Physics lessons were most useful to you and why? (Students were shown a printout of the index they saw on PLATO.)
- e. Why are some lessons more useful than others and how could the lessons be improved?

Fifty-two students were interviewed, approximately half the class. Most of these students had spent 8 to 10 hours using PLATO and had worked through an average of 12 lessons each. Almost without exception, they saw PLATO as a review and testing system. Some students described it as a system which allows one to "practice Physics problems" and others considered it as a way to obtain additional help when one did not understand the lecture course.

In response to the second question, students expressed many of the feelings which we have noted in the past (Oberem, 1984). Many students enjoyed the interactive non-threatening self-paced learning environment. Some students indicated that they found the extra problems and tests which PLATO provided very useful for self-assessment.

On the negative side, 29 of the students interviewed complained that at times they were unable to proceed with a lesson because they couldn't find out what answer the computer was expecting of them and help did not appear to be available in the program. They could not point to any lesson in particular, but rather complained that this was a general problem with PLATO lessons. Two students complained about the inflexibility of the programs. They did not like being forced to solve the problems in a particular way which was different from what they had been taught in class. One student did not like being forced to work through examples which were irrelevant.

With regard to the lessons themselves, many students seemed to think that the ones relevant to the most recent section of the work (torque) were the most useful. It seemed that they had forgotten the details of the earlier lessons and some students admitted that. The only lesson which appeared to stand out from the rest as being good was a lesson from the LDEC curriculum which provides an animated torque simulator which runs as a resident micro-PLATO program in the Viking PLATO terminal. This lesson does not provide a problem-solving activity.

Very few students had useful ideas about how to improve the lessons, other than to reiterate some of the comments they had made about PLATO not accepting their answers, even when they thought they were correct. Ten students felt that there should be more flexibility in the lessons to

allow the student more control over lesson flow. A few students requested more help and explanations in the lessons and felt that there should be more examples.

This survey confirmed our earlier results. Students in Physics courses generally find PLATO lessons helpful as an additional learning resource. However, at times they find them frustrating when their answers and methods are not accepted. They would like to be given greater flexibility to move about to try different sections of the lessons or different examples. ALBERT has been designed to address many of these problems and these students, having used conventional PLATO lessons in the early part of the year, were in a good position to make a comparative assessment of ALBERT.

### 7.3.2. Students' comments about ALBERT

Student reaction to ALBERT has been spontaneously positive. From the start, even during the initial testing, several students expressed excitement about what ALBERT could do and some requested additional problems. After the second phase of testing, 16 students who had used ALBERT were asked to answer a questionnaire containing the questions shown in Figure 7-8. 15 completed questionnaires were returned.

Appendix G contains a selection of responses to each question.

Since all of the students who used ALBERT had had prior experience of the PLATO Physics lessons earlier in the year, the first question was put to them to see whether they had found ALBERT to be different from the other lessons which they had used.

In response to this question, four students felt that ALBERT was different from other computer lessons because they were able to specify the problem. For example, one student wrote

"...the user can type in the problem that he personally finds difficult". (The emphasis was the student's.)

- 
1. Is ALBERT different from other computer lessons (PLATO programs) which you have used? If so, in what way?
  2. Do you feel that you learned anything while using ALBERT? If so what? (Please try to be specific.)
  3. Do you think that ALBERT can teach students how to solve problems? (Please try to give reasons for what you say.)
  4. What did you like most about ALBERT?
  5. What did you like least about ALBERT?
  6. How could ALBERT be improved?

**Figure 7-8: Questions used to test students' opinions of ALBERT**

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One student noted that ALBERT was not as rigid as other lessons. This was confirmed by five other students one of whom pointed out that

"You choose the way you wish to solve the problem".

Four students felt that ALBERT was different from other computer lessons in that one became more involved and "you have to think about the subject matter". One student expressed this involvement by saying

"ALBERT helps by 'participating' instead of just saying 'correct' or 'wrong try again'".

With the exception of one student who said "no" but did not elaborate, there was general agreement that ALBERT was different from other computer lessons. With their earlier experience of PLATO Physics lessons, these students were probably in a good position to make such a judgement.

Tawney (1979), who has reported on the evaluation of Science lessons in the CUSC project, observes that "questionnaires were more successful when the questions were specific" and maintains further that

"a student's claim that he has learnt something from a package is relatively worthless compared to his description of what he thinks he has learnt and why he thinks he has learnt it".

The next two questions were designed with this in mind. First students were asked whether they felt that they had learned anything while using ALBERT and if so what. In considering the responses, one must bear in mind that during the test period the students were not studying kinematics in their lecture course and several of them expressed the view that they "knew" this section of the work.

Several students felt that what they had learned was a problem-solving technique. To me the most gratifying responses came from the students who wrote

"It helped me to think what I was doing and not just substitution (sic) into formulas"; and

"It has taught me to ask myself questions about a certain problem before trying to solve it, not just 'plug in' values into a formula".

If students come away from using ALBERT realizing this, the program will have achieved one of the most important of its many purposes. An interesting additional piece of anecdotal information is that the student who wrote the former of the two comments above was initially very reluctant to use ALBERT. She felt that it would be a waste of time. She was later one of the students who requested additional problems!

In response to this question (2), six students explicitly stated that it made them think about the problem. Three had learned how to break a problem up into a series of logical steps. Two students felt that they had learned nothing. Not a single student stated that he/she had learned anything about 1-D kinematics.

In the third question, students were asked whether they thought that ALBERT could teach one how to solve problems. There was a good deal of overlap between the responses to this question and those to question 2. Several students commented on the fact that ALBERT shows one how to break a problem up into a series of logical steps and many of them stressed the fact that ALBERT forces one to think clearly about a problem.

Two students felt that the facility to type in the problem with which they were having difficulty was important and another student liked being able to try his own approach to get ALBERT's comments on it.

Open-ended questions like questions 4 and 5 have been used successfully at Rhodes University with students in many courses which have used PLATO. They generated a wide range of comments and have provided a useful gauge of student feeling towards PLATO in the past (Oberem, 1984).

What did students like most about ALBERT? Five students responded with variations of "I could type in any problems that I wanted". While this was not quite true (they were limited to a sheet of about 25 problems), it is significant that this point was firmly stated both at this point and in response to question 1. Two students elaborated upon this, making the point that they could choose problems of an appropriate level of difficulty and would not find themselves being forced to solve problems set by PLATO which were either too easy or too "complicated".

Some of the other comments made were

- "easy to use" (at least two students said this);
- "being able to check my method with the correct method";
- "the little encouraging comments....makes it much less impersonal";
- "the whole approach to problem-solving";
- "the way it conversed with you";
- "ALBERT speaks nicely" and
- "it gave me a reason to play on the computers".

We have always found that students respond to the question "what did you like least about....?" in a very helpful manner. Students who use PLATO at Rhodes University most frequently respond to this question by claiming that the computer sometimes does not accept answers which they believe to be correct. (This appears on approximately 40% of our questionnaires and is independent of subject area (Oberem, op. cit.)) Apart from one student who claimed that ALBERT had not wanted to accept the final answer in one problem, this comment did not appear. Two students made the observation that ALBERT's vocabulary is a "bit limited". This was not a reference to answers not being accepted and it was not very strongly put.

One student said that it was "not a major problem".

The most frequently expressed complaint about ALBERT was that it took too long to work through a problem. (Some students had trouble completing a problem in a 45 minute free period.) Of the six students who made this point, two mentioned the need for being able to type as a limiting factor. Another student made this point and added that she felt that this was a problem with computers in general. I sympathize with that view.

One student complained that ALBERT was "limited only to linear motion problems". Another student felt that ALBERT should offer more assistance about "what to do next, (i.e. think about...?)". This comment bears consideration in the light of the limitations mentioned in the last chapter about ALBERT's ability to give reasons why it is necessary to perform particular steps in a solution. If these reasons are generated, they could be turned into questions to lead the student into the next step in the way suggested here.

It is worth noting that no student complained about ALBERT being slow. This comment has been made in respect of certain other lessons, particularly where inappropriate use of graphics has resulted in slow plotting on the screen.

In response to the last question, five students asked that ALBERT should be expanded to deal with a wider range of problems. One student, no doubt oblivious to the implications of the request, felt that it should "include the rest of the Physics syllabus". These students are well aware that there are other PLATO lessons which cover quite a substantial portion of the Physics syllabus. The implication here is that ALBERT is different from these lessons and that it has an important role to play in addition to them.

One student made the important point that, in view of the length of time required to work through a problem using ALBERT, one should be able to restart the problem after signing off. (As mentioned earlier, this problem is receiving attention.)

Two students omitted to answer this question, and two suggested that the

vocabulary should be increased and that ALBERT's ability to accept formulas should be improved. The latter comment reflects more on the student's ability to work consistently with a set of symbols than any deficiency on ALBERT's part.

Finally, one student recommended that ALBERT should be given more personality. In a discussion with one student who used ALBERT (I do not know if it was the student who made the suggestion on the questionnaire), it was suggested that ALBERT should be able to take up some point unrelated to Physics, e.g., the weather. The same suggestion was made by a visiting Professor (Battino, 1986b) who has studied student motivation. Battino suggested that ALBERT might be programmed to come up with a joke or an "interesting" bit of graphics in a random way. My view of this is probably somewhat conservative, but I should like to trap comments which students make which are not directly related to the Physics and provide a light-hearted response to them.

There was much overlap between the categories of response to the different questions and some students repeated themselves. Table 7-2 summarizes the most frequent responses. (Comments which appeared only once or twice have not been included.)

Number of questionnaires received: 15	
Student learning:	
Makes one think more deeply about a problem:	10
Offers greater flexibility than other programs:	6
Like being able to choose the problem:	5
Helps one break the problem into steps:	3
Negative comments:	
Too time consuming / too much typing:	6
Limited vocabulary:	3
Suggestions:	
Extend ALBERT for other areas of Physics:	6

Table 7-2: Summary of student comments about ALBERT

In summary, the response of the students to ALBERT has been very favourable. Not a single student has rejected the system as being worthless. It is particularly encouraging to note that many of them feel that ALBERT makes one think about a problem rather than just showing how to plug numbers into a formula. It is significant that the students who used ALBERT see it in a broader context than just 1-D kinematics and particularly value the approach to problem-solving embodied in it. The suggestion that ALBERT should be expanded into other areas of Physics and the request for additional problems is indicative of the students' belief that ALBERT holds potential for them and that it does not replicate what is being taught in existing PLATO lessons.

### 7.3.3. Experts' views on ALBERT

ALBERT has been demonstrated to several "expert" Physicists and visitors to the University, and was reported on with extracts from student dialogues at the annual meeting of the South African Institute of Physics (Oberem, 1986). On these occasions it has generated a lot of interest and has been described as being "very different" from existing Physics courseware.

Two Physicists at Rhodes University, one a Senior Lecturer in the Department of Physics, the other a Senior Lecturer in the Faculty of Education working on problem-solving in elementary Physics, were asked to work through a problem using ALBERT and gave their assessment of the system.

The Physics lecturer had very few comments to offer. He appeared confident that students who used ALBERT would not only find out how to solve a particular kinematics problem, but that they would also be exposed to a useful general approach to problem-solving.

The other person offered many suggestions. Some of the comments were very specific, such as possible graphs which could be used in the qualitative discussion. At more general level, he felt that the process of extracting the information from the problem statement could be more closely tied to the qualitative discussion than it is now. For example, the sign of the component of acceleration can be predicted by considering the graph of  $a_x$

versus time. The tutoring module which guides the student through the extraction of the information given in the problem statement could be modified to make the connection with the qualitative discussion more clear.

He also felt that he might use a different approach in trying to get the students to relate the current goal to other quantities. He would begin with a quantity such as the change in velocity and discuss that in detail until its relationship to the other quantities was clarified. This illustrates one of the limitations of ALBERT rather clearly. The human expert tutor can explore a concept in detail and find out a good deal about what the student knows about it, after which the concept can be related to other concepts. With ALBERT, this level of interaction has not been provided and with the restrictions imposed by the need for typing, it could become a little tedious.

This person also questioned the usefulness of the model solution produced at the end by ALBERT. He maintained that ALBERT should rather summarize what the student has done. The sequence of concepts used should be reinforced and related again to the qualitative discussion. Although some students stated that they found it useful to compare their solution with the one generated by ALBERT, I agree that it would be useful for ALBERT to summarize the student's solution at the end. This would require fairly extensive modifications to ALBERT as the solution path taken by the student is not held in the context model at present.

Overall, this person appeared satisfied that ALBERT could help students to solve particular problems and that, with certain improvements, ALBERT's potential in this regard could be greatly enhanced.

#### **7.4. Discussion**

The dialogues collected have shown that ALBERT is capable of conducting a sensible discussion with a student about a problem not stored in the computer. It allows the student a degree of independence and flexibility not provided for in conventional CAI systems. The natural language system is particularly robust when students type in fairly complete sentences and is more prone to errors when their input is confined to just one or two

words.

As far as the method of solving the problem is concerned, ALBERT permits students to solve it in whatever way they wish and the results show that students take advantage of and appreciate this. Some students allowed ALBERT to impose his ideas upon them, while others simply stated the equations they wanted to use and were allowed to proceed in that way. However, ALBERT is intended for students having difficulty with their Physics problems and the data show that, for these students, ALBERT is capable of making them solve the problem using his method. Initial tests suggest that ALBERT can be put to good use at high school level as well as at University level.

The student response to ALBERT has been very favourable and many students would like to see the program extended into other areas of Physics. A particularly encouraging aspect of the student response to ALBERT has been a recognition on their part that ALBERT makes one think about a problem and approach it in a logical fashion. In this respect, ALBERT can be of much use to the students who use it.

The time taken to complete a problem, particularly for students who are completely lacking in keyboard skills, is a drawback to the system since it is very interactive and requires much more typing than a conventional CAI program.

Two expert Physicists who have reviewed ALBERT endorse its use, preferably with certain modifications to tie the qualitative discussion in more closely with what follows in the later sections of the program.

Overall, the results so far indicate that it is possible to implement a system like ALBERT in a conventional programming environment in such a way that it operates consistently, efficiently and acceptably.

## Chapter 8

### Conclusion

#### 8.1. Summary of results

This work has been concerned with the development of a natural language system to understand and teach textbook Physics problems about 1-D kinematics. Two automatic problem-solvers have been produced which can solve problems of this kind, and a tutoring system has been devised to guide students through them.

The natural language system which understands textbook problems makes use of a pattern matching technique which scans the problem statement for syntactic patterns which are semantically important. The pattern of the problem which is created and scanned is based on the semantic classification of the words used rather than the specific words themselves. The specific words are only used at the deepest level of understanding, during semantic processing.

This technique has proved fast, robust and completely adequate for a wide range of problems in the domain of interest. The approach is intermediate between a keyword system and a fully developed syntactic parser. The model of language processing developed for ALBERT is readily transportable to other systems and other domains of interest.

The two problem-solvers implemented are representative of two different approaches to solving problems of this kind. In the one case, the object is to pick an equation which contains the quantities which are given and in which the only unknown quantity is the one which must be calculated. In the other, the approach to the solution is based on an understanding of the fact that an acceleration brings about a change in velocity and that the displacement depends on the average velocity over a given time interval.

The first problem-solver operates by means of a goal-directed means-end analysis strategy. The second uses a more forward-directed approach and

may be interrogated for each step in a solution. Both of these problem-solvers are fast and adequate for the task at hand but both suffer from the problem that, while they can say what steps they are taking to solve the problem, they are not able to say why they do what they do. This limits the explanation capability of the teaching system.

The tutoring system consists of a tutorial management system, a tutorial model, a context model, a natural language dialogue interface and a set of specific tutorial modules. The tutorial management system determines the overall operation of the system. It has the tutorial model built into it and it drives the tutorial by continuously examining the context model. The tutorial model is based on current thinking about problem-solving in Physics.

The context model consists of a student model, a tutorial status model and a dynamic dialogue model. The student model is an overlay model which parallels the knowledge of the expert. It keeps track of what the student knows and which equations he has associated with which goals. The tutorial status model keeps track of the overall flow of the tutorial, while the dynamic dialogue model helps to maintain focus and coherence in the discussion.

The natural language system developed for dialogue handling first attempts to parse the student input by means of syntactic pattern recognition. This uses a slightly modified version of the natural language processor developed for understanding textbook problems. If this fails due to the fact that the student has used a highly contracted form of input or an unrecognized syntactic structure, a keyword matching system is called up in a second attempt at understanding what the student has said. This two-level approach has been very successful and is transportable to other domains, although the keyword component would require extensive modification.

The tutorial modules contain the specifics of how to teach and assess particular concepts and situations. They can be modified without changing the overall operation of the program and can be substituted with different modules if the system is moved to another domain.

Very few intelligent tutoring systems have been produced to date (none for Physics), and those that have have mostly been experimental systems which have been implemented as production systems, usually in languages such as LISP and PROLOG. Not many have been used extensively by students. The implementation of ALBERT has shown that an intelligent tutoring system can run effectively in a conventional programming environment and may augment an existing library of CAI lessons.

The traditional concept of a CAI dialogue in which the flow of the dialogue is designed in advance by the programmer and in which all the student's responses must be anticipated, has grown out of the programmed learning era. ALBERT breaks with this tradition and offers the student a degree of flexibility unattainable if one confines one's thinking to the traditional CAI approach.

ALBERT has already been used fairly extensively by students in three phases of testing. The results of this activity show firstly the viability of the system and secondly its potential for educational research in problem-solving and misconceptions. Student and expert reaction to ALBERT have been very positive. Many students find the use of ALBERT extremely worthwhile because they find that it makes them think about the Physics rather than just the equations and because of the way in which it helps them to break the problem down into a series of manageable steps. They would like to see ALBERT extended into other areas of Physics. However, the students' ability to type appears to have a bearing on their success with the system.

In its present form ALBERT can assist students who might be having difficulty with problems in 1-D kinematics. It is not only capable of leading a student through the problem of his/her choice, but it also teaches a useful general approach to problem-solving in Physics. This kind of individualized problem-solving assistance is not generally available with human tutors and is not possible in a conventional CAI program.

## 8.2. Future work on ALBERT

ALBERT will continue to be available to all Physics students at Rhodes

University and its performance will be monitored on a regular basis. Future work on ALBERT will be in three areas. Firstly, ALBERT's ability to assert himself with students and to teach them how to solve problems must be carefully examined and optimized. This may require modifications to the tutorial management system and the context model. Some of the suggestions mentioned in 7.3.3 could be incorporated.

A related problem is that at present, ALBERT does not provide the student with an assessment of his solution. ALBERT is satisfied as long as the student uses equations which ALBERT recognizes and eventually arrives at the correct numerical answer. The student may then compare his solution with ALBERT's and will hopefully become aware of a more efficient way of solving the problem, if he has not used it in the first place.

Also, it is possible for a student to waste a great deal of time (and typing effort) calculating unnecessary things. A problem-solving monitor such as ALBERT should know when to interrupt the student in a situation like that. At present, ALBERT does not interrupt. He will only make a suggestion if the student asks. It should be possible to monitor the student's solution path and to apply certain criteria for interrupting him.

Secondly, ALBERT should have an explanation facility and the ability to answer direct questions. To implement this, it may be necessary to modify the expert problem-solvers extensively. Some preliminary work has been done on this to find an effective way of incorporating the necessary knowledge into the problem-solving actions. In this regard, I have examined the possibility of separating the knowledge about which equations to use, and why they should be used, from the routine which generates the solution. The resulting structure has the characteristics of a procedural network. An efficient means of encoding the knowledge for 1-D kinematics has not yet been devised.

However, an overriding consideration with regard to the future of ALBERT is whether to develop ALBERT further in the present environment. It was acknowledged at the outset that the PLATO system was not necessarily the best environment in which to implement such a system. It was decided to use PLATO to take advantage of many of the ready-made facilities for

screen management and student answer processing. The use of PLATO has facilitated the development and testing of the present system but it may be advantageous to transport the ideas to another environment at this stage.

There has been considerable interest in ALBERT from many people who only have access to microcomputers. In South African schools there is a desperate shortage of qualified Science and Mathematics teachers. ALBERT could play an important role if it could be used to help make up for this deficit. However, very few schools can afford the high cost of linking in to a mainframe PLATO system. If ALBERT were available on a common microcomputer, it could be introduced at high school level. The feasibility of making a system such as ALBERT run on a microcomputer has yet to be investigated.

Also, animation has not been possible up to now due to the limitations of the data transmission rate from the mainframe to the PLATO terminals. While it is possible to write resident micro-PLATO programs to run in the terminal and to perform the animation, this is undesirable because only certain types of terminals operate in this way. On a microcomputer, the possibility for animated graphics is greatly improved.

Finally, up to this point, ALBERT has been the result of the efforts of one person. If some of the goals mentioned above are to be achieved, a team effort will be required.

### **8.3. ICAI and the future of CAI**

Present authoring languages and authoring systems are based on Skinnerian linear or at best Crowderian branching systems of programmed learning. While it is possible to produce a system such as ALBERT in a conventional authoring environment, one cannot expect the average lesson programmer to implement so complex a program. The time required would in any case probably make the production costs enormous.

However, it should be possible to produce an authoring environment which allows the development of systems like ALBERT. A framework within which to build a tutorial model, a context model and a set of tutorial modules

could be provided. If a natural language processor can be supplied in such a way that it can be "tuned" to a particular domain, this would greatly enhance such an authoring system.

Also, it needs to be recognized that any one-on-one teaching situation takes the form of a dialogue. CAI tutorials fall into this category but they do not take the form of a dialogue at present. When a page of information is presented to a student, should he not be able to discuss it with the system in the way that he might do with a live teacher? If the student is running a simulation, should he not be able to discuss his next move with the system or ask for help as he would do with a live teacher? There is a vast area here which has not yet even been considered.

The work on ALBERT has been initial and exploratory and the present version of the system is a prototype. It attempts to solve some problems in the field of CAI and it highlights others. If ALBERT can open new avenues for teachers and students of Physics and point the way to a better future through the use of computer-based learning, it will have achieved its purpose.

Appendix A  
ALBERT's Vocabulary

## Appendix A

### ALBERT's Vocabulary

The vocabulary in ALBERT is contextualized and categorized according to the semantic function of the words. The categories are defined in Table 3-1.

```
*****
*
vocabs  senten  $$ ALBERT's vocabulary
*
      (words,
*
*nouns (1) - fixed objects which cannot move.
      building=1, tree=1, table=1, leg=1/s=1,
      component=1, plane=1, head=1, stream=1, bridge=1,
      coordinate=1, road=1, surface=1, path=1,
      hill=1, incline=1, ground=1, track=1, wood=1,
      brakes=1, line=1, field=1, water=1, light=1
      gravity=1, motion=1, ascent=1, air=1, points=1,
      collision=1, fuel=1, pipe=1, pile=1,
*
*nouns (2) - moveable objects
      block=2, ball=2, man=2, boy=2, girl=2, car=2, train=2,
      body=2, balloon=2, automobile=2, bullet=2, truck=2,
      airplane=2, motorcycle=2, skier=2, flea=2, jumper=2,
      bike=2, bicycle=2, shell=2, rocket=2, engine=2,
      driver=2, hammer=2, bobsled=2,
*
*properties (3) - of moveable objects
      mass=3, distance=3, displacement=3, speed=3,
      velocity=3, force=3, run=3, height=3, point=3,
      acceleration=3, position=3, friction=3, resistance=3,
      time=3, period=3, interval=3, nothing=3, altitude=2,
      deceleration=3, instant=3, direction=3,
* variables also (3)
      v0=3, vf=3, x=3, t=3, t=3, F=3, vav=3, v=3,
*
*verbs (4)
      slide=4/s=4/ing=4, stand=4/s=4/ing=4,
      start=4/s=4/ing=4/ed=4, begin=4/s=4,
      bring=4/s=4/ing=4, brought=4, extend=4/s=4/ed=4/ing=4,
      travel=4/s=4/led=4/ling=4, projected=4, pushed=4,
      slam=4/s=4/med=4, strikes=4, penetrate=4/s=4,
      hit=4/s=4/ting=4, go=4/es=4/ing=4/ne=4,
      mov//e=4/es=4/ing=4/ed=4, fire=4/d=4, walk=4/s=4,
      throw//n=4/s=4, sit=4/s=4, jump=4/s=4/ed=4, shot=4,
      accelerat//e=4/es=4/ing=4/ed=4, speeding=4,
      decelerat//e=4/es=4/ing=4/ed=4, slowing=4,
      run//s=4, come=4/s=4, coming=4, roll=4/s=4, leave=4,
      pass=4/es=4/ed=4, reach=4/es=4/ed=4, attain=4/s=4/ed=4,
      cover=4/s=4/ed=4,
      did=4, will=4, would=4, could=4, be=4, had=4, does=4,
      act//s=4/ing=4/ed=4, experience=4/s=4, applied=4,
      rise=4/s=4/ing=4, subjected=4, might=4, should=4,
      undergo=4/es=4, produc//e=4/ed=4/es=4/ing=4,
      remove=4/s=4/d=4, being=4, proceeds=4,
```

\*intent  
 need=4/s=4/ed=4, require=4/s=4/d=4, give=4/s=4/n=4,  
 can=4, want=4, do=4, wish=4, like=4, know=4, must=4,  
 capable=4, neglect=4/ing=4,  
 \*

\*properties (5) - of fixed objects  
 inclined=5, frictionless=5, rough=5, smooth=5,  
 scalar=5,  
 coefficient=5,  
 \*

\*assignment words (6)  
 are=6, mak//e=6/es=6/ing=6, was=6, has=6, is=6,  
 of=6, with=6, equals=6, depends=6, due=6,  
 without=6, as=6, assum//e=6/ing=6,  
 \*

\*articles (7)  
 a=7, the=7, an=7,  
 \*

\*adverbs (8)  
 slow=8/ly=8, very=8, away=8,  
 along=8, just=8,  
 suddenly=8, subsequently=8,  
 \*

\*pronouns (9) \$\$ and other referents  
 his=9, her=9, he=9, she=9, they=9, their=9,  
 it=9/s=9, this=9, that=9,  
 there=9,  
 \*

\*units (10)  
 mile=10/s=10, hour=10/s=10, ft=10, foot=10, feet=10,  
 kg=10, m=10, s=10, degree=10/s=10, rad=10, metres=10  
 second=10/s=10, sec=10, radian=10/s=10, min=10/s=10,  
 cm=10, mps=10, mps<sub>1</sub><sup>-1</sup>=10, mps<sub>1</sub><sup>-2</sup>=10, mph=10,  
 kmphr=10, kmphr<sub>1</sub><sup>-1</sup>=10, mph<sub>1</sub><sup>-1</sup>=10, km<sub>2</sub><sup>-1</sup>=10, hr=10, h=10,  
 ftps=10, ftps<sub>2</sub><sup>-1</sup>=10, ftps<sub>1</sub><sup>-1</sup>=10, ftps<sub>2</sub><sup>-2</sup>=10,  
 meters=10, N=10, newtons=10, kgxmps<sub>2</sub><sup>-1</sup>=10  
 \*

\*numbers (11)  
 \* as read in by a store command, assumed correct.  
 \*

\*elapsed time (12)  
 until=12, tak//e=12/es=12/ing=12, when=12, then=12,  
 in=12, before=12, for=12, during=12, been=12, after=12,  
 end=12, later=12, while=12, taken=12,  
 into=12 \$\$ temporary classification  
 \*

\*questions (13)  
 what=13, why=13, how=13, where=13, explain=13,  
 find=13, determine=13, calculate=13, solve=13, work=13,  
 compute=13,  
 \*

\*spatial (14)  
 top=14, bottom=14, middle=14,  
 \*

\*connectives (15)  
 and=15, which=15, if=15, who=15/se=15,  
 \*

\*qualifiers (16)  
 large=16,motor=16,round=16,many=16,  
 straight=16,level=16,flat=16,small=16,toy=16,  
 initial=16/ly=16,final=16,first=16,model=16,  
 far=16,high=16,long=16,last=16,average=16,  
 landing=16,certain=16,big=16,fast=16,rapid=16,  
 resultant=16,next=16,magnitude=16,short=16,  
 vertically=16,total=16,horizontally=16,  
 increas//es=16/ing=16/ed=16,constant=16,  
 decreas//es=16/ing=16/ed=16,uniform=16/ly=16  
 chang//e=16/es=16/ing=16,zero=16,rate=16,  
 \*

\*position/direction (17)  
 up=17,down=17,between=17,at=17,from=17,apart=17,  
 towards=17,across=17,to=17,onto=17,on=17,off=17,  
 upon=17,by=17,above=17,below=17,upward=17/s=17,  
 downward=17/s=17,back=17,backward=17/s=17,out=17,  
 forward=17/s=17,positive=17,negative=17,beside=17,  
 right=17,rightward=17/s=17,left=17,leftward=17/s=17,  
 angle=17,vertical=17,horizontal=17,same=17,axis=17,  
 opposite=17,reverse=17,contact=17  
 contact=17,over=17,  
 \*

\*negatives (18)  
 not=18,won't=18,can't=18,isn't=18,  
 couldn't=18,shouldn't=18,wouldn't=18,  
 \*

\*"stop/stops" (19) \$\$ special single words  
 stop=19/s=19/ping=19,rest=19/s=19/ing=19,  
 stationary=19,  
 maximum=19,highest=19,  
 \*

\* verbs which imply "g"=+10 m/s<sup>2</sup>  
 \* (i.e. velocity in same direction as acceleration)  
 fall=20/s=20,drop=20/s=20/ped=20,  
 release=20/s=20/d=20,  
 \*

\*first person (21)  
 i=21,my=21,mine=21,we=21,our=21/s=21,your=21/s=21,  
 you=21,one=21/s=21,lets=21,let's=21,another=21,  
 \*

\*yells! (22)  
 yes=22,no=22,maybe=22,help=22,ok=22,stuck=22,  
 wow=22,gee=22,oh=22,don't=22,  
 \*

endoff=32)  
 \*

Appendix B

Syntactic patterns for problem statements

## Appendix B

### Syntactic patterns for problem statements

```

*
* This sets up the syntactic patterns for the
* natural language system.
*
*
*****
* The first section is for the problem statement.
* The info is used in unit "search".
*
set      phras(1)
* info about mass, speed, acceleration etc.
      'fckj',o04 01 02 00 76 0000000000    $$ 6 3 11 10
      'cfkj',o04 00 02 00 76 0000000000    $$ 3 6 11 10
      'kjb',o03 00 06 76 00 0000000000     $$ 11 10 2
      'kjab',o03 00 06 76 00 0000000000    $$ 11 10 1 2
      'cfgbfkj',o07 00 05 00 76 0000000000 $$ 3 6 7 2 6 11 10
      'dkj',o03 02 01 00 03 0000000000     $$ 4 11 10
      'tkj',o03 02 01 00 03 0000000000     $$ 20 11 10
      'dqkj',o04 00 02 00 76 0000000000    $$ 4 17 11 10
      'fkjq',o04 01 03 76 00 0000000000    $$ 3 11 10 17
      'crfkj',o05 00 03 00 76 0000000000   $$ 3 18 6 11 10
      'cfrkj',o05 00 03 00 76 0000000000   $$ 3 6 18 11 10
*
* participle phrases about zero speed and similar
      'pqs',o03 02 00 00 01 0000000000     $$ 16 17 19
      'dqs',o03 02 00 00 01 0000000000     $$ 4 17 19
      'bqs',o03 02 00 00 01 0000000000     $$ 2 17 19
      'diqs',o04 03 00 00 01 0000000000    $$ 4 9 17 19
      'sc',o02 00 00 00 01 0000000000      $$ 16 3
      'bs',o02 01 00 00 01 0000000000      $$ 2 19
      'fs',o02 01 00 00 01 0000000000      $$ 6 19
      'is',o02 01 00 00 01 0000000000      $$ 9 19
      'os',o02 01 00 00 01 0000000000      $$ 15 19
      'sb',o02 00 00 00 01 0000000000      $$ 19 2
      'sqkj',o04 02 02 76 00 0000000000    $$ 19 17 11 10
*
* implied acceleration =  $g = 10 \text{ m/s}^2$ 
      'bpq',o03 02 00 00 02 0000000000     $$ 2 16 17
      'dpq',o03 02 00 00 02 0000000000     $$ 4 16 17
      'dql',o03 01 00 00 02 0000000000     $$ 4 17 12
      'dkjppq',o05 04 00 00 02 0000000000  $$ 4 11 10 16 17
      't',o01 00 00 00 02 0000000000       $$ 20
*
* elapsed time phrases
      'lkj',o03 01 04 76 00 0000000000     $$ 12 11 10
      'lfkj',o04 02 04 76 00 0000000000    $$ 12 6 11 10
      'lgpkj',o05 03 04 76 00 0000000000   $$ 12 7 16 11 10
*
set      phras(31)
* frame of ref
      'qgea',o04 00 00 00 04 0000000000    $$ 17 7 5 1
      'qga',o03 00 00 00 04 0000000000    $$ 17 7 1
*
*

```

```

* friction
      'efcfk',o05 02 04 00 76 0000000000    $$ 5 6 3 6 11
*
* implied v0 and vf
*
      'qkjgkj',o06 00 00 00 05 0000000000    $$ 17 11 10 17 11 10
*
* questions
      'mfgc',o04 03 00 76 76 0000000000      $$ 13 6 7 3
      'mfic',o04 03 00 76 76 0000000000      $$ 13 6 9 3
      'mfgpc',o05 04 00 76 76 0000000000     $$ 13 6 7 16 3
      'mfipc',o05 04 00 76 76 0000000000     $$ 13 6 9 16 3
      'mfgpf',o05 06 00 76 76 0000000000     $$ 13 6 7 16 6
      'mfgsc',o05 06 00 76 76 0000000000     $$ 13 6 7 19 3
      'mpc',o03 02 00 76 76 0000000000       $$ 13 16 3
      'mpd',o03 01 00 76 76 0000000000       $$ 13 16 4
      'mpf',o03 01 00 76 76 0000000000       $$ 13 16 6
      'mpj',o03 02 00 76 76 0000000000       $$ 13 16 10
      'mddgpc',o06 05 00 76 76 0000000000    $$ 13 4 4 7 16 3
      'mddipc',o06 05 00 76 76 0000000000    $$ 13 4 4 9 16 3
      'mddgc',o05 04 00 76 76 0000000000     $$ 13 4 4 7 3
      'mddic',o05 04 00 76 76 0000000000     $$ 13 4 4 9 3
      'mc',o02 01 00 76 76 0000000000        $$ 13 3
      'mipc',o04 03 00 76 76 0000000000      $$ 13 9 16 3
      'mgpc',o04 03 00 76 76 0000000000      $$ 13 7 16 3
      'mic',o03 02 00 76 76 0000000000      $$ 13 9 3
      'mgc',o03 02 00 76 76 0000000000      $$ 13 7 3
      'mgsc',o04 03 00 76 76 0000000000     $$ 13 7 19 3
      'mmp',o03 02 00 76 76 0000000000      $$ 13 13 16
*
*****

```

Appendix C

Problems which ALBERT can solve

## Appendix C

### Problems which ALBERT can solve

The following is a list of 61 problems which ALBERT is known to be able to solve. The problems are taken verbatim from the sources quoted except that in most cases, the numbers have been converted to SI units. There has been no other modification to the wording. It should be noted that the books contain several more problems which can be used with minor modifications to the wording. Those problems marked with an "\*" require user-mediation. The sheet of supplementary problems given to some students contained many of the problems shown here.

Kane and Sternheim (1984)

1. A car proceeds to pass another. Its speed increases from 13 m/s to 27 m/s in 4 s. What is the average acceleration?
2. A train travelling with a velocity of  $30 \text{ m.s}^{-1}$  stops with a uniform acceleration in 50 s. (a)\* What is the acceleration of the train? (b) What is the distance travelled before coming to rest?
3. An antiaircraft shell is fired vertically upward with an initial velocity of  $500 \text{ m.s}^{-1}$ . (a) Compute the maximum height of the shell. (b) How long does it take to reach this height?
4. A boy standing beside a tall building throws a ball straight up with an initial velocity of  $15 \text{ m.s}^{-1}$ . (a) How high will the ball rise? (b) How long will it take for the ball to reach its maximum height?
5. A rock dropped from the top of a tower strikes the ground in 4 s. (a)\* Find the velocity of the rock just before it strikes the ground. (b) Find the height of the tower.

6. A stone is thrown vertically downward from a bridge with an initial velocity of  $10 \text{ m}\cdot\text{s}^{-1}$ . It strikes the water in 3 s. (a) What is the velocity of the stone as it strikes the water? (b) What is the height of the bridge above the water?

7. A stone dropped from a bridge strikes the water in 5 s. (a)\* What is the velocity of the stone when it strikes the water? (b) What is the height of the bridge?

Fleming (1978)

(Note the use of the phrase "negative acceleration" by this author.)

8. A car is travelling along a straight level road at a speed of  $30 \text{ m}\cdot\text{s}^{-1}$ . The brakes of the car are capable of producing a negative acceleration of  $-6 \text{ m}\cdot\text{s}^{-2}$ . (a) How long will it take for the car to stop?

9. A bobsled accelerates in a straight line at a constant rate for 6.0 seconds, from rest to  $12 \text{ m}\cdot\text{s}^{-1}$ . (a)\* How far does it travel in 6.0 seconds?

Warren (1979)

10. A man stands on a bridge and drops a stone from rest into the stream below. The stone is accelerated downward at  $9.8 \text{ m/s}^2$ , and takes 1.2 s to reach the stream. How far is it to the stream?

11. A ball is thrown straight up into the air with an initial velocity of 20 m/s. The acceleration due to gravity is downward at  $9.8 \text{ m/s}^2$ . How long will it take the ball to reach a height of 15 m?

12. A sportscar will accelerate from zero to 27 m/s in 9.5 s.  
(a) What is the average acceleration?  
(b) How far does it go?

13. A rapid transit train accelerates from rest to 13 m/s with an acceleration of  $1.2 \text{ m/s}^2$ .  
(a) How long does it take to reach this speed?  
(b) How far does it go?

14. A sportscar will travel 400 m from a standing start in 18.5 s.  
(a) What is the average acceleration?  
(b) What is the final speed, assuming a constant average acceleration?

15. A person throws a ball straight up into the air with a velocity of 25 m/s.  
(a) What is the maximum height reached by the ball?

Cromer (1974)

16. A constant horizontal force of 150 N is applied to a 60 kg block which is initially resting on a frictionless surface. After 3 s (a)\* What is its speed? (b)\* How far has it moved?

17. A 45 kg water skier starts from rest in the water and is accelerated to a speed of 10 m/s in 2 s. What is the total force on the skier during the period of acceleration?

18. A car accelerates from rest to 26.8 m/s in 11 s.  
(a) What is its acceleration during this period?  
(b) How far does it travel during the acceleration period?

19. How long does it take an object starting from rest to fall 40 ft?

20. In a head-on collision, a car going 27 m/s is brought to rest in 0.1 s. What is the acceleration during the collision?

21. A ball is thrown straight up in the air with an initial speed of 12 m/s.  
(a) How long does it take the ball to reach its highest point?  
(b) How high does the ball go?

- 22.\* When making a vertical jump, a grasshopper extends its legs 2.5 cm in 0.025 s.  
(a) What is the acceleration of the grasshopper while extending its legs?

23. A  $5 \times 10^{-4}$  kg flea takes 0.001 s to go from rest to its takeoff speed of 1.2 m/s. During this period its rear legs are in contact with the ground.

(a) What is the acceleration of the flea during the takeoff period?

(b) What is the force on the flea during the takeoff period?

24.\* A force of 180 N is applied on a 30 kg mass parallel to its initial velocity of 5 m/s. What is the speed of the mass after moving 25 m?

ALONSO and FINN (1971)

25. A body is moving with an initial velocity of  $3 \text{ m}\cdot\text{s}^{-1}$ , and has a constant acceleration of  $4 \text{ m}\cdot\text{s}^{-2}$  in the same direction as the velocity. What is (a) the velocity of the body at the end of 7 s? (b) the distance covered at the end of 7 s?

26.\* An airplane, in taking off, covers a 600-m path in 15 s. Assuming a constant acceleration, (a) Calculate the acceleration in  $\text{m}\cdot\text{s}^{-2}$ .

SASSC Physical Science (Control Data S A, 1982)

27. Calculate how many seconds a truck takes to accelerate from  $2 \text{ m}\cdot\text{s}^{-1}$  to  $20 \text{ m}\cdot\text{s}^{-1}$  at a uniform acceleration of  $0,9 \text{ m}\cdot\text{s}^{-2}$ .

28.\* A cyclist is accelerating uniformly at  $2,5 \text{ m}\cdot\text{s}^{-2}$  for 4 s. If his initial velocity was  $5 \text{ m}\cdot\text{s}^{-1}$ , calculate the distance covered during the 4 s.

29.\* An object is accelerated uniformly at a rate of  $2 \text{ m}\cdot\text{s}^{-2}$ . Calculate its velocity after 5 seconds.

30. A car slows down uniformly from  $40 \text{ m}\cdot\text{s}^{-1}$  to  $20 \text{ m}\cdot\text{s}^{-1}$  in 5 s. Calculate the distance covered in 5 s.

31. A steel ball dropped from the top of a building reaches the ground in 3 s. Find the height of the building.

BUECHE (1972)

32. An automobile starts from rest and attains a speed of 15.5 m/s in 20 sec. (a) Find its average acceleration (b) The distance it travels in this time assuming uniform acceleration.

33. A car travelling at 27 m/s has its brakes slammed on and stops in 4 sec. (a) Find its deceleration (b) How far it goes before stopping.

34. A bullet with a speed of 51 m/s strikes a block of wood and penetrates 0.05 m before coming to rest. (a) Find its deceleration (b) Find the time taken to stop it.

35. An automobile starts from rest and attains a speed of 12.3 m/s after travelling 61.5 m. How long did it take to reach this speed?

36. A body accelerating at  $3 \text{ ft/s}^2$  is travelling at a certain instant at a speed of 18.5 m/s. If it started from rest (a) How long has it been accelerating (b) How far has it gone in this time?

37. A stone is thrown straight up with an initial speed of 25 m/s. (a) How high does the stone go. (b) How long does it take to reach its highest point?

FREEMAN (1968)

38. A train coasting at 56 ft/s was brought uniformly to rest by its brakes in 8.0 sec. Compute (a) its acceleration, (b) how far it travelled while coming to a stop.

39. A car, travelling at constant speed, is given a constant acceleration of  $0.80 \text{ m/s}^2$  for the next 10 sec, during which time it travels 200 m. Find (a) the initial speed of the car and (b) its speed at the end of the 10-sec interval.

BUECHE (1969)

40.\* A bullet moving at 60 m/sec penetrates a block of wood 9.0 cm before stopping. Find its average deceleration.

41. A car moving at 60 ft/s comes to rest with constant deceleration in a distance of 240 ft. How long does it take to stop?

42. What average force is required to stop a 2000 kg car in a distance of 2.0 m if the initial speed of the car is 30 m/sec?

SHORTLY and WILLIAMS (1965)

43. A motorcycle moving with an initial velocity of 20 m/s experiences a constant deceleration of  $3 \text{ m/s}^2$ . How far does the motorcycle move during the first 4 s after its velocity begins to decrease?

44.\* A car has an initial velocity of 15 m/s and experiences a constant deceleration of  $2 \text{ m/s}^2$ . How far has the car moved by the time its velocity is reduced to 5 m/s?

SEARS and ZEMANSKI (1957)

45. An airplane taking off from a landing field has a run of 370 m. If it starts from rest, moves with constant acceleration, and makes the run in 30 sec, with what velocity in m/s did it take off?

46. A body starts from rest, moves in a straight line with constant acceleration and covers a distance of 64 ft in 4 sec. (a) What was the final velocity?

STEAD 1955

47. A train, starting from rest, has a uniform acceleration of  $1.23 \text{ m/s}^2$ . How long will it take to reach a speed of 27 m/s?

48. A body of mass 10 kg, moving at a speed of 2.5 m/s, is brought to rest in 20 seconds by an opposing force. Calculate the force, assuming it to be constant.

49. A mass of 0.2 kg, initially at rest, is acted upon by a constant force of 5 N. (a) Find the distance it travels in 10 seconds.

50. A motor car, of mass 1000 kg, is travelling at 13 m/s. The brakes are then applied and the car is brought to rest in 11 seconds. Find the retarding force due to the brakes, assuming it to be uniform.

BROAD (1965)

51. A body initially at rest has an acceleration of  $2.1 \text{ ft/s}^2$ . What is its velocity after (a) 3 seconds and (b) 40 seconds?

52. A particle has an initial velocity of 14 ft/s. and an acceleration of  $3.5 \text{ ft/s}^2$ . Find its velocity after (a) 12 seconds and (b) after 24 seconds.

53. If a body has an initial velocity of 12 ft/s. and an acceleration of  $3.6 \text{ ft/s}^2$ , how long does the body take to attain a velocity of 40 ft/s.?

54. What is the acceleration of a car while its velocity is being increased from 10 m/s to 25 m/s in 30 s?

55. How long does it take to speed a car up from 7 m/s to 27 m/s if the acceleration is  $1.07 \text{ m/s}^2$ ?

56.\* A body is dropped from rest down a shaft 74 m deep. Find the time the body takes to reach the bottom.

57. A body has an initial velocity of 2.5 m/s and an acceleration of  $1.4 \text{ m/s}^2$ . Determine how far it has moved in (a) 2 seconds and (b) 20 seconds.

58. Determine the acceleration of a body, whose initial velocity is 1.5 m/s and whose displacement is 63 m after 12 seconds.

Miscellaneous

59. A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it during its motion up the plane.

60. A ball rolls down a hill with a constant acceleration of  $0.3 \text{ m/s}^2$  it starts from rest, what will be its speed after it has travelled a distance of 350 m?

61. A car which has a mass of 1.3 kg is moving with constant speed on a level road, when it suddenly experiences a constant force of 5 N for 12 seconds. After this, its speed is 25 m/s. How far did it travel in the 12 seconds?

-----

Appendix D

Dialogues from the simulated ALBERT experiment

## Appendix D

### Dialogues from the simulated ALBERT experiment

The dialogues shown here have been reconstructed from the student data file which recorded the students' discussions with ALBERT in the simulated ALBERT experiment. Due to the nature of the data, the screen format (e.g., carriage return and line feeds) was not the same as it appears in the dialogues.

From the second dialogue, the time each party took to respond is shown in parenthesis.

Dialogues DS-1 to DS-4 relate to problem 1.

Dialogues DS-5 to DS-9 relate to problem 2.

Dialogues DS-10 to DS-16 relate to problem 3.

Dialogues DS-17 to DS-19 relate to problem 4.

Dialogue DS-1 (Problem 1):

Albert: How would you like to start?  
Student: Given mass= 0.020 kg ; force= 1025 N ; acc= ?  
Albert: You are specifying too many quantities at once.  
Student: Use F=ma  
Albert: What do you wish to calculate?  
Student: a  
Albert: Then you can't use F=ma as it stands.  
Student: a=F/m  
Albert: Ok. Why did you choose the formula F=ma?  
Student: Newton's third law of motion  
Albert: Are you sure?  
Student: no  
Albert: F=ma is Newton's second law. Please type a value for a.  
Student: a=1025+.02  
Albert: You have operators in your answers. Please simplify.  
Student: 51250 m/s<sup>2</sup>  
Albert: Well done. I agree with your answer and the units are correct.

Dialogue DS-2 (Problem 1):

This student pressed NEXT to get a new line and terminated the input unintentionally. At this stage the terminator key was moved to LAB.

Latre typing time: 176.8 s  
Albert: How would you like to start?  
Latre (39.0 s): Write an equation  
Albert ( 8.1 s): What equation?  
Latre (11.5 s): F=ma  
Albert (13.2 s): Why did you choose that one?  
Latre (47.1 s): Because it takes the values given in the problem into (student pressed NEXT for a new line and terminated input - fixed.)  
Albert (17.7 s): What are you trying to calculate?  
Latre (25.9 s): The acceleration of the bullet  
Albert (15.4 s): On what does the acceleration depend?  
Latre (38.9 s): The mass and force acting on the bullet.  
Albert (23.3 s): Sorry I do not understand "andforce".  
Latre (32.3 s): The mass and force acting on the bullet.  
Albert (14.5 s): So you want to use F=ma?  
Latre ( 5.6 s): Yes  
Albert (16.5 s): Good. You need to rearrange the formula.  
Latre (35.8 s): a=F/m  
Albert (23.6 s): Good. Please type in the value and units for a.  
Latre (67.2 s): 51250 m/s<sup>2</sup>  
Albert (21.1 s): Well done. I agree with that answer.

Dialogue DS-3 (Problem 1):

Swanepoel typing time: 116.5 s  
Albert: How would you like to start?  
Swanepoel ( 72.3 s): what formula may be used?  
Albert ( 13.8 s): What do you wish to calculate?  
Swanepoel ( 41.7 s): acceleration of the bullet  
Albert ( 26.6 s): Sorry I do not understand "acceleration of".  
Swanepoel ( 37.2 s): acceleration of the bullet  
Albert ( 19.3 s): On what does the acceleration of the bullet depend?  
Swanepoel ( 45.1 s): the initial force  
Albert ( 35.6 s): Do you know a formula which relates force and acceleration?  
Swanepoel ( 46.8 s):  $F=ma$   
Albert ( 19.6 s): Is that the same as  $F=ma$ ?  
Swanepoel ( 8.6 s): yes  
Albert ( 32.3 s): Good. You will have to rearrange the formula to calculate acceleration.  
Swanepoel ( 72.8 s):  $a=f/m$   
Albert ( 16.7 s): Good. Please type in the value and units for a.  
Swanepoel ( 59.0 s): 51250 m/s  
Albert ( 64.4 s): Are "m/s" the units of acceleration?  
Swanepoel ( 34.4 s):  $m/s^2$   
Albert ( 19.6 s): Well done. You have solved the problem.

Dialogue DS-4 (Problem 1):

Donaldson typing time: 63.0 s  
Albert: How would you like to start?  
Donaldson ( 24.2 s): Writing down what has been given  
Albert ( 10.4 s): What is given?  
Donaldson ( 37.6 s): mass=0.020 kg force=1025 N  
Albert ( 20.5 s): Ok. What are you trying to calculate?  
Donaldson ( 27.8 s): The acceleration of the mass  
Albert ( 37.4 s): Do you mean the acceleration of the bullet?  
Donaldson ( 10.4 s): Yes  
Albert ( 7.9 s): On what does this depend?  
Donaldson ( 36.2 s): The force exerted on the bullet  
Albert ( 30.2 s): Good. How is the acceleration related to the force?  
Donaldson ( 41.1 s):  $F = m \cdot a$   
Albert ( 38.4 s): That's right. You will have to rearrange the formula before you can calculate the acceleration.  
Donaldson ( 28.2 s): I agree ie.  $a = F/m$   
Albert ( 26.6 s): Good. Please type in the value and units you get for a.  
Donaldson ( 59.5 s): 51250 m/s<sup>2</sup>  
Albert ( 22.4 s): Well done. You have solved the problem.

Dialogue DS-5 (Problem 2):

Albert: How would you like to start?  
Martin (210.4 s): I need to find the initial speed, so I need an equation which has time, acceleration and final speed in it.  
Albert ( 27.0 s): That is true. Do you know the equation?  
Martin ( 19.5 s): I'm not sure.  
Albert ( 17.8 s): What do you know about the car?  
Martin ( 64.1 s): It accelerated at  $0.5 \text{ m/s}^2$  for 30 seconds.  
Albert ( 15.4 s): What does that tell you?  
Martin ( 78.8 s): For 30 seconds it increased its speed by  $0.5 \text{ m}$  for every second.  
Albert ( 51.5 s): The units of speed are not "m". Please correct your statement.  
Martin ( 64.6 s): For 30 seconds it increased its speed by  $0.5 \text{ m/s}$  for every second.  
Albert ( 26.8 s): Good. So by how much did its speed change in 30 sec?  
Martin ( 52.7 s): Change in speed =  $30 \times 0.5$   
Albert ( 41.6 s): Please evaluate the expression and put in the units.  
(TERM-calc is available.)  
Martin ( 30.2 s):  $30 \times 0.5 = 15 \text{ m/s}$   
Albert ( 18.0 s): Good. Now can you tell me the initial speed?  
Martin ( 38.4 s): Yes, it is  $25 - 15 = 10 \text{ m/s}$ .  
Albert ( 23.4 s): Well done. You have solved the problem.

Dialogue DS-6 (Problem 2):

Donaldson typing time: 50.6 s  
Albert: How would you like to start?  
Donaldson (147.2 s): Given : uniform acceleration =  $0.5 \text{ m/s}^2$   
time = 30 seconds  
velocity =  $25 \text{ m/s}$   
initial speed = ?  
Albert ( 68.7 s): You have specified too many quantities. Sorry, I do not understand "= ?". What are you trying to calculate?  
Donaldson ( 38.3 s): I am trying to calculate the initial speed of the car  
Albert ( 9.1 s): On what does this depend?  
Donaldson ( 20.5 s): On the acceleration  
Albert ( 27.3 s): What can you calculate using acceleration?  
Donaldson ( 26.2 s): The distance travelled by the car  
Albert ( 52.1 s): That is true, but you can also find the change in speed. How is  $\Delta v$  related to acceleration?  
Donaldson (252.2 s):  $\Delta v = a \times t$   
Albert ( 30.0 s): Excellent. So what is the change in speed for this car?  
Donaldson ( 27.4 s):  $15 \text{ m/s}$   
Albert ( 55.3 s): Very good. Since  $\Delta v$  is  $15 \text{ m.s}^{-1}$ , and  $v_f$  is  $25 \text{ m.s}^{-1}$  what is the initial speed?  
Donaldson ( 11.6 s):  $10 \text{ m/s}$   
Albert ( 21.1 s): Well done. You have solved the problem.

Dialogue DS-7 (Problem 2):

A bug in ALBERT resulted in some of the input not being displayed on the screen. This resulted in some confusion.

Latre typing time: 144.1 s

Albert: How would you like to start?

Latre (33.0 s): By writing an equation.

Albert (11.4 s): What do you wish to calculate?

Latre (27.4 s): I want to calculate the initial speed of the car.

Albert (12.8 s): Ok what do you know about the car?

Latre (41.2 s): I know its acceleration is  $0.5 \text{ m/s}^2$  for 30 seconds.

Albert (20.5 s): Good. What does that tell you?

Latre (\*\*\*\* s): The information can be used to calculate the distance the car will travel. However I do not think this is the right way to approach the problem.

Albert (50.2 s): how much does the speed change?

Latre (\*\*\*\* s): By 15 m/s.

Albert (11.5 s): How do you know?

Latre (39.8 s): Could you restate the line before.

Albert (24.7 s): How do you know it is  $15 \text{ m.s}^{-1}$ ?

Latre (59.6 s): Multiply  $0.5 \text{ m/s}^2$  by 30 seconds.

Albert (24.4 s): Good. Thus what is  $v_i$ ?

Latre (25.6 s):  $10 \text{ m/s}$ .

Albert (14.2 s): Well done. You have solved the problem.

~~Dialogue DS-8 (Problem 2):~~

Swanepoel typing time: 275.3 s

Albert: How would you like to start?

Swanepoel (212.1 s): which formula should i use ?

Albert ( 28.8 s): What do you wish to calculate?

Swanepoel ( 26.8 s): initial speed of motor car

Albert ( 15.0 s): What do you know about the car?

Swanepoel (103.8 s): it accelerated uniformly at  $0.5 \text{ m.s}^{-1}$  for 30 s

Albert ( 37.4 s): Good, can you calculate the amount by which the

speed changed in the 30s then?

Swanepoel (114.7 s): no

Albert ( 26.9 s): Do you know the definition of acceleration?

Swanepoel ( 67.7 s): change in speed per unit time

Albert ( 56.6 s): Right, that is  $a = \Delta v / \Delta t$ . Can you use this to find the change in speed?

Swanepoel (115.8 s):  $0.5 \text{ m.s}^{-1} \times 30 \text{ s}$

Albert ( 66.3 s): Sorry, I do not agree. If  $a = \Delta v / \Delta t$ , then the change in speed  $\Delta v = at$ . Can you calculate  $\Delta v$ ?

Swanepoel ( 31.9 s):  $.5 \times 30$

Albert ( 17.3 s): Correct, but what are the units?

Swanepoel ( 27.5 s):  $.5 \text{ m.s}^{-1} \times 30 \text{ s}$

Albert ( 34.7 s): Sorry I do not understand that. Please work out the

value and units

Swanepoel ( 25.2 s): 15m

Albert ( 40.1 s): m are not the units of speed.

Swanepoel ( 91.6 s):  $15 \text{ m.s}^{-1}$

Albert ( 23.7 s): Good. So the change in speed is  $15 \text{ m/s}$ . Do you

know the final speed?

Swanepoel ( 21.2 s):  $25 \text{ m.s}^{-1}$

Albert ( 14.6 s): Great. Can you work out the initial speed?

Swanepoel ( 32.0 s): no

Albert ( 55.7 s): Ok. There was a change in speed of  $15 \text{ m/s}$  after which

the final speed was  $25 \text{ m/s}$ .  $\Delta v = v_f - v_i$ .

Can you work it out now?

Swanepoel ( 41.1 s):  $10 \text{ m.s}^{-1}$

Albert ( 17.5 s): Well done. You have solved the problem.

Dialogue DS- 9 (Problem 2):

Coombes typing time: 351.1 s  
Albert: How would you like to start?  
Coombes (143.9 s): write the equations of motion  
Albert ( 13.8 s): What do you want to calculate?  
Coombes ( 23.2 s): the initial speed.  
Albert ( 8.8 s): On what does this depend?  
Coombes ( 39.6 s): the acceleration and the final speed  
Albert ( 24.4 s): What effect does the acceleration have on the motion?  
Coombes ( 60.3 s): a positive effect the car is accelerated to 25 m/s.  
Albert ( 26.9 s): What do you mean by "positive effect"?  
Coombes ( 43.6 s): the cars speed is increased to 25 m/s  
Albert ( 20.1 s): So the acceleration brings about a change in speed?  
Coombes ( 8.1 s): yes  
Albert ( 13.1 s): Does the change in speed depend only on the acceleration?  
Coombes (107.1 s): no the weight of the car , the coefficient of friction and the initial speed, which is what we want to find  
Albert ( 63.9 s): In this problem we may assume that the coefficient of friction is 0. Now on what does the change in speed depend?  
Coombes ( 17.4 s): the acceleration  
Albert ( 23.6 s): Do you mean that  $\Delta v = \text{acceleration}$ ?  
Coombes (105.2 s): yes the change in speed is brought about by an acceleration  
  
Albert ( 24.4 s): How would you calculate the change in speed?  
Coombes (116.2 s): the final speed - the acceleration \* the time that the car is accelerated  
Albert ( 63.6 s): Are you saying that the change in speed depends on the final speed?  
Coombes ( 70.0 s): the final speed - the change in speed will give the initial speed  
Albert ( 44.3 s): That is correct. How do you calculate the change in speed?  
Coombes ( 48.4 s): the acceleration \* the time the car is accelerated  
Albert ( 24.4 s): Very good.  $\Delta v = a \times t$ . You know a, do you know t?  
Coombes ( 19.3 s): yes it is 30 seconds  
Albert ( 47.1 s): That does not seem to be given in your problem statement  
but we can use that value if you like. What is the change in speed then?  
Coombes ( 28.8 s): 15 m/s  
Albert ( 14.6 s): Good. Now can you calculate the initial speed?  
Coombes ( 47.4 s): 25 m/s - 10 m/s = 15 m/s the initial speed  
Albert ( 24.8 s): Well done. That is correct. You have solved the problem.

Press NEXT for another record.

Dialogue DS-10 (Problem 3):

Donaldson typing time: 212.2 s  
Albert: How would you like to start?  
Donaldson (161.0 s): car has a mass of 0.6 kg  
initial speed = 1.2 m/s  
distance travelled = 0.3 m  
final velocity = 0 m/s  
required to find the \_\_\_\_\_  
Albert ( 47.2 s): You have specified many attributes of the car.  
Please refer to one at a time.  
What do you wish to calculate?  
Donaldson ( 26.6 s): the acceleration of the car  
Albert ( 9.1 s): Why?  
Donaldson ( 96.1 s): the force of the car is related to the acceleration by  
the following formula  $F=ma$   
Albert ( 34.4 s): Good. You know the mass so you need to find a.  
What else do you know about the car?  
Donaldson ( 21.2 s): I know the initial and the final speed  
Albert ( 16.0 s): Good. Anything else?  
Donaldson ( 24.7 s): I also know that the car has travelled a distance of 0.3 m  
Albert ( 18.6 s): Excellent. How is the distance travelled related to the speed?  
Donaldson ( 55.4 s): distance = change of velocity/time  
Albert ( 31.4 s): Are you sure?  
Donaldson ( 96.6 s): No I think it should be  $\Delta v \times t = d$   
Albert ( 37.6 s): Do mean change is speed times time = distance travelled?  
Press NEXT for more.  
Donaldson ( 9.1 s): yes  
Albert ( 51.2 s): Sorry, I do not agree. distance travelled is average speed  $\times$  time. Do you remember now?  
Donaldson ( 22.9 s): yes  
Albert ( 43.3 s): Since  $x = v_{av} \times t$  you can work out t very easily. How long did the car take to come to rest?  
Donaldson ( 40.3 s):  $t = 0.25$  s  
Albert ( 10.9 s): Are you sure?  
Donaldson ( 45.3 s): no is  $t = 0.5$  s  
Albert ( 32.1 s): Good! Now you know the time interval and the speed. Can you work out the acceleration?  
Donaldson ( 32.3 s): yes  $a = 2.4$  m/s  
Albert ( 9.2 s): Are you sure?  
Donaldson ( 66.6 s): Is  $a = 1.2$  m/s<sup>2</sup>?  
Albert ( 37.1 s): No. The numerical value of your first answer is right. I'm worried about the direction.  
Donaldson ( 41.5 s): Sorry the acceleration is negative i.e  $a = -2.4$  m/s<sup>2</sup>  
Albert ( 15.4 s): Excellent. Now can you answer the original question?  
Donaldson ( 25.7 s):  $F = -1.44$  N  
Albert ( 20.2 s): Well done! You have solved the problem.

Press NEXT for another record.

Albert: How would you like to start?  
 Martin ( 33.5 s): Do I need to consider friction?  
 Albert ( 37.2 s): The problem says nothing about friction. You may neglect it.  
 Martin ( 72.6 s): I can use the equation  $F=ma$ , but I first need to find the acceleration.  
 Albert ( 37.2 s): Good. On what does the acceleration depend?  
 Martin ( 29.6 s): Speed and time.  
 Albert ( 38.5 s): Good. It is related to the change of speed and the time. Do you know these quantities?  
 Martin ( 92.2 s): Change of speed is  $1.2-0=1.2$  m/s, but I don't know time.  
 Albert ( 41.1 s): Good. You know the change of speed. What else do you know about the motion?  
 Martin ( 87.7 s): It travels 3 m, thus time will be  $1.2 \div 0.3 = 4$  sec.  
 Albert ( 56.2 s): Good. You know the distance travelled. Is time = speed  $\times$  distance?  
 Martin ( 61.2 s): No, time = speed + distance.  
 Albert ( 25.9 s): Correct. Can you calculate the time?  
 Martin (133.1 s): time is 4 sec, acceleration will be  $1.2 \div 4 = 0.3$  m/s<sup>2</sup>.  
 Albert ( 32.9 s): You used the initial speed. The speed is not constant.  
 Martin ( 65.3 s): I used change in speed, as calculated earlier in the problem.  
 Albert ( 93.6 s): The time is not 4 seconds.  $x=vt$  but  $v$  is not constant so you can't use the initial speed to calculate time.  
 Martin (120.1 s): I used change in speed and change in time.  
 Albert ( 50.3 s): How did you calculate the time? You cannot use initial speed or change in speed to calculate time.  
 Martin ( 47.9 s): Change in speed = change in distance  
 Albert ( 62.8 s): That is not right. distance = average speed  $\times$  time.  
 time is thus distance  $\div$  average speed. Do you know the average speed?  
 Martin ( 40.2 s): It will be 0.6 m/s  
 Albert ( 22.9 s): Do you mean average speed is 0.6 m/s?  
 Martin ( 7.0 s): yes  
 Albert ( 15.5 s): Good. So how long was it moving?  
 Martin ( 53.0 s):  $0.3 \div 0.6 = 0.5$  sec  
 Albert ( 38.7 s): Very good. Now you know the change in speed and the time. What is the acceleration?  
 Martin ( 75.0 s): It is  $1.2 \div 0.5 = 2.4$  m/s<sup>2</sup>  
 Albert ( 37.2 s): Sorry, I do not understand "2,4".  
 Martin ( 22.4 s): It is 2.4 m/s<sup>2</sup>

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Albert ( 26.9 s): Good. In what direction will this be?  
 Martin ( 40.1 s): negative  
 Albert ( 11.9 s): Which way is positive?  
 Martin ( 16.0 s): forwards  
 Albert ( 40.8 s): Good. (We have assumed that all along.) Now can you answer the question in the problem statement?  
 Martin (101.8 s): Force is  $0.6 \times 2.4 = 1.44$  N  
 Albert ( 11.5 s): In which direction?  
 Martin ( 14.7 s): down  
 Albert ( 14.1 s): Well done you have solved the problem.

Dialogue DS-12 (Problem 3):

Latre typing time: -659.6 s

Albert: How would you like to start?

Latre (116.1 s): I would like to calculate the acceleration of the car.

Albert ( 31.6 s): On what does that depend?

Latre (158.7 s): The velocity of the car and the time it takes to reach a particular point. The time is , so how should I go on?

Albert ( 28.2 s): Does the acceleration depend on velocity?

Latre ( 39.2 s): No it depends on the difference in velocity.

Albert ( 25.1 s): Right. Do you know the change in velocity in this case?

Latre ( 52.0 s): Yes it changes by 1.2 m/s.

Albert ( 17.4 s): Right. Do you know the time?

Latre ( 37.2 s): No, this is where I get stuck. What should I do?

Albert ( 13.6 s): On what does the time depend?

Latre ( 72.1 s): The distance travelled and the speed at which the car travels.

Albert ( 22.3 s): Right. Do you know the distance travelled?

Latre (144.6 s): Yes and the velocity. This would give the time as

0.25 seconds. However this means we must assume that the car has a constant velocity.

Albert ( 32.8 s): What value did you use for the velocity?

Latre ( 21.0 s): 1.2 m/s.

Albert ( 33.9 s): That is the initial speed. How does the speed

Latre ( 35.5 s): The speed decreases.

Albert ( 32.0 s): Right so you can't use 1.2 m/s. What now?

Latre (141.8 s): I will have to try to solve the problem without finding the acceleration, but I do not know how to go about this.

Albert ( 76.0 s): Don't give up yet. Since the speed decreases linearly with time, average speed\*time=distance travelled. Can you calculate the time now?

Latre (104.4 s): Yes, thanks. The time is 0.5 seconds.

Albert ( 60.8 s): Excellent. Now can you calculate the acceleration?

Latre (161.8 s): Yes. It is  $-2.4 \text{ m/s}^2$ . The negative sign is because the car is actually decelerating.

Albert ( 25.2 s): Very good. Now can you solve the problem?

Latre ( 61.8 s): Yes I think so. The resultant force is -1.44 N.

Albert ( 22.9 s): What does the - sign mean now?

Latre ( 80.4 s): It shows the direction of the force, since force is a vector, with both direction and magnitude.

Albert ( 30.7 s): What is the direction of the force in this case?

Latre ( 37.9 s): The direction of the force is down the plane.

Albert ( 22.3 s): Well done. You have solved the problem.

Press NEXT for another record.

Dialogue DS-13 (Problem 3):

(This student did the problem a second time.)

Latre typing time: 167.7 s

Albert: How would you like to start?

Latre (\*\*\*\* s): I would like to calculate the acceleration of the car.

Albert (31.6 s): On what does that depend?

Latre (\*\*\*\* s): The velocity of the car and the time it takes to reach a particular point. The time is , so how should I go on?

Albert (28.2 s): Does the acceleration depend on velocity?

Latre (39.2 s): No it depends on the difference in velocity.

Albert (25.1 s): Right. Do you know the change in velocity in this case?

Latre (52.0 s): Yes it changes by 1.2 m/s.

Albert (17.4 s): Right. Do you know the time?

Latre (37.2 s): No, this is where I get stuck. What should I do?

Albert (13.6 s): On what does the time depend?

Latre (72.1 s): The distance travelled and the speed at which the car travels.

Albert (22.3 s): Right. Do you know the distance travelled?

Latre (\*\*\*\* s): Yes and the velocity. This would give the time as

0.25 seconds. However this means we must assume that the car has a constant velocity.

Albert (32.8 s): What value did you use for the velocity?

Latre (21.0 s): 1.2 m/s.

Albert (33.9 s): That is the initial speed. How does the speed

Latre (35.5 s): The speed decreases.

Albert (32.0 s): Right so you can't use 1.2 m/s. What now?

Latre (\*\*\*\* s): I will have to try to solve the problem without finding the acceleration, but I do not know how to go about this.

Albert (76.0 s): Don't give up yet. Since the speed decreases linearly with time, average speed  $\times$  time = distance travelled. Can you calculate the time now?

Latre (\*\*\*\* s): Yes, thanks. The time is 0.5 seconds.

Albert (60.8 s): Excellent. Now can you calculate the acceleration?

Latre (\*\*\*\* s): Yes. It is  $-2.4 \text{ m/s}^2$ . The negative sign is because the car is actually decelerating.

Albert (25.2 s): Very good. Now can you solve the problem?

Latre (61.8 s): Yes I think so. The resultant force is  $-1.44 \text{ N}$ .

Albert (22.9 s): What does the - sign mean now?

Latre (80.4 s): It shows the direction of the force, since force is a vector, with both direction and magnitude.

Albert (30.7 s): What is the direction of the force in this case?

Latre (37.9 s): The direction of the force is down the plane.

Albert (22.3 s): Well done. You have solved the problem.

Dialogue DS-14 (Problem 3):

Mckellar typing time: 890.2 s  
Albert: How would you like to start?  
Mckellar ( 62.8 s): calculate the acceleration  
Albert ( 8.1 s): Why?  
Mckellar ( 90.5 s): use acceleration in formula  $f=ma$   
Albert ( 13.7 s): On what does the acceleration depend?  
Mckellar (123.9 s): initial speed, final speed and distance.  
Albert ( 46.1 s): That is true. But what is the definition of acceleration?  
Mckellar ( 73.6 s): change in velocity+time.  
Albert ( 19.6 s): Do you know the change in velocity?  
Mckellar ( 22.4 s): yes  
Albert ( 5.4 s): and the time?  
Mckellar ( 21.8 s): no  
Albert ( 26.0 s): But you know the distance. How is the time related to the distance?  
Mckellar ( 80.0 s): time=distance+speed  
Albert ( 24.3 s): Good. Can you work out a value for time?  
Mckellar (155.8 s):  $t=0.3+1.2=0.025$  sec  
Albert ( 31.2 s): You have used the final speed. The speed is not constant. Does this matter?

\*\*\*\*\* This session was interrupted by a power failure.  
The following lines, lost when the power went off, were reconstructed from memory immediately after the event.

Mckellar: Yes  
Albert: What now?  
Mckellar: Use deceleration (or calculate deceleration)  
Albert: No Since the speed decreases linearly with time you can use the average speed,  $x = v_{av} t$ .  
Can you calculate the time now?  
Mckellar: Yes

\*\*\*\*\* The session continued when the power was restored.

Mckellar (152.7 s): yes,  $v$  average =  $1.2-0.0+2=0.6$   
Albert ( 26.2 s): what are the units?  
Mckellar ( 30.6 s): m/s  
Albert ( 11.1 s): Good now can you work out the time take?  
Mckellar ( 92.3 s):  $t=0.3+0.6=0.05$  sec  
Albert ( 23.7 s): Please check your working.  $0.3+0.6 \neq 0.05$ .  
Mckellar (306.6 s):  $t=0.5$  s  
Albert ( 33.2 s): Great! Now you said that acceleration is  $\Delta v/t$ .  
Can you work out the acceleration?  
Mckellar (162.0 s):  $a=1.2/0.5=2.4$  m/s<sup>2</sup>  
Albert ( 28.9 s): Good. What about the direction?  
Mckellar ( 80.5 s): down the slope  
Albert ( 19.5 s): Good. Now you can work out the force, can't you?  
Mckellar (112.0 s):  $f=0.6 \times 2.4=1.44$  N  
Albert ( 10.2 s): And the direction is?  
Mckellar ( 25.6 s): down the slope  
Albert ( 18.0 s): Well done. You have solved the problem.

Dialogue DS-15 (Problem 3):

This student makes several wild guesses at equations for velocity.

Swanepoel typing time: 173.8 s

Albert: How would you like to start?

Swanepoel ( 95.2 s): how can the resultant force be calculated ?

Albert ( 22.7 s): What do you know about the car?

Swanepoel ( 56.4 s): mass of 0.6 kg, initial speed 1.2 m/s

Albert ( 14.2 s): Do you know anything else?

Swanepoel ( 37.4 s): it travels 0.3 m before stopping

Albert ( 13.4 s): Good. What else?

Swanepoel ( 54.4 s): it travels up an inclined plane

Albert ( 19.3 s): Ok. Do you know the final velocity?

Swanepoel ( 6.4 s): 0

Albert ( 33.3 s): Good. Since you know the mass, what else do you  
u

need to know to calculate the force?

Swanepoel ( 32.1 s): acceleration

Albert ( 25.7 s): Good. Do you know how to calculate the acceleration

from the other things you know?

Swanepoel ( 55.9 s): 0.36 m/s

Albert ( 39.2 s): Are "m/s" the units of acceleration?

Swanepoel ( 11.1 s): 0.36 m/s<sup>2</sup>

Albert ( 16.8 s): Ok. How did you get that answer?

Swanepoel ( 49.9 s):  $1/2 \times \text{mass} \times \text{velocity}^2$

Albert ( 35.8 s): Do you mean  $a=0.5 \times m \times v^2$ ?

Swanepoel ( 26.2 s):

Albert ( 21.4 s): Sorry I do not understand. Please repeat your  
answer.

Swanepoel ( 7.0 s): yes

Albert ( 97.3 s): Oh dear! I do not agree. That looks like kinetic

energy rather than acceleration. What now?

Swanepoel ( 76.8 s): what formula should i use

Albert ( 55.6 s): Since we know the displacement and the initial  
and final velocities, we should try to use them.

How is the displacement related to velocity?

Swanepoel (158.1 s): displacement equals velocity  $\times$  time

Albert ( 27.1 s): Do you mean  $x=v \times t$ ?

Swanepoel ( 40.6 s): yes

Albert ( 21.4 s): What is the value of v then?

Swanepoel ( 32.9 s): 0

Albert ( 36.7 s): So the displacement =  $v \times t$  is also 0?

Swanepoel ( 24.7 s): 0.3 m

Albert ( 18.2 s): So how can v be 0?

Swanepoel ( 50.6 s): 1.2 m/s

Albert ( 58.1 s): That is the initial velocity. The velocity is  
not

constant. How do you get a value for v in  
 $x=v \times t$ ?

Swanepoel (198.5 s):  $v=x/t$

Albert ( 80.6 s): No it is not! displacement is average velocity  
times

time in this case, i.e.  $x=v_{av} \times t$ . What now?

Swanepoel ( 89.6 s): i give up

Albert ( 65.7 s): Don't do that.  $v_{av}=1/2 \times (v_0+v_f)$ . What is the  
value  
of  $v_{av}$ ?

Press NEXT for more.

/dialogue DS-15 continues

Dialogue DS- 15 continued.

Swanepoel ( 33.0 s): .6 m/s

Albert ( 47.7 s): Very good! That's right. Now since  $x = v_{av} \times t$  can you

work out a value for  $t$ ?

Swanepoel ( 61.4 s):  $t = 0.25$  s

Albert ( 25.3 s): Sorry I do not agree. Please check your calculation.

Swanepoel ( 40.3 s): 0.5 s

Albert ( 42.0 s): Excellent! Now since you know the time interval and

the initial and final velocities, can you work out the acceleration?

Swanepoel (244.4 s): -2.4 m/s

Albert ( 37.4 s): The units of acceleration are not "m/s".

Swanepoel ( 21.5 s): -2.4 m/s<sup>2</sup>

Albert ( 27.4 s): Very good. Can you work out the force?

Swanepoel ( 27.4 s): 1.44 N

Albert ( 10.9 s): Are you sure?

Swanepoel ( 41.2 s): yes

Albert ( 43.8 s): You had -2.4 m.s<sup>-2</sup> for the acceleration. What did

the negative sign mean?

Swanepoel ( 24.1 s): deceleration

Albert ( 25.2 s): What does deceleration mean?

Swanepoel ( 18.2 s): slowing down

Albert ( 25.2 s): Very good. What does this tell you about the direction

of the acceleration?

Swanepoel ( 13.3 s): down

Albert ( 14.7 s): Do you mean down the plane?

Swanepoel ( 22.8 s): yes

Albert ( 45.8 s): Good. 1.44 N is the correct magnitude for the force.

What do you know about its direction?

Swanepoel ( 21.9 s): -1.44 N

Albert ( 25.6 s): And the negative sign tells you what?

Swanepoel ( 32.6 s): the force is downwards

Albert ( 18.0 s): Well done. You have solved the problem.

Press NEXT to repeat.

Dialogue DS-16 (Problem 3):

---

Coombes typing time: 215.8 s

Albert: How would you like to start?

Coombes ( 93.2 s): calculate the acceleration

Albert ( 13.1 s): Why?

Coombes (151.3 s): we know that the force acting on the car is its mass  $\times$  its acceleration

Albert ( 17.3 s): Good. On what does acceleration depend?

Coombes ( 54.9 s): the initial speed and the distance before coming to rest

Albert ( 51.6 s): Sorry I do not understand "initial". I am looking for the definition of acceleration.

Coombes ( 78.5 s): the initial speed and the distance before it came to rest

Albert ( 24.4 s): What is the definition of acceleration?

Coombes ( 56.3 s): a change in velocity

Albert ( 15.0 s): Do you mean  $a = \Delta v$ ?

Coombes ( 7.4 s): yes

Albert ( 18.3 s): Do you know the change in velocity this in this case?

Coombes ( 52.5 s): yes the initial speed was 1.2 m/s and the final speed is 0 m/s

Albert ( 61.2 s): Ok. But the definition of acceleration is change in

velocity per unit time.  $a = \Delta v / \Delta t$ . Do you know  $\Delta t$ ?

Coombes ( 9.0 s): no

Albert ( 27.8 s): Ok. You know how far it went. How is the distance

travelled related to the time taken?

Press NEXT for more.

---

Coombes ( 12.2 s): 0.3 m

Albert ( 25.0 s): 0.3 m is the distance travelled. How is this related to  $\Delta t$ ?

Coombes ( 54.8 s): the velocity = the distance divided by the time

Albert ( 16.4 s): Very good. Can you calculate  $\Delta t$ ?

Coombes (120.3 s): yes, its 0.5 sec

Albert ( 44.5 s): Excellent. Now what is the change in velocity?

Coombes ( 22.8 s): -1.2 m/s

Albert ( 18.4 s): Very good. Can you work out a value for  $a$ ?

Coombes ( 61.7 s): yes its  $-2.4 \text{ m/s}^2$

Albert ( 19.2 s): Correct. Now what is the resultant force?

Coombes ( 23.3 s): -1.44 N

Albert ( 12.8 s): Good what does the negative sign tell you?

Coombes ( 39.0 s): that the force was retarding the motion of the car

Albert ( 21.9 s): Well done you have solved the problem.

Dialogue DS-17 (Problem 4):

Albert: How would you like to start?  
Martin ( 98.7 s): It has an acceleration of  $-10 \text{ m/s}^2$   
Albert ( 42.0 s): Good. What does the - sign tell you?  
Martin ( 19.1 s): Its decelerating  
Albert ( 16.3 s): Ok. What else do you know?  
Martin ( 89.9 s): Initial speed is 15 m/s and it needs to travel 8 m.  
Albert ( 48.0 s): Since it is deceleration, how high will it go before it comes to rest?  
Martin (156.4 s): 12.5 m  
Albert ( 9.9 s): How do you know that?  
Martin ( 80.5 s): I guessed  
Albert ( 31.9 s): Ok. What is its speed at 8 m then?  
Martin (105.0 s): I don't know  
Albert ( 27.3 s): You guessed the 12.5 m. I do not agree with that.  
Martin ( 24.3 s): Help please  
Albert ( 82.8 s): You know the acceleration. You know the initial speed. You know it comes to rest at the top of its flight. Can you work out the time taken to stop  
Martin (105.7 s): time is  $7.5 \div 10 = 0.75 \text{ sec}$   
Albert ( 61.4 s): Good. You know the time and the initial and final speed, can you work out how high it went?  
Martin ( 83.2 s):  $15 \times 0.75 = 20 \text{ m}$

---

Albert ( 48.0 s): I do not agree.  $x = vt = 15 \times 0.75 = 11.25 \text{ m}$ .  
Martin (422.9 s): Ok, so time taken to reach 8 m will be  $8 \div 11.25 \times 0.75 = 0.53 \text{ sec}$   
Albert ( 71.6 s): Sorry, I do not agree with your answer. Can you calculate the speed at 8 m?  
Martin (146.6 s): 10.65 m/s  
Albert ( 68.0 s): It will be 8.06 m/s. Now since you know the change in speed and the distance, can you calculate the time?  
Martin (127.0 s):  $8 \div 6.94 = 1.15 \text{ sec}$   
Albert ( 62.3 s): Sorry, I do not agree with your answer. distance = average speed  $\times$  time. Please check your calculation.  
Martin (122.8 s): average speed = 6.94 m/s ?  
Albert (121.6 s): No. How did you calculate that?  
Martin ( 38.9 s): initial speed - speed at 8 m  
Albert ( 39.4 s): That is the change in speed. How do you calculate average speed?  
Martin (113.5 s):  $(15 + 8.06) \div 2 = 11.53 \text{ m/s}$   
Albert ( 22.3 s): Good. Now how long does it take to reach 8 m?  
Martin ( 60.9 s):  $8 \div 11.53 = 0.69 \text{ sec}$   
Albert ( 50.2 s): Good. That answer is correct, but there is another answer which is correct too. Do you know it?  
Martin ( 14.7 s): no

---

Albert ( 57.9 s): The stone is also at 8 m on the way down. How long does it take to get from 8 m to the top of its flight?  
Martin (110.1 s): 0.06 sec  
Albert ( 28.8 s): Good. So how long does it take to come down from the top to 8 m?  
Martin ( 28.5 s): 0.06 sec  
Albert ( 18.9 s): Good. So what is the second answer to the question?  
Martin ( 14.1 s): 0.81 sec  
Albert ( 18.4 s): Well done. You have solved the problem.

Dialogue DS-18 (Problem 4):

Donaldson typing time: 78.8 s

Albert: How would you like to start?

Donaldson ( 66.4 s): initial velocity = 15 m/s

distance travelled = 8 m

final velocity = 0

find t

Albert ( 20.9 s): How do you intend to find t?

Donaldson ( 25.2 s): By using an equation of motion

Albert ( 16.8 s): What equation?

Donaldson ( 54.1 s):  $s = \text{initial velocity} \times \text{time} + \frac{1}{2} \times a \times t^2$

Albert ( 31.2 s): How do you know that the final velocity is 0 m/s?

Donaldson ( 84.1 s): As the stone is moving upwards its velocity is decreasing. When it finally reaches a height of 8 m, its velocity has decreased to 0

Albert ( 27.5 s): How do you know 8 m is the maximum height?

Donaldson ( 37.4 s): It may not be the maximum height but it is the height that was given

Albert ( 63.9 s): You are right. It does not have to be the maximum

height. We are not told that it is. We can't assume speed is 0 there. What now?

Donaldson ( 55.9 s): I agree with you, but actually we don't need the final velocity to calculate time

Albert ( 60.3 s): Right! Do you still want to use the equation:

$x = v_0 t + \frac{1}{2} a t^2$ ?

Donaldson ( 32.8 s): yes

Albert ( 25.1 s): Ok. You will have to rearrange the formula.

---

Donaldson (145.5 s):  $2(s - v_0 t) / a = t^2$

Albert ( 69.9 s): I do not recognise that formula. You may be using

a slightly different notation. Do not worry. Please type in the value and units of t.

Donaldson ( 36.6 s):  $t = 1.18 \text{ s}$

Albert ( 94.8 s): Sorry, I do not agree with your answer.

$x = v_0 t + \frac{1}{2} a t^2$  then the answer has the form

$-b \pm \sqrt{b^2 - 4ac} / 2a$ . Try again.

Donaldson ( 59.4 s): what is b and c?

Albert (113.5 s): We are using a quadratic equation.

$\frac{1}{2} a t^2 + v_0 t - x = 0$  hence  $t = -v_0 \pm \sqrt{v_0^2 - 4 \times (\frac{1}{2} a) \times (-x)} / 2 \times \frac{1}{2} a$

Can you calculate t?

Donaldson (107.8 s): -1 s

Albert ( 35.3 s): Sorry, I do not agree. First, is there only one answer

to this question?

Donaldson ( 6.7 s): no

Albert ( 8.3 s): Good. Why?

Donaldson ( 40.7 s): there is a + or - sqrt

Albert ( 12.0 s): Is there a physical reason?

Donaldson ( 11.3 s): I don't know

Albert ( 65.0 s): If 8 m is not the maximum height, then there will be

two times at which the height is 8 m. Do you agree

that  $-5t^2 + 15t - 8 = 0$ ?

Donaldson ( 20.2 s): yes

Albert ( 9.0 s): Can you solve this for t?

Press NEXT for more.

/dialogue DS-18 continues

Dialogue DS-18 continued.

Donaldson (192.8 s): no

Albert ( 70.0 s): Oh dear!  $t = -15 \pm \sqrt{15^2 - 4 \times (-5) \times (-8)} + (2 \times (-5))$ .

Can you work out a value of t from this?

Donaldson ( 50.9 s): Is  $t = -8/5$  s and  $t = 8/3$  s ?

Albert ( 78.3 s): Sorry I do not agree. If you work it out you will

get 0.68s and 2.3 s respectively for the two times. Is that alright?

Donaldson ( 42.8 s): Please explain .I dont understand

Albert ( 26.5 s): Do you wish me to explain further?

Donaldson ( 9.6 s): yes

Albert (100.1 s): We know  $v_0 = 15$  m/s. We know  $x = 8$ m. We know  $a = -10$ m/s<sup>2</sup>.

We use  $x = v_0 t + 1/2 a t^2$ . This gives  $-5t^2 + 15t - 8 = 0$

Hence:  $t = 0.68$ s or  $t = 2.3$ s. Ok?

Donaldson ( 18.6 s): yes

Albert ( 39.7 s): Well done. It's a pity the mathematics gave you

trouble!

Press NEXT for another record.

Dialogue DS-19 (Problem 4):

Latre typing time: 241.5 s

Albert: How would you like to start?

Latre (161.4 s): I do not know how to start this problem.

Albert ( 19.2 s): Ok. On what does the time depend?

Latre ( 43.8 s): The time depends on the distance and the acceleration.

Albert ( 30.2 s): Is that all?

Latre ( 33.2 s): Sorry and the speed.

Albert ( 44.7 s): Right. distance travelled= average speed  $\times$  time.

Do you know the average speed?

Latre ( 51.2 s): No.

Albert ( 10.6 s): On what does it depend?

Latre ( 58.0 s): The average speed will be 7.5 m/s.

Albert ( 64.9 s): That would be true if the stone came to rest at a

height of 8 m. average speed=1/2 initial speed minus final speed.

Latre (163.6 s): How do you find the final speed?

Albert ( 39.6 s): How would you calculate the change in speed?

Latre ( 44.8 s): Acceleration  $\times$  time.

Albert ( 80.8 s): Good. So  $1/2 (v_i + v_f) = 1/2 (v_i + (v_i + at)) =$  average speed.

Latre ( 90.2 s): But I dont know t so how can I use this?

Albert ( 83.1 s):  $x =$  average speed  $\times t = 1/2 (v_i + (v_i + at)) \cdot t$  which you can

solve for t. Try simplifying the equation.

Latre (167.4 s):  $t = 2(d - v_i) / a$

Albert ( 37.0 s): Sorry I do not agree with you. Please check your algebra.

\*\*\* The student signed off. She claimed that she had run out of time.

Press NEXT for another record.

Appendix E

Syntactic patterns for the dialogue system

Appendix E

Syntactic patterns for the dialogue system

```

*
*
*****
* This section is for the dialogue.
* These are used in unit classif.
set      phras(61)
*
* assertion (-1)
*   with numbers
      'cfk',o03 00 02 00 76 0000000000    $$ 3 6 11
      'ifk',o03 00 02 00 76 0000000000    $$ 9 6 11
      'dqk',o03 00 02 00 76 0000000000    $$ 4 17 11
      'lk',o02 00 01 00 76 0000000000     $$ 12 11
      'iddk',o04 00 03 00 76 0000000000    $$ 9 4 4 11
*   no numbers
      'bfd',o03 02 02 76 76 0000000000    $$ 2 6 4
      'ifd',o03 02 02 76 76 0000000000    $$ 9 6 4
      'ifp',o03 00 02 76 76 0000000000    $$ 9 6 16
      'ifgc',o04 03 00 76 76 0000000000   $$ 9 6 7 3
      'ifc',o03 02 00 76 76 0000000000   $$ 9 6 3
      'ifggc',o05 04 03 76 76 0000000000  $$ 9 6 7 17 3
      'fgpc',o04 03 02 76 76 0000000000  $$ 6 7 16 3
      'dfpc',o04 03 02 76 76 0000000000  $$ 4 6 16 3
      'cfp',o03 00 02 76 76 0000000000   $$ 3 6 16
*
*   directions
      'iddq',o04 03 00 00 05 0000000000   $$ 9 4 4 17
      'cfq',o03 02 00 00 05 0000000000   $$ 3 6 17
      'ifq',o03 02 00 00 05 0000000000   $$ 9 6 17
      'qfq',o03 02 00 00 05 0000000000   $$ 17 6 17
      'qqq',o03 02 00 00 05 0000000000   $$ 17 7 17
      'qddq',o04 03 00 00 05 0000000000  $$ 17 4 4 17
      'lgqc',o04 02 00 00 05 0000000000  $$ 12 7 17 3
      'hga',o03 00 01 00 05 0000000000   $$ 8 7 1
      'hqq',o03 00 01 00 05 0000000000   $$ 8 7 17
      'qga',o03 00 01 00 05 0000000000   $$ 17 7 1
*
* equation (0)
      ';',o01 00 00 00 00 0000000000     $$ 63
*
* negation (1) (negative assertion)
*
*   with number
      'ifrk',o04 00 00 00 01 0000000000   $$ 9 6 18 11
      'irk',o03 00 00 00 01 0000000000   $$ 9 18 11
      'idrd',o04 00 00 00 01 0000000000   $$ 9 4 18 4
      'irdk',o04 00 00 00 01 0000000000   $$ 9 18 4 11
*
*   without number
*
* intent (2)
      'udqmg',o05 05 00 00 02 0000000000  $$ 21 4 17 13 7
set      phras(91)
      'udqd',o04 03 00 00 02 0000000000  $$ 21 4 17 4
      'udm',o03 02 00 00 02 0000000000   $$ 21 4 13
      'umc',o03 01 00 00 02 0000000000   $$ 21 13 3

```

```
*
* question (3)
*
* assistance (4)
   'urdc',o04 03 00 00 04 0000000000    $$ 21 18 4 3
   'urdgc',o05 04 00 00 04 0000000000    $$ 21 18 4 7 3
   'urdm',o04 03 00 00 04 0000000000    $$ 21 18 4 13
*
*****
```

Appendix F  
ALBERT-student dialogues

## Appendix F

### ALBERT-student dialogues

This section contains a representative selection of ALBERT - student dialogues.

The following points should be noted with regard to the dialogues.

1. They are numbered in approximately chronological sequence. ALBERT has been improved along the way, and the later dialogues, D-60 and above, are representative of the present capability of the system.
2. The format of the reconstructed dialogues does not match the screen format as seen by the student. Apart from the graphics which is missing here, carriage return and line feeds do not always correspond and in the reconstructed dialogues more lines begin with "ALBERT" than would be the case on the screen.
3. In every dialogue, two of ALBERT's statements are not fully stored due to their length. The statement "Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we" is cut off at this point. On the screen it continues with the words "shall need an axis of reference (x-axis). In which direction would you choose the x-axis? (See Figure 6-24.)

The line "(The x-axis has been drawn horizontally for conv" continues with "ience.)". (See Figure 6-24.) This problem can be corrected, but as the students do not experience any such truncation, it has not been regarded as serious.

Dialogue D-1:

This was ALBERT's first dialogue with a student. Various bugs in ALBERT resulted in much confusion. (This student used words for symbols in some places.)

Cayzer typing time: 167.8 s

Cayzer(171): A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

Albert: It is always useful to consider a problem qualitatively first.....

Press NEXT.

Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

Cayzer(39): yes

Albert: Ok.

Albert: And that means.....

Cayzer(21): help

Albert: Since  $\Delta v \neq 0$  and  $\Delta t \neq 0$ ,  $\Delta v / \Delta t \neq 0$  so it is accelerating.

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Cayzer(27): horizontal

Albert: Do you mean as shown above?

Cayzer(10): y

Albert: Sorry, I do not recognise "y".

(Use COPY to fix typing errors, or rephrase your sentence.)

Cayzer(14): yes

Albert: Your axis is at right angles to the direction of motion. That is not a good choice.

Dialogue continues. Press NEXT.

Cayzer(20): vertical

Albert: Sorry, I do not understand that.

(Use COPY to fix typing errors, or rephrase your sentence.)

Cayzer(41): the axis should be vertical

Albert: Sorry, I do not understand that.

(Use COPY to fix typing errors, or rephrase your sentence.)

Cayzer(13): help

Albert: It is usually a good idea to choose the axis of reference in the direction of the velocity during the early part of the motion.

Cayzer(11): help

Albert: In this case, the best choice would be vertically up. (Try it that way!)

Cayzer(25): vertically up

Albert: Do you mean as shown above?

Cayzer(5): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Cayzer(18): downwards

Albert: Do you mean as shown?

Cayzer(6): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?

Cayzer(20): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Dialogue continues. Press NEXT.

Cayzer(16): slowing down  
 Albert: Good! I agree with that.  
 Albert: You have said that the bullet is slowing down.  
 Now please tell me which one of the graphs above correctly shows how the velocity changes with time.  
 Cayzer(9): 3  
 Albert: You say that the answer is 3 .  
 Albert: Good, I agree.  
 Albert: The bullet in this problem moves in a straight line.  
 We may think of it as moving along the x-axis.  
 Albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?  
 (The x-axis has been drawn horizontally for conv  
 Cayzer(15): 2  
 Albert: You say that the answer is 2 .  
 Albert: Good, I agree.  
 Albert: output needed here.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
 Press NEXT.  
 Albert: So to sum up: We are considering a bullet which moves with constant acceleration.  
 Albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.  
 Albert: The speed changes linearly with time.  
 Albert: We are given the initial speed, the final speed, the acceleration,  
 Albert: and  
 we are asked to calculate the distance travelled.  
 Albert: -----  
 Albert: Now to the solution of the problem.....  
 (Remember, symbols used are:  $v_g$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)  
 Press NEXT.  
 Albert: How would you like to start?  
 Cayzer(29): to find time taken  
 Albert: Ok. The current goal is to calculate t.  
 Albert: On what does t depend or what quantities could be used to calculate it?  
 Cayzer(33):  $v_g$   $v_f$   $a$   
 Albert: You say it depends on the initial speed.  
 Albert: Yes, but that's not much use here.  
 Albert: You say it depends on the time.  
 Albert: No!  
 Albert: What else?  
 Cayzer(24):  $a$   
 Albert: You say it depends on the acceleration.  
 Albert: Good! I agree!  
 Albert: What else?  
 Cayzer(15):  $v_f$   
 Albert: You say it depends on the final speed.  
 Albert: Yes, but that's not much use here.  
 Albert: What else?  
 Cayzer(14):  $x$   
 Albert: You say it depends on the distance.

Albert:  
 Albert: What else?  
 Cayzer(31): change in speed  
 Albert: You say it depends on the change in speed.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates these quantities?  
 Cayzer(68):  $t = \text{change in speed} / a$   
 Albert: You want to use  $t = \text{change}$ .  
 Albert: Sorry, I don't recognise that.  
 Albert: Do you wish to use to calculate  $t$ ?  
 Cayzer(34): a  
 Albert: You say it depends on the acceleration.  
 Albert: Good! I agree!  
 Albert: Do you wish to use to calculate  $t$ ?  
 Cayzer(67): change in speed  
 Albert: You say it depends on the change in speed.  
 Albert: Good! I agree!  
 Albert: Do you wish to use to calculate  $t$ ?  
 Cayzer(7): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate  $t$ ?  
 Cayzer(10): yes  
 Albert: Checking....  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Cayzer(28): help  
 Albert: You should try to find  $t$  now by substituting back.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate  $t$ ?

Cayzer(19): yes  
 Albert: Checking....  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Cayzer(85): help  
 Albert: You should try to find  $\Delta v$  now.  
 Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
 Cayzer(20): a  
 Albert: You say it depends on the acceleration.  
 Albert: Yes, but that's not much use here.  
 Albert: What else?  
 Cayzer(28): x  
 Albert: You say it depends on the distance.  
 Albert: Yes, but that's not much use here.  
 Albert: What else?  
 Cayzer(22): F  
 Albert: You say it depends on the force.  
 Albert: No!  
 Albert: What else?  
 Cayzer(9): t  
 Albert: You say it depends on the time.  
 Albert: Yes, but that's not much use here.  
 Albert: What else?  
 Cayzer(5): help  
 Albert: You can use the initial speed  
 Albert: and the final speed tial speed  
 Albert: to calculate the change in

Dialogue continues. Press NEXT.

Albert: On what does  $x$  depend or what quantities could be used to calculate it?

Cayzer(10):  $t$

Albert: You say it depends on the time.

Albert: Good! I agree!

Albert: What else?

Cayzer(13):  $v_0$

Albert: You say it depends on the initial speed.

Albert: Yes, but that's not much use here.

Albert: What else?

Cayzer(8):  $a$

Albert: You say it depends on the acceleration.

Albert: Yes, but that's not much use here.

Albert: What else?

Cayzer(6): help

Albert: You can use the time

Albert: and the average speed

Albert: to calculate the distance.

Albert: i.e., you could use  $x = v_{av} \cdot t$ .

Albert: Do you wish to use  $x = v_{av} \cdot t$  to calculate  $x$ ?

Cayzer(18): yes

Albert: Checking....

Albert: You don't know  $v_{av}$ .

Albert: What do you wish to do now?

Cayzer(76):  $v_{av} = [v_0 + v_f] / 2$

Albert: You want to use  $v_{av} = [v_0 + v_f] / 2$ .

Albert: What do you wish to calculate?

Cayzer(10):  $v_{av}$

Albert: Ok. The current goal is to calculate  $v_{av}$ .

Albert: Fine!

Albert: Type in the value you get for  $v_{av}$ .

Cayzer(13): 50 m/s

Albert: You say that the average speed is 50 m/s.

Albert: Good, I agree.

Albert: What do you wish to do now?

Cayzer(23): find  $x$

Albert: Ok. The current goal is to calculate  $x$ .

Albert: Do you wish to use  $x = v_{av} \cdot t$  to calculate  $x$ ?

Cayzer(8): yes

Albert: Checking....

Albert: Fine!

Albert: Type in the value you get for  $x$ .

Cayzer(30): 500 m

Albert: You say that the distance is 500 m.

Albert: Good, I agree.

Albert: Well done! You have solved the problem.

Albert: Press NEXT to do another problem,  
or DATA to see Albert solve this one.

No more data for cayzer.  
Press NEXT to enter a new name.

Dialogue D-3

A further example of early difficulties. This student did not complete the problem.

Sellers typing time: 92.7 s

Sellers (93): a bullet is fired straight up into the air with an initial speed of 100 m/s how high does it go?

Albert: It is always useful to consider a problem qualitatively first.....

Press NEXT.

Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

Sellers (122): yes

Albert: And that means.....

Sellers (25): help

Albert: Since  $\Delta v \neq 0$  and  $\Delta t \neq 0$ ,  $\Delta v / \Delta t \neq 0$  so it is accelerating.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Sellers (62): positive

Albert: That only makes sense relative to an axis.

Sellers (16): help

Albert: It is usually a good idea to choose the axis of reference in the direction of the velocity during the early part of the motion.

Albert: That only makes sense relative to an axis.

Sellers (83): up

Albert: Do you mean as shown above?

Sellers (9): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Sellers (22): up

Albert: Do you mean as shown?

Sellers (10): yes

Albert: I do not agree. Think again.

Sellers (37): down

Albert: Do you mean as shown?

Sellers (7): yes

Albert: That's right!

Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?

Sellers (45): 1

Albert: You say that the answer is 1.

Albert: Sorry, I do not agree with that.

Albert: Think! Does the acceleration vary?

Sellers (20): 2

Albert: You say that the answer is 2.

Albert: Sorry, I do not agree with that.

Albert: Acceleration is constant. So, which is it?

Sellers (14): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Dialogue continues. Press NEXT.

Sellers(100): slowing down  
 Albert: Good! I agree with that.  
 Albert: You have said that the bullet is slowing down.  
 Now please tell me which one of the graphs above correctly  
 shows how the velocity changes with time.  
 Sellers(36): 2  
 Albert: You say that the answer is 2 .  
 Albert: Sorry, I do not agree with that.  
 Albert: Think! The acceleration is constant so how does  $v_x$  vary  
 Sellers(23): 1  
 Albert: You say that the answer is 1 .  
 Albert: Good, I agree.  
 Albert: The bullet in this problem moves in a straight line.  
 We may think of it as moving along the x-axis.  
 Albert: Which one of the three diagrams above correctly shows  
 the positions of the bullet along the x-axis  
 which are equally spaced in time?  
 (The x-axis has been drawn horizontally for conv  
 Sellers(129): 3  
 Albert: You say that the answer is 3 .  
 Albert: Sorry, I do not agree with that.  
 Sellers(54): 1  
 Albert: You say that the answer is 1 .  
 Albert: Sorry, I do not agree with that.  
 Sellers(4): 2  
 Albert: You say that the answer is 2 .  
 Albert: Good, I agree.  
 Albert: output needed here.

Albert: -----  
 Albert: Now for a summary of what we know.....  
 Press NEXT.  
 Albert: So to sum up: We are considering a bullet which moves  
 with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
 is in the opposite direction to the velocity,  
 so it is slowing down.  
 Albert: The speed changes linearly with time.  
 Albert: We are given the initial speed, the final speed, the a  
 cceleration,  
 Albert: and  
 we are asked to calculate the distance travelled.  
 Albert: -----  
 Albert: Now to the solution of the problem.....  
 (Remember, symbols used are:  $v_g$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)  
 Press NEXT.  
 Albert: How would you like to start?  
 Sellers(6): help  
 Albert: You should try to find  $t$  now.  
 Albert: On what does  $t$  depend or what quantities could be  
 used to calculate it?  
 Sellers(76):  $v_f$  &  $s$   
 Albert: You say it depends on the final speed.  
 Albert: No, not directly.  
 Albert: What else?  
 Sellers(7): help

Dialogue continues. Press NEXT.

Albert: You can use the acceleration  
 Albert: and the change in speed  
 Albert: to calculate the time.  
 Albert: Do you know a formula which relates these quantities?  
 Sellers(127):  $v_f = v_o + at$   
 Albert: You want to use  $v_f = v_o + at$ .  
 Albert: Sorry, I do not recognise that equation.  
 (You could try making t the subject of the formula.)  
 Albert: Do you know a formula which relates these quantities?  
 Sellers(57): lkdfjglkdfg;kldrkdj fghjghjkkhjkgkhhjhjkjhkhk  
 jkjkjkjkhk  
 Albert: Sorry, I do not recognise " lkdfjglkdfg;kldrkdj".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Sellers(8): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 Sellers(9): no  
 Albert: Checking....  
 Albert: Type in a new formula.  
 Sellers(54): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 Sellers(24): yes okay  
 Albert: ←  
 Sellers(5): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 Sellers(30): yes i have told you that already  
 Albert: ←  
 Sellers(24): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 Sellers(8): yes  
 Albert: Checking....  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Sellers(24): nothing  
 Albert: Sorry, I do not recognise " nothing".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Sellers(45): help  
 Albert: You should try to find  $\Delta v$  now.  
 Albert: On what does  $\Delta v$  depend or what quantities could be  
 used to calculate it?  
 Sellers(49): time acceleration distance  
 Albert: You say it depends on the time.  
 Albert: No, not directly.  
 Albert: You say it depends on the acceleration.  
 Albert: No, not directly.  
 Albert: You say it depends on the distance.  
 Albert: No, not directly.  
 Albert: What else?  
 Sellers(14): speed  
 Albert: You say it depends on the speed.  
 Albert:  
 Initial speed or final speed or what?  
 Albert: What else?

Dialogue continues. Press NEXT.

Sellers(10): both  
 Albert: Sorry, I do not recognise " both".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Sellers(18): initial  
 Albert: Sorry, I do not understand that.  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Sellers(20): kkkk  
 Albert: Sorry, I do not recognise " kkkk".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Sellers(3): help  
 Albert: You can use the initial speed  
 Albert: and the final speed tial speed  
 Albert: to calculate the change in speed.  
 Albert: Do you know a formula which relates these quantities?  
 Sellers(13): no  
 Albert: Checking....  
 Albert: Type a formula or ask for help.  
 Sellers(110):  $a=v_f-v_o+t$   
 Albert: You want to use  $a=v_f-v_o+t$ .  
 Albert:  $a=v_f-v_o+t$  does not contain  $\Delta v$ .  
 Albert: Do you know a formula which relates these quantities?  
 Sellers(11): help  
 Albert: You could use  $\Delta v=v_f-v_o$ .  
 Albert: Do you wish to use  $\Delta v=v_f-v_o$  to calculate  $\Delta v$ ?  
 Sellers(10): yes  
 Albert: Checking....  
 Albert: Fine!  
 Albert: Type in the value you get for  $\Delta v$ .

Sellers(13): 100

No more data for sellers.  
 Press NEXT to enter a new name.

Dialogue D-5:

An example of a successful dialogue in the early stages. ALBERT was producing a spurious comment about a formula due to a bug in the context model.

Genney typing time: 75.6 s

Genney (78): A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

Albert: It is always useful to consider a problem qualitatively first.....

Press NEXT.

Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

Genney (10): yes

Albert: And that means.....

Genney (13): there is an acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Genney (8): up

Albert: Do you mean as shown above?

Genney (7): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Genney (6): down

Albert: Do you mean as shown?

Genney (3): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?

Genney (8): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Genney (14): slowing down

Albert: Good! I agree with that.

Albert: You have said that the bullet is slowing down.

Now please tell me which one of the graphs above correctly shows how the velocity changes with time.

Genney (8): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The bullet in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience)

Genney (11): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: output needed here.

Albert: -----

Albert: Now for a summary of what we know.....

Press NEXT.

Dialogue continues. Press NEXT.

Albert: So to sum up: We are considering a bullet which moves with constant acceleration.  
 Albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.  
 Albert: The speed changes linearly with time.  
 Albert: We are given the initial speed, the final speed, the acceleration,  
 Albert: and  
       we are asked to calculate the distance travelled.  
 Albert: -----  
 Albert: Now to the solution of the problem.....  
       (Remember, symbols used are:  $v_g$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Genney (30):  $v_f = v_g + a \times t$   
 Albert: You want to use  $v_f = v_g + a \times t$ .  
 Albert: What do you wish to calculate?  
 Genney (7):  $v_f$   
 Albert: The value of  $v_f$  is given in the problem statement.  
 Albert: What do you wish to calculate?  
 Genney (13):  $v_g$   
 Albert: The value of  $v_g$  is given in the problem statement.  
 Albert: What do you wish to calculate?  
 Genney (9):  $t$   
 Albert: Ok. The current goal is to calculate  $t$ .  
 Albert: ~~If you want to use a formula, please type it in.~~  
 Albert: Ok!  
 Albert: You need to rearrange the formula.  
 Genney (21):  $t = (v_f - v_g) / a$   
 Albert: You want to use  $t = (v_f - v_g) / a$ .  
 Albert: Fine!  
 Albert: Type in the value you get for  $t$ .  
 Genney (14): 10 seconds  
 Albert: You say that the time is 10 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Genney (58):  $x = t \times [(v_f + v_g) / 2]$   
 Albert: You want to use  $x = t \times [(v_f + v_g) / 2]$ .  
 Albert: What do you wish to calculate?  
 Genney (6):  $x$   
 Albert: Ok. The current goal is to calculate  $x$ .  
 Albert: ~~If you want to use a formula, please type it in.~~  
 Albert: Ok!  
 Albert: Type in the value you get for  $x$ .  
 Genney (8): 500m  
 Albert: You say that the distance is 500 m.  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
       or DATA to see Albert solve this one.

No more data for genney.  
 Press NEXT to enter a new name.

Dialogue D-9:

An example of a successful dialogue in the early stages of testing.

Mcbean typing time: 52.9 s  
Mcbean(56): A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?  
Albert: It is always useful to consider a problem qualitatively first.....  
Press NEXT.  
Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.  
Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?  
Mcbean(19): yes  
Albert: Ok.  
Albert: And that means.....  
Mcbean(18): it is accelerating  
Albert: Right! There is an acceleration.  
Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we  
Mcbean(14): up  
Albert: Do you mean as shown above?  
Mcbean(7): yes  
Albert: Good! I agree!  
Albert: What is the direction of the acceleration?  
Mcbean(17): down  
Albert: Do you mean as shown?  
Mcbean(11): yes  
Albert: Excellent! I agree.  
Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?  
Mcbean(47): 1  
Albert: You say that the answer is 1.  
Albert: Good, I agree.  
Albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
Mcbean(24): slowing down  
Albert: Good! I agree with that.  
Albert: You have said that the bullet is slowing down. Now please tell me which one of the graphs above correctly shows how the velocity changes with time.  
Mcbean(18): 3  
Albert: You say that the answer is 3.  
Albert: Sorry, I do not agree with that.  
Albert: Think! The acceleration is constant so how does  $v_x$  vary  
Mcbean(12): 2  
Albert: You say that the answer is 2.  
Albert: Good, I agree.  
Albert: The bullet in this problem moves in a straight line. We may think of it as moving along the x-axis.  
Albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?  
(The x-axis has been drawn horizontally for convenience)  
Mcbean(56): 1

Dialogue continues. Press NEXT.



Dialogue D-15:

This student did not know how to type a  $\Delta$ . This resulted in a great deal of confusion over the formulas.

Van heard typing time: 120.8 s 05/19/86

Van heard(137): A bullet is fired straight up into the air with an initial speed of 100 m/s. How high does it go?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the bullet in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a bullet which moves. Does its velocity change during the period of interest?

Van heard(16): yes

Albert: Ok.

Albert: And that means.....

Van heard(25): There is an acceleration.

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Van heard(17): vertical

Albert: Up or down?

Van heard(6): up

Albert: Do you mean as shown above?

Van heard(5): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Van heard(9): down

Albert: Do you mean as shown?

Van heard(5): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the bullet varies with time?

Van heard(15): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the bullet is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Van heard(34): slowing down

Albert: Good! I agree with that.

Albert: You have said that the bullet is slowing down.

Now please tell me which one of the graphs above correctly shows how the velocity changes with time.

Van heard(21): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The bullet in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the bullet along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for conv

Dialogue continues. Press NEXT.



Albert: You say it depends on the acceleration.  
 Albert: Good! I agree!  
 Albert: So  $t$  depends on  $a$  and what else?  
 Van heard(86):  $v_{av}$   
 Albert: You say it depends on the average speed.  
 Albert:  
     Yes, but that's not much use here.  
 Albert: You can use the acceleration much use  
 Albert: and the change in speed  
 Albert: to calculate the time.  
 Albert: Do you know a formula which relates these quantities?  
 Van heard(18): no  
 Albert: Checking....  
 Albert: Type a formula or ask for help.  
 Van heard(13): help  
 Albert: You could use  $\Delta v = a \times t$ .  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate  $t$ ?  
 Van heard(12): yes  
 Albert: Checking....  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Van heard(98):  $_{-}v = (v_f + v_g) / 2$   
 Albert: You want to use  $_{-}v = (v_f + v_g) / 2$ .  
 Albert: What do you wish to calculate?  
 Van heard(19):  $_{-}v$   
 Albert: Sorry, I do not recognise "  $_{-}v$ ".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Van heard(121):  $_{-}v = 5.56$   
 Albert: ←  
 Albert: What do you wish to calculate?  
 Van heard(29):  $_{-}v$   
 Albert: Sorry, I do not recognise "  $_{-}v$ ".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Van heard(10):  $-v$   
 Albert: Sorry, I do not recognise "  $-v$ ".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Van heard(31):  $_{-}v$   
 Albert: Sorry, I do not recognise "  $_{-}v$ ".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Van heard(9): help  
 Albert: You should try to find  $\Delta v$  now.  
 Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
 Van heard(10): help  
 Albert: Please try to answer.  
 Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
 Van heard(50):  $v_f$  and  $v_g$   
 Albert: You say it depends on the final speed.  
 Albert: Good! I agree!  
 Albert: You say it depends on the initial speed.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates these quantities?  
 Van heard(73):  $(v_f + v_g) / 2 =_{-}v$   
 Albert: You want to use  $(v_f + v_g) / 2 =_{-}v$ .  
 Albert:  $(v_f + v_g) / 2 =_{-}v$  does not contain  $\Delta v$ .

Dialogue continues. Press NEXT.

Albert: Do you know a formula which relates these quantities?  
 Van heard(25): no  
 Albert: Checking....  
 Albert: Type a formula or ask for help.  
 Van heard(5): help  
 Albert: You could use  $\Delta v = v_f - v_g$ .  
 Albert: Do you wish to use  $\Delta v = v_f - v_g$  to calculate  $\Delta v$ ?  
 Van heard(55): help  
 Albert: You could use  $\Delta v = v_f - v_g$ .  
 Albert: Do you wish to use  $\Delta v = v_f - v_g$  to calculate  $\Delta v$ ?  
 Van heard(11): yes  
 Albert: Checking....  
 Albert: Fine!  
 Albert: Type in the value you get for  $\Delta v$ .  
 Van heard(33): -100 m/s  
 Albert: You say that the change in speed is -100 m/s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Van heard(12): t  
 Albert: Ok. The current goal is to calculate t.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate t?  
 Van heard(8): yes  
 Albert: Checking....  
 Albert: No.  
     Please check your working.  
 Albert: You need to rearrange the formula.  
 Van heard(131):  $t = \Delta v / a$   
 Albert: You want to use  $t = \Delta v / a$ .  
 Albert: Fine!  
 Albert: Type in the value you get for t.  
 Van heard(49): 11.1  
 Albert: You say that the time is 11.1.  
 Albert: Please specify the units.  
 Albert: Type in the value you get for t.  
 Van heard(13): 11.1 s  
 Albert: You say that the time is 11.1 s.  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for t.  
 Van heard(43):  $t = 11.1$  s  
 Albert: You say that the time is 11.1 s.  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for t.  
 Van heard(26):  $t = 10$  s  
 Albert: You say that the time is 10 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Van heard(18): x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Van heard(42):  $\Delta v, t, a,$   
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: So x depends on t and what else?  
 Van heard(18):  $\Delta v$   
 Albert: You say it depends on the change in speed.

Dialogue continues. Press NEXT.

Albert: No, not directly.  
 Albert: So  $x$  depends on  $t$  and what else?  
 Van heerd(38):  $v_0$   
 Albert: You say it depends on the initial speed.  
 Albert: No, not directly.  
 Albert: You can use the time  
 Albert: and the average speed  
 Albert: to calculate the distance.  
 Albert: Do you know a formula which relates these quantities?  
 Van heerd(83):  $v_{av} = (v_f - v_0) / 2$   
 Albert: You want to use  $v_{av} = (v_f - v_0) / 2$ .  
 Albert:  $v_{av} = (v_f - v_0) / 2$  does not contain  $x$ .  
 Albert: Do you know a formula which relates these quantities?  
 Van heerd(25): no  
 Albert: Checking....  
 Albert: Type a formula or ask for help.  
 Van heerd(3): help  
 Albert: You could use  $x = v_{av} * t$ .  
 Albert: Do you wish to use  $x = v_{av} * t$  to calculate  $x$ ?  
 Van heerd(39): yes  
 Albert: Checking....  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?

No more data for van heerde.  
 Press NEXT to enter a new name.

Dialogue D-20:

Genney typing time: 109.4 s 06/06/86

Genney(111): Determine the force required to bring to rest in a distance of 100 m, a truck with a mass of 300 kg, travelling at 20 m/s.

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the truck in general terms. We will not use the values of any quantity. OT RE

Albert: So, this problem is about a truck which moves. Does its velocity change during the period of interest?

Genney(10): yes

Albert: Ok.

Albert: And that means.....

Genney(6): acceleration

Albert: If the velocity is changing, then the body is...

Genney(8): accelerating

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Genney(13): upwards

Albert: Do you mean as shown above?

Genney(3): yes

Albert: Your axis is at right angles to the direction of motion. That is not a good choice.

Genney(7): sideways

Albert: Sorry, I do not recognise "sideways".

(Use COPY to fix typing errors, or rephrase your sentence.)

Genney(16): choose y axis

Albert: Your axis is at right angles to the direction of motion. That is not a good choice.

Genney(19): horizontal

Albert: Do you mean as shown above?

Genney(4): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Genney(16): backwards

Albert: Do you mean as shown?

Genney(4): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the truck varies with time?

Genney(10): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: Since the truck is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Genney(13): slowing down

Albert: Speed is a scalar quantity. It is always positive. We must work with the x-component of the velocity.

Albert: Good! I agree with that.

Albert: You have said that the truck is slowing down. Now please tell me which one of the graphs above correctly shows how the velocity changes with time.

Genney(8): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The truck in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the truck along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience.)

Genney(10): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: The distance travelled in a given time decreases.

Albert: -----

Albert: Now for a summary of what we know.....  
Press NEXT.

Albert: So to sum up: We are considering a truck which moves with constant acceleration.

Albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.

-----

Albert: The x-component of velocity changes linearly with time.

Albert: We are given the initial velocity, the final velocity, the displacement, the mass,

Albert: and we are asked to calculate the force acting.

Albert: -----

Albert: Now to the solution of the problem.....  
(Remember, symbols used are:  $v_g$ ,  $v_f$ ,  $x$ ,  $t$ ,  $a$ ,  $m$ ,  $F$ ,  $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?

Genney(71): find a

Albert: Ok. The current goal is to calculate a.

Albert: On what does a depend or what quantities could be used to calculate it?

Genney(24):  $s, v_f, v_g$

Albert: You say it depends on the final velocity.

Albert: No, not directly.

Albert: On what does a depend?

Genney(205):  $F=600\text{ N}$

Albert: You say that the force is 600 N.

Albert: Are you sure? Think about the direction.

Albert: On what does a depend?

Genney(22):  $F=-600\text{ N}$

Albert: You say that the force is -600 N.

Albert: Good, I agree.

Albert: (I.e. the x-component of the force.)

Albert: Well done! You have solved the problem.

Dialogue continues. Press NEXT.

Dialogue D-26:

This illustrates the problems students had specifying the direction of the x-axis.

Hobson typing time: 157.3 s 06/07/86

Hobson(161): A toy car with mass of 0.6 kg is projected up an incline with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it during

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Hobson(12): yes

Albert: Ok.

Albert: And that means.....

Hobson(6): accelerates

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Hobson(16): at some angle up

Hobson(5): help

Albert: It is usually a good idea to choose the axis of reference in the direction of the velocity during the early part of the motion.

Hobson(23): in the direction of velocity

Hobson(4): help

Albert: In this case, the best choice would be at an angle up. (Try it that way!)

Hobson(25): at an angle up

Albert: Do you mean as shown above?

Hobson(4): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Hobson(23): at an angle down

Albert: Do you mean as shown?

Hobson(14): no

Albert: How would you choose it then?

Hobson(13): parallel to x

Albert: Do you mean as shown?

Hobson(6): no

Albert: How would you choose it then?

Hobson(27): in the opposite direction to x

Albert: Do you mean as shown? (If not, suggest something else.)

Hobson(10): yes

Albert: I do not agree. Think again.

Hobson(10): help

Albert: If it is slowing down, the direction of the acceleration will be opposite to that of the axis. If it is speeding up, the directions will be the same.

Hobson(23): in the direction of -x

Hobson(14): help

Albert: The direction of a is opposite to the x-axis.  
Hobson(3): help  
Albert: The direction of a is opposite to the x-axis.  
Hobson(2): help  
Albert: The direction of a is opposite to the x-axis.  
Hobson(19): opposite to the x axis  
Albert: Do you mean as shown? (If not, suggest something else.)

Hobson(9): no  
Albert: How would you choose it then?  
Hobson(7): left  
Albert: Do you mean as shown?  
Hobson(16): at an anlge down  
Hobson(15): at an angle down  
Albert: Do you mean as shown?  
Hobson(12): no  
Albert: How would you choose it then?  
Hobson(11): idiot  
Albert: Sorry, I do not recognise " idiot".  
(Use COPY to fix typing errors, or rephrase your sentence.)

No more data for hobson.  
Press NEXT to enter a new name.

Dialogue D-36:

This student fooled ALBERT by using FONT-d to type a  $\Delta$ .

Blackie typing time: 314.1 s 06/07/86

Blackie(316): A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it.

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: So to sum up: We are considering a car which moves with constant acceleration. B to skip

Albert: During the early part of the motion, the acceleration is in the opposite direction to the velocity, so it is slowing down.

Albert: The x-component of velocity changes linearly with time.

Albert: We are given the initial velocity, the final velocity, the displacement, the mass,

Albert: and

we are asked to calculate the force acting.

Albert: -----

Albert: Now to the solution of the problem.....

(Remember, symbols used are:  $v_g$ ,  $v_f$ ,  $x$ ,  $t$ ,  $a$ ,  $m$ ,  $F$ ,  $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?

Blackie(245): use  $x = (v_f - v_g)t/2$

Albert: You want to use  $x = (v_f - v_g)t/2$ .

Albert: What do you wish to calculate?

Blackie(9): t

Albert: Ok. The current goal is to calculate t.

Albert: You want to use  $x = (v_f - v_g)t/2$ ....

Albert: Sorry, I do not recognise that equation.

(Try making t the subject of the formula.)

Albert: On what does t depend or what quantities could be used to calculate it?

Blackie(52):  $t = 2x / (v_f - v_g)$

Albert: You want to use  $t = 2x / (v_f - v_g)$ .

Albert: No.

Please check your working.

Albert: On what does t depend or what quantities could be used to calculate it?

Blackie(131): help

Albert: Please try to answer.

Albert: On what does t depend or what quantities could be used to calculate it?

Blackie(48):  $v_g$ ,  $v_f$ ,  $a$ ,  $x$

Albert: You say it depends on the initial velocity.

Albert: No, not directly.

Albert: You say it depends on the final velocity.

Albert: No, not directly.

Albert: You say it depends on the displacement.

Albert: Good! I agree!

Albert: You can use the displacement placement.

Albert: and the average velocity

Albert: to calculate the time.  
 Albert: Do you know a formula which relates  $x$ ,  $v_{av}$ , and  $t$ ?  
 Blackie(92):  $t=x/v_{av}$   
 Albert: You want to use  $t=x/v_{av}$ .  
 Albert: Fine!  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?  
 Blackie(155): help  
 Albert: You should try to find  $t$  now by substituting back.  
 Albert: Do you wish to use  $x=v_{av}t$  to calculate  $t$ ?  
 Blackie(165): there is not enough data to find  $t$  using  $x=v_{av}t$   
 Albert: You want to use  $x=v_{av}t$ .  
 Albert: Ok!  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?  
 Blackie(13): help  
 Albert: You should try to find  $v_{av}$  now.  
 Albert: On what does  $v_{av}$  depend or what quantities could be used to calculate it?  
 Blackie(22): displacement and time  
 Albert: You say it depends on the displacement.  
 Albert: No!  
 Albert: You say it depends on the time.  
 Albert: No!  
 Albert: On what does  $v_{av}$  depend?  
 Blackie(38):  $v_i$  and  $v_f$   
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!

Albert: You say that the time is 0.5 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Blackie(32): find the acceleration  
 Albert: Ok. The current goal is to calculate  $a$ .  
 Albert: On what does  $a$  depend or what quantities could be used to calculate it?  
 Blackie(35):  $v_i$ ,  $v_f$ ,  $t$   
 Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: You can use the time  
 Albert: and the change in velocity  
 Albert: to calculate the acceleration.  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Blackie(141):  $a=v_f-v_i/t$   
 Albert: You want to use  $a=v_f-v_i/t$ .  
 Albert: No.  
 Please check your working.  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Blackie(618):  $a=\Delta v/t$   
 Albert: You want to use  $a=\Delta v/t$ . } student used FONT-d!  
 Albert: Fine!  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?

Dialogue continues. Press NEXT.

Blackie(47):  $\Delta v = 0.6 \text{ m/s}$   
 Albert: +  
 Albert: What do you wish to do now?  
 Blackie(23): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate a?  
 Blackie(17): yes  
 Albert: Checking....  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Blackie(58):  $a = \Delta v / t = 0.5 \text{ m/s}^2$   
 Albert: You want to use  $a = \Delta v / t = 0.5 \text{ m/s}^2$ .  
 Albert: What do you wish to calculate?  
 Blackie(25):  $F = ma$   
 Albert: You want to use  $F = ma$ .  
 Albert: What do you wish to calculate?  
 Blackie(6): F  
 Albert: Ok. The current goal is to calculate F.  
 Albert: You want to use  $F = ma$ ....  
 Albert: Ok!  
 Albert: You don't know a.  
 Albert: What do you wish to do now?  
 Blackie(16): i do know a  
 Albert: +  
 Albert: What do you wish to do now?  
 Blackie(458): OH ALBERT!!!!let us begin again you are getting bo  
 th of us very confused!  
 Albert: Sorry, I do not recognise " confused,.  
 (Use COPY to fix typing errors, or rephrase your sentence.)

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Blackie(72): I want to find t using  $t = x/v$   
 Albert: You want to use  $t = x/v$ .  
 Albert: Ok. The current goal is to calculate t.  
 Albert: You want to use  $t = x/v$ .  
 Albert: No.  
 You have used an unrecognised symbol.  
 Albert: Do you wish to use  $x = v_{av} \times t$  to calculate t?  
 Blackie(15): yes  
 Albert: Checking....  
 Albert: No.  
 Please check your working.  
 Albert: Type in the value you get for t.  
 Blackie(32): 0.25 s  
 Albert: You say that the time is 0.25 s.  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for t.  
 Blackie(75): 0.5 s  
 Albert: You say that the time is 0.5 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Blackie(26): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate a?  
 Blackie(7): no  
 Albert: Checking....  
 Albert: Type in a new formula.  
 Blackie(24):  $v_f = v_0 + at$   
 Albert: You want to use  $v_f = v_0 + at$ .

Dialogue continues. Press NEXT.

Albert: Ok!  
 Albert: You need to rearrange the formula.  
 Blackie(41):  $a = (v_f - v_i) / t$   
 Albert: You want to use  $a = (v_f - v_i) / t$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Blackie(42):  $-2.4 \text{ m/s}^2$   
 Albert: You say that the acceleration is  $-2.4 \text{ m/s}^2$ .  
 Albert: Good, I agree.  
 Albert: (I.e. the x-component of the acceleration.)  
 Albert: What do you wish to do now?  
 Blackie(26): find the force  
 Albert: Ok. The current goal is to calculate F.  
 Albert: Do you wish to use  $F = m \times a$  to calculate F?  
 Blackie(6): yes  
 Albert: Checking....  
 Albert: Fine!  
 Albert: Type in the value you get for F.  
 Blackie(85):  $14.4 \text{ N}$   
 Albert: You say that the force is  $14.4 \text{ N}$ .  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for F.  
 Blackie(39):  $1.44 \text{ kg/m/s}^2$   
 Albert: You say that the force is  $1.44$ .  
 Albert: Please specify the units.  
 Albert: Type in the value you get for F.  
 Blackie(36):  $1.44 \text{ kg/m/s}^2$   
 Albert: You say that the force is  $1.44$ .

Albert: Please specify the units.  
 Albert: Type in the value you get for F.  
 Blackie(22):  $1.44 \text{ kg/m/s}^2$   
 Albert: You say that the force is  $1.44$ .  
 Albert: Please specify the units.  
 Albert: Type in the value you get for F.  
 Blackie(16): ALBERT!!!!!!!!!!!!  
 Albert: Sorry, I do not recognise "ALBERT!!!!".  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Blackie(44): I don't know what I've done wrong  
 Albert: ALBERT will provide an explanation shortly.  
 Albert: Type in the value you get for F.  
 Blackie(9): help  
 Albert:  $F = -1.44 \text{ N}$ .  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

Press NEXT for another record for blackie.

Dialogue D-43:

This student used "a" for "acceleration" and ignored ALBERT's instructions.

Genney typing time: 133.2 s 08/20/86

Genney(136): A 5000 kg train moving on a level track experiences a constant force of 1000 N for 12 s. If its initial speed was 1 m/s, what was its final speed?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the train in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a train which moves. Does its velocity change during the period of interest?

Genney(5): y

Albert: Ok.

Albert: And that means.....

Genney(2): a

Albert: In which direction is that?

Albert: If the velocity is changing, then the body is...

Genney(3): a

Albert: In which direction is that?

Albert:  $\Delta v/\Delta t=?$

Genney(1): a

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(2): a

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(2): a

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(1): a

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(1): a

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(7): acceleration

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(7): right

Albert: Type "acceleration"!

Genney(9): acceleration right

Albert: In which direction is that?

Albert: Type "acceleration"!

Genney(4): help

Albert: Since  $\Delta v \neq 0$  and  $\Delta t \neq 0$ ,  $\Delta v/\Delta t \neq 0$  so it is accelerating.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get ↑→↘↙←↗.)

Dialogue continues. Press NEXT.

Genney(6): right  
 Albert: Do you mean as shown above?  
 Genney(3): y  
 Albert: Good! I agree!  
 Albert: What is the direction of the acceleration?  
 Genney(3): right  
 Albert: Do you mean as shown?  
 Genney(2): y  
 Albert: Excellent! I agree.  
 Albert: Now, which one of the graphs above correctly shows how the acceleration of the train varies with time?  
 Genney(8): 2  
 Albert: You say that the answer is 2.  
 Albert: Good, I agree.  
 Albert: Since the train is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
 Genney(7): speeding up  
 Albert: Good! I agree with that.  
 Albert: You have said that the train is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.  
 Genney(4): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert: The train in this problem moves in a straight line. We may think of it as moving along the x-axis.  
 Albert: Which one of the three diagrams above correctly shows the positions of the train along the x-axis which are equally spaced in time?  
 (The x-axis has been drawn horizontally for convenience.)  
 Dialogue continues. Press NEXT.

Genney(7): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
 The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
 Press NEXT.  
 Albert: So to sum up: We are considering a train which moves with constant acceleration.  
 Albert: During the early part of the motion, the acceleration is in the same direction as the velocity, so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: We are given the initial velocity, the time interval, the mass, the force,  
 Albert: and  
 we are asked to calculate the final velocity.  
 Albert: -----  
 Albert: Now to the solution of the problem.....  
 (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)  
 Press NEXT.  
 Albert: How would you like to start?  
 Genney(10): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: On what does a depend or what quantities could be used to calculate it?

Dialogue continues. Press NEXT.

Genney (7):  $F, m$   
 Albert: You say it depends on the mass.  
 Albert: Good! I agree!  
 Albert: So  $a$  depends on  $m$  and what else?  
 Genney (3):  $F$   
 Albert: You say it depends on the force.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $m$ ,  $F$ , and  $a$ ?  
 Genney (9):  $a=F/m$   
 Albert: You want to use  $a=F/m$ .  
 Albert: Fine!  
 Albert: Type in the value you get for  $a$ .  
 Genney (19):  $a=0.25 \text{ m/s}^2$   
 Albert: You say that the acceleration is  $0.25 \text{ m/s}^2$ .  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for  $a$ .  
 Genney (33):  $a=0.2 \text{ m/s}^2$   
 Albert: You say that the acceleration is  $0.2 \text{ m/s}^2$ .  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Genney (29):  $v_f$   
 Albert: Ok. The current goal is to calculate  $v_f$ .  
 Albert: On what does  $v_f$  depend or what quantities could be used to calculate it?  
 Genney (2):  $a$   
 Albert: You say it depends on the acceleration.  
 Albert: No, not directly.  
  
 Albert: On what does  $v_f$  depend?  
 Genney (7):  $v_g$   
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 Albert: So  $v_f$  depends on  $v_g$  and what else?  
 Genney (6):  $t$   
 Albert: You say it depends on the time.  
 Albert: No, not directly.  
 Albert: You can use the initial velocity  
 Albert: and the change in velocity  
 Albert: to calculate the final velocity.  
 Albert: Do you know a formula which relates  $v_g$ ,  $\Delta v$ , and  $v_f$ ?  
 Genney (18): yes  
 Albert: Checking....  
 Albert: Please type in the formula you want to use.  
 Genney (14):  $v_f=v_g+at$   
 Albert: You want to use  $v_f=v_g+at$ .  
 Albert: Ok!  
 Albert: Type in the value you get for  $v_f$ .  
 Genney (14):  $34 \text{ m/s}$   
 Albert: You say that the final velocity is  $34 \text{ m/s}$ .  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

Press NEXT for another record for genney.

Dialogue D-47:

Genney typing time: 78.2 s 09/26/86  
Genney(82): A fast car accelerates from rest to  $27 \text{ m}\cdot\text{s}^{-1}$  in 7.5 s. Assuming the acceleration to be uniform, how far does it travel in this time?  
Albert: It is always useful to consider a problem qualitatively first.....  
Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.  
Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)  
Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.  
Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?  
Genney(7): yes  
Albert: Ok.  
Albert: And that means.....  
Genney(10): there is acceleration  
Albert: Right! There is an acceleration.  
Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we  
Albert: (You can use FONT and w,d, etc. to get  $\rightarrow$ ,  $\leftarrow$ ,  $\uparrow$ ,  $\downarrow$ ,  $\leftarrow$ ,  $\rightarrow$ .)  
Genney(7): right  
Albert: Do you mean as shown above?  
Genney(2): y  
Albert: Good! I agree!  
Albert: What is the direction of the acceleration?  
Genney(3): right  
Albert: Do you mean as shown?  
Genney(2): y  
Albert: Excellent! I agree.  
Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?  
Genney(6): 1  
Albert: You say that the answer is 1.  
Albert: Good, I agree.  
Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
Genney(8): speeding up  
Albert: Good! I agree with that.  
Albert: You have said that the car is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.  
Genney(5): 2  
Albert: You say that the answer is 2.  
Albert: Good, I agree.  
Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.  
Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?  
(The x-axis has been drawn horizontally for conveni

Dialogue continues. Press NEXT.

Genney (8): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the same direction as the velocity,  
         so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement?  
 Genney (42):  $v_g = 27 \text{ m.s}^{-1}$   
 Albert: You say that the initial velocity is 27 m/s.  
 Albert: Sorry, I do not agree with that.  
 Albert: There is still some given information which you  
         haven't mentioned.  
 Genney (18):  $v_f = 27 \text{ m.s}^{-1}$   
 Albert: You say that the final velocity is 27 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: There is still some given information which you  
         haven't mentioned.  
 Genney (7):  $t = 7.5 \text{ s}$   
 Albert: You say that the time is 7.5 s.  
 Albert: Good, I agree.  
 Albert: There is still some given information which you  
         haven't mentioned.  
 Genney (9):  $v_g = 0 \text{ m/s}$   
 Albert: You say that the initial velocity is 0 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Genney (6):  $x$   
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_g$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Genney (11): find  $\Delta v$   
 Albert: Ok. The current goal is to calculate  $\Delta v$ .

Dialogue continues. Press NEXT.

Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?

Genney(12):  $v_f, v_g$

Albert: You say it depends on the final velocity.

Albert: Good! I agree!

Albert: You say it depends on the initial velocity.

Albert: Good! I agree!

Albert: Do you know a formula which relates  $v_g, v_f$ , and  $\Delta v$ ?

Genney(25):  $\Delta v = v_f - v_g$

Albert: You want to use  $\Delta v = v_f - v_g$ .

Albert: Ok!

Albert: Type in the value you get for  $\Delta v$ .

Genney(17):  $\Delta v = 27 \text{ m}\cdot\text{s}^{-1}$

Albert: You say that the change in velocity is 27 m/s.

Albert: (That's the x-component of the change in velocity.)

Albert: Good, I agree.

Albert: What do you wish to do now?

Genney(16): find a

Albert: Ok. The current goal is to calculate a.

Albert: On what does a depend or what quantities could be used to calculate it?

Genney(20):  $\Delta v, t$

Albert: You say it depends on the change in velocity.

Albert: Good! I agree!

Albert: You say it depends on the time.

Albert: Good! I agree!

Albert: Do you know a formula which relates  $t, \Delta v$ , and  $a$ ?

Genney(5): yes

Albert: Checking....

Albert: Please type in the formula you want to use.

Genney(12):  $a = \Delta v / t$

Albert: You want to use  $a = \Delta v / t$ .

Albert: Fine!

Albert: Type in the value you get for a.

Genney(22):  $a = 27 / 7.5 \text{ m}\cdot\text{s}^{-2}$

Albert: You say that the acceleration is 3.6 m/s<sup>2</sup>.

Albert: (That's the x-component of the acceleration.)

Albert: Good, I agree.

Albert: What do you wish to do now?

Genney(100): find x

Albert: Ok. The current goal is to calculate x.

Albert: On what does x depend or what quantities could be used to calculate it?

Genney(18):  $x = (1/2) \cdot a \cdot t^2$

Albert: You want to use  $x = (1/2) \cdot a \cdot t^2$ .

Albert: No.

        Please check your working.

Albert: On what does x depend or what quantities could be used to calculate it?

Genney(26):  $x = v_g t + (1/2) \cdot a \cdot t^2$

Albert: You want to use  $x = v_g t + (1/2) \cdot a \cdot t^2$ .

Albert: Ok!

Albert: Type in the value you get for x.

Genney(26):  $x = (1/2) \cdot 3.6 \cdot (7.5)^2 \text{ m}$

Albert: You say that the displacement is 0.5 m.

Albert: Sorry, I do not agree with that.

        .....

Albert: Type in the value you get for x.

Genney(36):  $x = 101.25 \text{ m}$

Albert: You say that the displacement is 101.3 m.

Albert: (That's the x-component of the displacement.)

Albert: Good, I agree.

Albert: Well done! You have solved the problem.

Albert: Press NEXT to do another problem,  
        or DATA to see ALBERT solve this one.

Dialogue D-52:

Blackie typing time: 139.5 s 09/26/86

Blackie(143): A fast car accelerates from rest to  $27 \text{ m.s}^{-1}$  in 7.5 s. Assuming the acceleration to be uniform, how far does it travel in this time?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Blackie(7): yes

Albert: Ok.

Albert: And that means.....

Blackie(7): acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow \rightarrow \searrow \swarrow \leftarrow \leftarrow \leftarrow$ .)

Blackie(17): right

Albert: Do you mean as shown above?

Blackie(8): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Blackie(6): right

Albert: Do you mean as shown?

Blackie(9): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Blackie(7): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Blackie(9): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Blackie(12): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience)

Dialogue continues. Press NEXT.

Blackie(15): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the same direction as the velocity,  
         so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement?  
 Blackie(181):  $v_f=27 \text{ m.s}^{-1}$   $t=7.5\text{s}$   $v_0=0 \text{ m.s}^{-1}$   
 Albert: You say that the final velocity is 27 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the time is 7.5 s.  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 0 m/s.  
 Albert: Sorry, I do not agree with that.

Albert: There is still some given information which you  
         haven't mentioned.

Blackie(59):  $v_0=0 \text{ m.s}^{-1}$   
 Albert: You say that the initial velocity is 0 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Blackie(7): x  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Blackie(18): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: On what does a depend or what quantities could be  
         used to calculate it?  
 Blackie(53):  $v=u+at$   
 Albert: You want to use  $v=u+at$ .  
 Albert: Sorry, I do not recognise that equation.  
         (There is an unrecognised symbol in your equation.)

Dialogue continues. Press NEXT.

Albert: On what does a depend or what quantities could be used to calculate it?  
 Blackie(29):  $v_f = v_g + at$   
 Albert: You want to use  $v_f = v_g + at$ .  
 Albert: Ok!  
 Albert: You need to rearrange the formula.  
 Blackie(38):  $(v_f - v_g) / t = a$   
 Albert: You want to use  $(v_f - v_g) / t = a$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Blackie(51): 3.6 m/s<sup>2</sup>  
 Albert: You say that the acceleration is 3.6 m/s<sup>2</sup>.  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Blackie(34):  $v_f^2 = v_g^2 + 2as$   
 Albert: You want to use  $v_f^2 = v_g^2 + 2as$ .  
 Albert: What do you wish to calculate?  
 Blackie(5): s  
 Albert: Sorry, I do not understand that.  
 (Use COPY to fix typing errors, or rephrase your sentence.)  
 Blackie(6): x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: You want to use  $v_f^2 = v_g^2 + 2as$ ....  
 Albert:  $v_f^2 = v_g^2 + 2as$  does not contain x.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Blackie(47):  $v_f^2 = v_g^2 + 2ax$   
 Albert: You want to use  $v_f^2 = v_g^2 + 2ax$ .  
 Albert: Ok!  
 Albert: You need to rearrange the formula.  
 Blackie(43):  $(v_f^2 - v_g^2) / 2a = x$   
 Albert: You want to use  $(v_f^2 - v_g^2) / 2a = x$ .  
 Albert: Fine!  
 Albert: Type in the value you get for x.  
 Blackie(63): 101.25 m  
 Albert: You say that the displacement is 101.3 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

Press NEXT for another record for blackie.

Dialogue D-53:

Blackie typing time: 213.1 s 09/26/86

Blackie(216): A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. If it travels 0.3 m before coming to rest, calculate the resultant force acting on it.

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Blackie(20): yes

Albert: Ok.

Albert: And that means.....

Blackie(19): acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow$ ,  $\downarrow$ ,  $\leftarrow$ ,  $\rightarrow$ .)

Blackie(59): angle up

Albert: Do you mean as shown above?

Blackie(5): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Blackie(17): backwards

Albert: Do you mean as shown?

Blackie(5): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Blackie(14): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Blackie(22): slowing down

Albert: Good! I agree with that.

Albert: You have said that the car is slowing down.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Blackie(11): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience.)

Dialogue continues. Press NEXT.

Blackie(14): 2  
 Albert: You say that the answer is 2.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time decreases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the opposite direction to the velocity,  
         so it is slowing down.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement?  
 Blackie(111):  $m=0.6$  kg  $v_0=1.2$  m/s  $x=0.3$ m  $v_f=0$  m/s  
 Albert: You say that the mass is 0.6 kg.  
 Albert: Good, I agree.  
 Albert: You say that the initial velocity is 1.2 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the displacement is 0.3 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 0 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Blackie(18): F  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start? '  
 Blackie(81):  $v_f^2=v_0^2+2ax$   
 Albert: You want to use  $v_f^2=v_0^2+2ax$ .  
 Albert: What do you wish to calculate?  
 Blackie(7): a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: You want to use  $v_f^2=v_0^2+2ax$ ....  
 Albert: Sorry, I do not recognise that equation.  
 (Try making a the subject of the formula.)  
 Albert: On what does a depend or what quantities could be  
         used to calculate it?

Dialogue continues. Press NEXT.

Blackie(63):  $(v_f^2 - v_g^2) / 2x = a$   
 Albert: You want to use  $(v_f^2 - v_g^2) / 2x = a$ .  
 Albert: Sorry, I do not recognise that equation.  
 (Try making a the subject of the formula.)  
 Albert: On what does a depend or what quantities could be used to calculate it?  
 Blackie(61):  $a = (v_f^2 - v_g^2) / 2x$   
 Albert: You want to use  $a = (v_f^2 - v_g^2) / 2x$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Blackie(57):  $a = -2.4 \text{ m/s}^2$   
 Albert: You say that the acceleration is  $-2.4 \text{ m/s}^2$ .  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Blackie(12): find F  
 Albert: Ok. The current goal is to calculate F.  
 Albert: On what does F depend or what quantities could be used to calculate it?  
 Blackie(15):  $F = ma$   
 Albert: You want to use  $F = ma$ .  
 Albert: Ok!  
 Albert: Type in the value you get for F.  
 Blackie(62): 2.4N  
 Albert: You say that the force is 2.4 N.  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for F.  
 Blackie(26): -2.4 N  
  
 Albert: You say that the force is -2.4 N.  
 Albert: Sorry, I do not agree with that.  
 Albert: Type in the value you get for F.  
 Blackie(7): help  
 Albert:  $F = -1.44 \text{ N}$ .  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

Press NEXT for another record for blackie.

Dialogue D-55:

This student used ALBERT's method.

Mcbean typing time: 174.0 s 09/26/86

Mcbean(178): A fast car accelerates from rest to 27 m/s in 7.5 s. Assuming the acceleration to be uniform, how far does it travel in this time?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Mcbean(29): yes it is accelerating

Albert: Good! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow$   $\rightarrow$   $\downarrow$   $\leftarrow$ .)

Mcbean(12): right

Albert: Do you mean as shown above?

Mcbean(5): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Mcbean(9): right

Albert: Do you mean as shown?

Mcbean(5): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Mcbean(7): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Mcbean(23): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Mcbean(23): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience)

Mcbean(13): 1

Albert: You say that the answer is 1.

Dialogue continues. Press NEXT.

Albert: Good, I agree.  
 Albert: The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
                   Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
                   with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
                   is in the same direction as the velocity,  
                   so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
                   extract all the useful information from the problem  
                   statement.....  
 Albert: So, what information is given in the problem  
                   statement?  
 Mcbean(68):  $v_g = 0$  m/s,  $v_f = 27$  m/s,  $t = 7.5$  s,  
 Albert: You say that the initial velocity is 0 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 27 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the time is 7.5 s.  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Mcbean(14): x  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
                   (Remember, symbols used are:  $v_g$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Mcbean(15): find x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: On what does x depend or what quantities could be  
                   used to calculate it?  
 Mcbean(53): we shall use  $v_f$ ,  $v_g$ ,  $a$   
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: On what does x depend?  
 Mcbean(10): a  
 Albert: You say it depends on the acceleration.  
 Albert: No, not directly.  
 Albert: You can use the time  
 Albert: and the average velocity

Dialogue continues. Press NEXT.

Albert: to calculate the displacement.  
 Albert: Do you know a formula which relates  $t$ ,  $v_{av}$ , and  $x$ ?  
 Mcbean(62):  $v_{av}=x/t$   
 Albert: You want to use  $v_{av}=x/t$ .  
 Albert: Sorry, I do not recognise that equation.  
 (Try making  $x$  the subject of the formula.)  
 Albert: Do you know a formula which relates  $t$ ,  $v_{av}$ , and  $x$ ?  
 Mcbean(28):  $x=v_{av}t$   
 Albert: You want to use  $x=v_{av}t$ .  
 Albert: Ok!  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?  
 Mcbean(28): find  $v_{av}$   
 Albert: Ok. The current goal is to calculate  $v_{av}$ .  
 Albert: On what does  $v_{av}$  depend or what quantities could be used to calculate it?  
 Mcbean(38):  $v_f$ ,  $v_g$   
 Albert: You say it depends on the final velocity.  
 Albert: Good! I agree!  
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $v_g$ ,  $v_f$ , and  $v_{av}$ ?  
 Mcbean(65):  $v_{av}=(v_f+v_g)/2$   
 Albert: You want to use  $v_{av}=(v_f+v_g)/2$ .  
 Albert: Fine!  
 Albert: Type in the value you get for  $v_{av}$ .  
 Mcbean(27): 13.5 m/s  
 Albert: You say that the average velocity is 13.5 m/s.

Albert: (That's the x-component of the average velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Mcbean(18): find  $x$   
 Albert: Ok. The current goal is to calculate  $x$ .  
 Albert: Do you wish to use  $x=v_{av}t$  to calculate  $x$ ?  
 Mcbean(11): yes  
 Albert: Checking....  
 Albert: Fine!  
 Albert: Type in the value you get for  $x$ .  
 Mcbean(44): 101.25 m  
 Albert: You say that the displacement is 101.3 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

Press NEXT for another record for mcbean.

Dialogue D-56:

This student used ALBERT's method.

Mcbean typing time: 373.9 s 09/26/86

Mcbean(376): A toy car with a mass of 0.6 kg is projected up an inclined plane with an initial speed of 1.2 m/s. if it travels 0.3 m before coming to rest, calculate the resultant force acting on

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Mcbean(58): yes it is slowing down

Albert: Sure, it is slowing down.

Albert: And that means.....

Mcbean(30): negative acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow$ ,  $\rightarrow$ ,  $\downarrow$ ,  $\leftarrow$ .)

Mcbean(19): right

Albert: Do you mean as shown above?

Mcbean(11): yes

Albert: That is not a good choice. You will have to resolve vectors into their components unnecessarily.

Mcbean(31): angle up

Albert: Do you mean as shown above?

Mcbean(7): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Mcbean(10): backwards

Albert: Do you mean as shown?

Mcbean(13): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Mcbean(25): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: You have said that the car is slowing down.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Mcbean(14): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience)  
Dialogue continues. Press NEXT.

Mcbean(15): 2  
 Albert: You say that the answer is 2.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time decreases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the opposite direction to the velocity,  
         so it is slowing down.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement?  
 Mcbean(96):  $m=0.6$  kg,  $v_0=1.2$  m/s,  $x=0.3$ ,  $v_f=0$  m/s,  
 Albert: You say that the mass is 0.6 kg.  
 Albert: Good, I agree.  
 Albert: You say that the initial velocity is 1.2 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the displacement is 0.3.  
 Albert: You did not specify units, or your units were invalid.  
 Albert: You say that the final velocity is 0 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: There is still some given information which you  
         haven't mentioned.  
 Mcbean(92):  $x=0.3$  m  
 Albert: You say that the displacement is 0.3 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Mcbean(42): resultant force acting on car  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Mcbean(15): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: On what does a depend or what quantities could be  
         used to calculate it?  
 Mcbean(56):  $v_0$ ,  $v_f$ ,  $t$

Dialogue continues. Press NEXT.

Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: You can use the time  
 Albert: and the change in velocity  
 Albert: to calculate the acceleration.  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Mcbean(87):  $a = \Delta v / t$   
 Albert: You want to use  $a = \Delta v / t$ .  
 Albert: Fine!  
 Albert: You don't know  $t$ .  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Mcbean(37):  $\Delta v = 1.2 \text{ m/s}$   
 Albert: You say that the change in velocity is  $1.2 \text{ m/s}$ .  
 Albert: Are you sure? Think about the direction.  
 Albert: What do you wish to do now?  
 Mcbean(91): find  $t$   
 Albert: Ok. The current goal is to calculate  $t$ .  
 Albert: On what does  $t$  depend or what quantities could be used to calculate it?  
 Mcbean(59):  $v_g, v_f, a$   
 Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: On what does  $t$  depend?  
 Mcbean(9):  $a$   
 Albert: You say it depends on the acceleration.  
 Albert:  
     Yes, but that's not much use here.  
 Albert: You can use the displacement much use  
 Albert: and the average velocity  
 Albert: to calculate the time.  
 Albert: Do you know a formula which relates  $x$ ,  $v_{av}$ , and  $t$ ?  
 Mcbean(67):  $x = v_{av} t$   
 Albert: You want to use  $x = v_{av} t$ .  
 Albert: Ok!  
 Albert: You don't know  $v_{av}$ .  
 Albert: What do you wish to do now?  
 Mcbean(21): find  $v_{av}$   
 Albert: Ok. The current goal is to calculate  $v_{av}$ .  
 Albert: On what does  $v_{av}$  depend or what quantities could be used to calculate it?  
 Mcbean(25):  $v_g, v_f$ ,  
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 Albert: You say it depends on the final velocity.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $v_g$ ,  $v_f$ , and  $v_{av}$ ?  
 Mcbean(59):  $v_{av} = (v_f + v_g) / 2$   
 Albert: You want to use  $v_{av} = (v_f + v_g) / 2$ .  
 Albert: Fine!

Dialogue continues. Press NEXT.

Albert: Type in the value you get for  $v_{av}$ .  
 Mcbean(31): 0.6 m/s  
 Albert: You say that the average velocity is 0.6 m/s.  
 Albert: (That's the x-component of the average velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Mcbean(21): find x  
 Albert: The value of x is given in the problem statement.  
 Albert: What do you wish to do now?  
 Mcbean(60): i mean find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: Do you wish to use  $\Delta v = a \cdot t$  to calculate a?  
 Mcbean(70): we need t  
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: Do you wish to use  $\Delta v = a \cdot t$  to calculate a?  
 Mcbean(14): yes  
 Albert: Checking....  
 Albert: You don't know t.  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Mcbean(60):  $t = x / v_{av}$   
 Albert: You want to use  $t = x / v_{av}$ .  
 Albert: What do you wish to calculate?  
 Mcbean(6): t  
 Albert: Ok. The current goal is to calculate t.  
 Albert: You want to use  $t = x / v_{av}$ ...calculate  
 Albert: Fine!

Albert: Type in the value you get for t.  
 Mcbean(26): 0.5 s  
 Albert: You say that the time is 0.5 s.  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Mcbean(14): find  $\Delta v$   
 Albert: Ok. The current goal is to calculate  $\Delta v$ .  
 Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
 Mcbean(13): a, t  
 Albert: You say it depends on the time.  
 Albert: No, not directly.  
 Albert: On what does  $\Delta v$  depend?  
 Mcbean(23):  $v_g, v_f$   
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 Albert: You say it depends on the final velocity.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $v_g, v_f$ , and  $\Delta v$ ?  
 Mcbean(63):  $\Delta v = v_f - v_g$   
 Albert: You want to use  $\Delta v = v_f - v_g$ .  
 Albert: Ok!  
 Albert: Type in the value you get for  $\Delta v$ .  
 Mcbean(18): 1.2 m/s  
 Albert: You say that the change in velocity is 1.2 m/s.  
 Albert: Are you sure? Think about the direction.  
 Albert: Type in the value you get for  $\Delta v$ .  
 Mcbean(74): -1.2 m/s

Dialogue continues. Press NEXT.

Albert: You say that the change in velocity is  $-1.2$  m/s.  
 Albert: (That's the x-component of the change in velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Mcbean(11): find a  
 Albert: Ok. The current goal is to calculate a.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate a?  
 Mcbean(6): yes  
 Albert: Checking....  
 Albert: No.  
       Please check your working.  
 Albert: You need to rearrange the formula.  
 Mcbean(23):  $a = \Delta v / t$   
 Albert: You want to use  $a = \Delta v / t$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Mcbean(44):  $2.4$  m/s  
 Albert: You say that the acceleration is  $2.4$  m/s.  
 Albert: Sorry, I do not agree with your units.  
 Albert: Type in the value you get for a.  
 Mcbean(24):  $2.4$  m/s<sup>2</sup>  
 Albert: You say that the acceleration is  $2.4$  m/s<sup>2</sup>.  
 Albert: Are you sure? Think about the direction.  
 Albert: Type in the value you get for a.  
 Mcbean(25):  $-2.4$  m/s<sup>2</sup>  
 Albert: You say that the acceleration is  $-2.4$  m/s<sup>2</sup>.  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.

Albert: What do you wish to do now?  
 Mcbean(16): find F  
 Albert: Ok. The current goal is to calculate F.  
 Albert: On what does F depend or what quantities could be used to calculate it?  
 Mcbean(9): m, a  
 Albert: You say it depends on the mass.  
 Albert: Good! I agree!  
 Albert: You say it depends on the acceleration.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates a, m, and F?  
 Mcbean(8):  $F = ma$   
 Albert: You want to use  $F = ma$ .  
 Albert: Ok!  
 Albert: Type in the value you get for F.  
 Mcbean(68):  $-1.44$  N  
 Albert: You say that the force is  $-1.44$  N.  
 Albert: (That's the x-component of the force.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
       or DATA to see ALBERT solve this one.

Press NEXT for another record for mcbean.

Dialogue D-61:

A successful first-time user.

Sangerhau typing time: 53.1 s 10/03/86

Sangerhau(57): A fast car accelerates from rest to  $27 \text{ m.s}^{-1}$  in 7 .5 s. Assuming the acceleration to be uniform, how far does it travel in this time?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: However, if you have done this problem before, you may wish to skip the qualitative discussion.

Albert: Press NEXT to continue, (STRONGLY RECOMMENDED) or press LAB to skip the qualitative discussion. (NOT RECOMMENDED)

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Sangerhau(10): yes

Albert: Ok.

Albert: And that means.....

Sangerhau(11): acceleration occurs

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow \rightarrow \downarrow \leftarrow$ .)

Sangerhau(9): right

Albert: Do you mean as shown above?

Sangerhau(5): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Sangerhau(6): right

Albert: Do you mean as shown?

Sangerhau(4): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Sangerhau(14): 3

Albert: You say that the answer is 3.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Sangerhau(14): speeding up

Sangerhau(27): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Sangerhau(20): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience.)

Dialogue continues. Press NEXT.

Sangerhau (17): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the same direction as the velocity,  
         so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement?  
 Sangerhau (72):  $v_B = 0$  m/s  
 $v_f = 27$  m/s  
 $t = 7.5$  s  
 $a$  is uniform  
 Albert: You say that the initial velocity is 0 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 27 m/s.  
 -----  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the time is 7.5 s.  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Sangerhau (24): distance travelled in this time  
 Albert: The value of  $t$  is given in the problem statement.  
 Albert: I do not agree.  
 Albert: What are you asked to find?  
 Sangerhau (18):  $x$   
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_B$   $v_f$   $x$   $t$   $a$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Sangerhau (56): by using the equation  $a = (v_f - v_B) / t$   
 Albert: You want to use  $a = (v_f - v_B) / t$ .  
 Albert: What do you wish to calculate?  
 Sangerhau (6):  $a$   
 Albert: Ok. The current goal is to calculate  $a$ .  
 Albert: You want to use  $a = (v_f - v_B) / t$ ....

Dialogue continues. Press NEXT.

Albert: No.  
 Please check your equation; I do not recognize it.  
 Albert: On what does a depend or what quantities could be used to calculate it?  
 Sangerhau(47):  $v_f$ ,  $v_g$  &  $t$   
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: On what does a depend?  
 Sangerhau(71):  $a = (v_f - v_g) / t$   
 Albert: You want to use  $a = (v_f - v_g) / t$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Sangerhau(23): 27/7.5 m/s  
 Albert: You say that the acceleration is 3.6.  
 Albert: You did not specify units, or your units were invalid.  
 Albert: Type in the value you get for a.  
 Sangerhau(15): 3.6 m/s<sup>2</sup>  
 Albert: You say that the acceleration is 3.6 m/s<sup>2</sup>.  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Sangerhau(49):  $x = v_g t + 0.5 a t^2$   
 Albert: You want to use  $x = v_g t + 0.5 a t^2$ .  
 Albert: What do you wish to calculate?  
 Sangerhau(7): x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: You want to use  $x = v_g t + 0.5 a t^2$ ....  
 Albert: Ok!  
 Albert: Type in the value you get for x.  
 Sangerhau(14): 101.25 m  
 Albert: You say that the displacement is 101.3 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
 or DATA to see ALBERT solve this one.

No more data for sangerhaus.  
 Press NEXT to enter a new name.

Dialogue D-65:

Hobson typing time: 134.4 s 10/06/86

Hobson(141): A fast car accelerates from rest to 27 m/s in 7.5 s. Assuming acceleration to be uniform, how far does it travel in this time?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: Press NEXT to continue.

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Hobson(9): yes

Albert: Ok.

Albert: And that means.....

Hobson(11): acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use FONT and w,d, etc. to get  $\uparrow \rightarrow \downarrow \leftarrow$ .)

Hobson(19): right

Albert: Do you mean as shown above?

Hobson(9): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Hobson(8): right

Albert: Do you mean as shown?

Hobson(4): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Hobson(14): 1

Albert: You say that the answer is 1.

Albert: Sorry, I do not agree with that.

Albert: Think! Does the acceleration vary?

Hobson(18): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Hobson(12): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Hobson(8): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for conveni

Dialogue continues. Press NEXT.

Hobson(10): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves  
         with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  
         is in the same direction as the velocity,  
         so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to  
         extract all the useful information from the problem  
         statement.....  
 Albert: So, what information is given in the problem  
         statement? (Type in the values and units, e.g. m=3kg.)  
 Hobson(60):  $v_0=0$ ,  $t=7.5$ ,  $v_f=27$   
 Albert: You say that the initial velocity is 0.  
 Albert: You did not specify units, or your units were invalid.  
 Albert: You say that the time is 7.5. your unit  
 Albert: You did not specify units, or your units were invalid.  
 Albert: You say that the final velocity is 27.  
 Albert: You did not specify units, or your units were invalid.  
 Albert: (2 to go.)ot specify  
  
 Hobson(57):  $v_0=0$  m/s,  $t=7.5$  s,  $v_f=27$  m/s  
 Albert: You say that the initial velocity is 0 m/s.  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the time is 7.5 s.  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 27 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Hobson(13): x  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
         (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Hobson(42):  $a=(v_f-v_0)/t$   
 Albert: You want to use  $a=(v_f-v_0)/t$ .  
 Albert: What do you wish to calculate?  
 Hobson(8): a  
 Albert: Ok. The current goal is to calculate a.

Dialogue continues. Press NEXT.

Albert: You want to use  $a = (v_f - v_0) / t$ ....  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Hobson(32):  $a = 3.6 \text{ m/s}^2$   
 Albert: You say that the acceleration is  $3.6 \text{ m/s}^2$ .  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Hobson(52):  $x = v_0 t + 0.5 (at^2)$   
 Albert: You want to use  $x = v_0 t + 0.5 (at^2)$ .  
 Albert: What do you wish to calculate?  
 Hobson(6): x  
 Albert: Ok. The current goal is to calculate x.  
 Albert: You want to use  $x = v_0 t + 0.5 (at^2)$ ....  
 Albert: Ok!  
 Albert: Type in the value you get for x.  
 Hobson(39):  $x = 101.25 \text{ m}$   
 Albert: You say that the displacement is  $101.3 \text{ m}$ .  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
           or DATA to see ALBERT solve this one.  
 Hobson(64): A fast car accelerates from rest to  $27 \text{ m/s}$  in  $7.5 \text{ s}$ .  
 Assuming acceleration to be uniform, how far does it travel in th  
 is time?  
 Albert: It is always useful to consider a problem  
           qualitatively first.....;;;;;;;;;

Dialogue continues. Press NEXT.

Dialogue D-69:

A first-time user.

Harrison typing time: 204.9 s 10/08/86

Harrison(209): a car accelerates from rest to  $30 \text{ m.s}^{-1}$  in 7.5 s. Assuming the acceleration to be uniform, how far does it travel in this time?

Albert: It is always useful to consider a problem qualitatively first.....

Albert: Press NEXT to continue.

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Harrison(11): y

Albert: Ok.

Albert: And that means.....

Harrison(11): acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use the FONT key and w,d, etc. to get  $\rightarrow$ ,  $\leftarrow$ ,  $\uparrow$ ,  $\downarrow$ .)

Harrison(13): right

Albert: Do you mean as shown above?

Harrison(4): y

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Harrison(6): right

Albert: Do you mean as shown?

Harrison(4): y

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Harrison(8): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Harrison(15): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Harrison(69): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience.)

Harrison(12): 2

Albert: You say that the answer is 2.

Albert: Sorry, I do not agree with that.

Dialogue continues. Press NEXT.

Albert: In that one, the distance travelled in a given time decreases. That would mean it is slowing down.  
 So which one is it?  
 Harrison(7): 3  
 Albert: You say that the answer is 3.  
 Albert: Sorry, I do not agree with that.  
 Albert: In that one, the distance travelled in a given time is constant. That would mean it is moving with constant speed.  
 So which one is it?  
 Harrison(5): help  
 Albert: It is graph 1.  
 Albert: In that one, the distance travelled in a given time is constant. That would mean it is moving with constant speed.  
 So which one is it?  
 Harrison(7): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
             Press NEXT.  
 Albert: So to sum up: We are considering a car which moves with constant acceleration.  
 Albert: During the early part of the motion, the acceleration  $a$  is in the same direction as the velocity, so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to extract all the useful information from the problem statement.....  
 Albert: So, what information is given in the problem statement? (Type in the values and units, e.g.  $m=3\text{kg}$ .)  
 Harrison(77):  $v_i=0\text{ m/s}$ .  $v_f=27\text{ m/s}$ .  $t=7.5\text{ s}$ .  
 Albert: You say that the initial velocity is  $0\text{ m/s}$ .  
 Albert: (That's the x-component of the initial velocity.)  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is  $27\text{ m/s}$ .  
 Albert: Sorry, I do not agree with that.  
 Albert: You say that the time is  $7.5\text{ s}$ .  
 Albert: Good, I agree.  
 Albert: (1 to go.) agree.  
 Harrison(30):  $v_f=30\text{ m/s}$ .  
 Albert: You say that the final velocity is  $30\text{ m/s}$ .  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Harrison(11): x  
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----

Dialogue continues. Press NEXT.

Albert: Now to the solution of the problem.....  
 (Remember, symbols used are:  $v_g$ ,  $v_f$ ,  $x$ ,  $t$ ,  $a$ ,  $m$ ,  $F$ ,  $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Harrison(23): acceleration?  
 Albert: Ok. The current goal is to calculate  $a$ .  
 Albert: On what does  $a$  depend or what quantities could be used to calculate it?  
 Harrison(22):  $v_f$  and  $t$   
 Albert: You say it depends on the final velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: So  $a$  depends on  $t$  and what else?  
 Harrison(30):  $\Delta v$   
 Albert: You say it depends on the change in velocity.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Harrison(22):  $a = \Delta v \cdot t$   
 Albert: You want to use  $a = \Delta v \cdot t$ .  
 Albert: No.  
 You have used an unrecognised symbol.  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Harrison(24):  $\Delta v = a/t$   
 Albert: You want to use  $\Delta v = a/t$ .  
 Albert: Sorry, I do not recognise that equation.  
 (Try making  $a$  the subject of the formula.)  
 Albert: Do you know a formula which relates  $t$ ,  $\Delta v$ , and  $a$ ?  
 Harrison(18):  $a = \Delta v/t$   
 Albert: You want to use  $a = \Delta v/t$ .  
 Albert: Fine!  
 Albert: You don't know  $\Delta v$ .  
 Albert: What do you wish to do now?  
 Harrison(24):  $v_f - v_g$   
 Albert: Sorry, I couldn't figure that out! Try again.  
 Albert: What do you wish to do now?  
 Harrison(10): find  $\Delta v$   
 Albert: Ok. The current goal is to calculate  $\Delta v$ .  
 Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?  
 Harrison(15):  $v_f$  and  $v_g$   
 Albert: You say it depends on the final velocity.  
 Albert: Good! I agree!  
 Albert: You say it depends on the initial velocity.  
 Albert: Good! I agree!  
 Albert: Do you know a formula which relates  $v_g$ ,  $v_f$ , and  $\Delta v$ ?  
 Harrison(24):  $\Delta v = v_f - v_g$   
 Albert: You want to use  $\Delta v = v_f - v_g$ .  
 Albert: Ok!  
 Albert: Type in the value you get for  $\Delta v$ .  
 Harrison(12): 30 m/s  
 Albert: You say that the change in velocity is 30 m/s.  
 Albert: (That's the x-component of the change in velocity.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?

Dialogue continues. Press NEXT.

Harrison(12): a?  
 Albert: Ok. The current goal is to calculate a.  
 Albert: Do you wish to use  $\Delta v = a \times t$  to calculate a?  
 Harrison(6): y  
 Albert: Checking....  
 Albert: No.  
       Please check your equation.  
 Albert: You need to rearrange the formula.  
 Harrison(18):  $a = \Delta v / t$   
 Albert: You want to use  $a = \Delta v / t$ .  
 Albert: Fine!  
 Albert: Type in the value you get for a.  
 Harrison(57): 4 m/s<sup>2</sup>  
 Albert: You say that the acceleration is 4 m/s<sup>2</sup>.  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: What do you wish to do now?  
 Harrison(8): x?  
 Albert: Ok. The current goal is to calculate x.  
 Albert: On what does x depend or what quantities could be used to calculate it?  
 Harrison(62): a.  $v_{\text{g}}$  t.  
 Albert: You say it depends on the acceleration.  
 Albert: No, not directly.  
 Albert: You say it depends on the initial velocity.  
 Albert: No, not directly.  
 Albert: You say it depends on the time.  
 Albert: Good! I agree!  
 Albert: You can use the time  
 Albert: and the average velocity  
 Albert: to calculate the displacement.  
 Albert: Do you know a formula which relates t,  $v_{\text{av}}$ , and x?  
 Harrison(63):  $x = v_{\text{g}}t + (1/2)at^2$   
 Albert: You want to use  $x = v_{\text{g}}t + (1/2)at^2$ .  
 Albert: Ok!  
 Albert: Type in the value you get for x.  
 Harrison(69): 112.5 m  
 Albert: You say that the displacement is 112.5 m.  
 Albert: (That's the x-component of the displacement.)  
 Albert: Good, I agree.  
 Albert: Well done! You have solved the problem.  
 Albert: Press NEXT to do another problem,  
       or DATA to see ALBERT solve this one.

Dialogue D-74:

A first-time High School user.

Mills n typing time: 115.1 s 10/09/86  
Mills n(118): 1. A motor car, initially moving with constant speed, undergoes a uniform acceleration of  $0.5 \text{ m/s}^2$  for 30 seconds. After this, its speed is 30 m/s. Calculate its initial speed.  
Albert: It is always useful to consider a problem qualitatively first.....  
Albert: Press NEXT to continue.  
Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.  
Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?  
Mills n(27): yes  
Albert: Ok.  
Albert: And that means.....  
Mills n(25): ?  
Albert: Sorry, I do not recognise " ".  
(Use COPY to fix typing errors, or rephrase your sentence.)  
Mills n(59): it means that time increases proportionally  
Albert: If the velocity is changing, then the body is...  
Mills n(20): accelerating  
Albert: Right! There is an acceleration.  
Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we  
Albert: (You can use the FONT key and w,d, etc. to get  $\uparrow \rightarrow \downarrow \leftarrow$ .)  
Mills n(28): right

Albert: Do you mean as shown above?  
Mills n(12): yes  
Albert: Good! I agree!  
Albert: What is the direction of the acceleration?  
Mills n(36): forwards  
Albert: Do you mean as shown?  
Mills n(7): yes  
Albert: Excellent! I agree.  
Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?  
Mills n(20): 1  
Albert: You say that the answer is 1.  
Albert: Sorry, I do not agree with that.  
Albert: Think! Does the acceleration vary?  
Mills n(12): no  
Albert: You say correctly that the acceleration is constant, so  
Albert: which graph is it? that the ac  
Mills n(6): 3  
Albert: You say that the answer is 3.  
Albert: Good, I agree.  
Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
Mills n(21): speeding up  
Albert: Good! I agree with that.  
Albert: You have said that the car is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Dialogue continues. Press NEXT.

Mills n(23): 2

Albert: You say that the answer is 2.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line.  
We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows  
the positions of the car along the x-axis  
which are equally spaced in time?

(The x-axis has been drawn horizontally for conveni

Mills n(45): 3

Albert: You say that the answer is 3.

Albert: Sorry, I do not agree with that.

Albert: In that one, the distance travelled in a given time  
is constant. That would mean it is moving with constant speed.  
So which one is it?

Mills n(6): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert:

The distance travelled in a given time increases.

Albert: -----

Albert: Now for a summary of what we know.....

Press NEXT.

Albert: So to sum up: We are considering a car which moves  
with constant acceleration.

Albert: During the early part of the motion, the acceleration  
is in the same direction as the velocity,  
so it is speeding up.

Albert: The x-component of velocity changes linearly with time.

Albert: -----

Albert: For any problem of this kind, it is important to  
extract all the useful information from the problem  
statement.....

Albert: So, what information is given in the problem  
statement? (Type in the values and units, e.g.  $m=3\text{kg}$ .)

Mills n(211):  $v_0=0$

$a=0.5\text{ m/s}^2$

$t=30\text{ s}$

$v_f=30\text{ m/s}$

Albert: You say that the initial velocity is 0.

Albert: You did not specify units, or your units were invalid.

Albert: You say that the acceleration is  $0.5\text{ m/s}^2$ .

Albert: (That's the x-component of the acceleration.)

Albert: Good, I agree.

Albert: You say that the time is  $30\text{ s}$ .

Albert: Good, I agree.

Albert: You say that the final velocity is  $30\text{ m/s}$ .

Albert: (That's the x-component of the final velocity.)

Albert: Good, I agree.

Albert: What are you asked to find?

Mills n(36): initial velocity

Albert:

Albert: That's right!

Albert: That completes the descriptive part.

Press NEXT.

-----  
Dialogue continues. Press NEXT.

Albert: -----

Albert: Now to the solution of the problem.....

(Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?

Mills n(23): finding a formula

Albert: Alright.

Albert: What do you wish to calculate?

Mills n(12): initial speed

Albert: Speed is a scalar quantity. It is always positive. We must work with the x-component of the velocity.

Albert: Ok. The current goal is to calculate  $v_0$ .

Albert: On what does  $v_0$  depend or what quantities could be used to calculate it?

Mills n(54):  $v_f$  and  $t$  and  $a$

Albert: You say it depends on the final velocity.

Albert: Good! I agree!

Albert: You say it depends on the time.

Albert: No, not directly.

Albert: You say it depends on the acceleration.

Albert: No, not directly.

Albert: You can use the final velocity

Albert: and the change in velocity

Albert: to calculate the initial velocity.

Albert: Do you know a formula which relates  $v_f$ ,  $\Delta v$ , and  $v_0$ ?

Mills n(38): no

Albert: Checking....

Albert: Type a formula or ask for help.

Mills n(4): help

Albert: You could use  $\Delta v = v_f - v_0$ .

Albert: Do you wish to use  $\Delta v = v_f - v_0$  to calculate  $v_0$ ?

Mills n(27): yes

Albert: Checking....

Albert: You don't know  $\Delta v$ .

Albert: What do you wish to do now?

Mills n(17): find a formula

Albert: Alright.

Albert: What do you wish to calculate?

Mills n(17): initial speed

Albert: I assume you mean the x-component of the velocity.

Albert: Ok. The current goal is to calculate  $v_0$ .

Albert: Do you wish to use  $\Delta v = v_f - v_0$  to calculate  $v_0$ ?

Mills n(28): no

Albert: Checking....

Albert: Type in a new formula.

Mills n(59):  $v_f = v_0 + at$

Albert: You want to use  $v_f = v_0 + at$ .

Albert: Ok!

Albert: You need to rearrange the formula.

Mills n(47):  $v_0 = at - v_f$

Albert: You want to use  $v_0 = at - v_f$ .

Albert: No.

Please check your equation.

Albert: You need to rearrange the formula.

Mills n(6): help

Dialogue continues. Press NEXT.

Albert: It should be  $v_0 = v_f - a \times t$ .  
Albert: Type in the value you get for  $v_0$ .  
Mills n(44): x m/s  
Albert: You say it depends on the displacement.  
Albert: No, not directly.  
Albert: You say it depends on the mass.  
Albert: No!  
Albert: Type in the value you get for  $v_0$ .  
Mills n(57): 2 m/s  
Albert: You say that the initial velocity is 2 m/s.  
Albert: Sorry, I do not agree with that.  
Albert: Type in the value you get for  $v_0$ .  
Mills n(36): 15 m/s  
Albert: You say that the initial velocity is 15 m/s.  
Albert: (That's the x-component of the initial velocity.)  
Albert: Good, I agree.  
Albert: Well done! You have solved the problem.  
Albert: Press NEXT to do another problem,  
or DATA to see ALBERT solve this one.

Press NEXT for another record for mills n.

Dialogue D-80:

Buchner typing time: 276.7 s 10/14/86  
Buchner(279): a motor car, initially moving with constant speed, undergoes a uniform acceleration of  $0.5 \text{ m/s}^2$  for 30 seconds. After this its speed is 25 m/s. Calculate its initial speed.  
Albert: It is always useful to consider a problem qualitatively first.....  
Albert: Press NEXT to continue.  
Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.  
Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?  
Buchner(41): yes  
Albert: Ok.  
Albert: And that means.....  
Buchner(46): it is accelerating  
Albert: Right! There is an acceleration.  
Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we  
Albert: (You can use the FONT key and w,d, etc. to get  $\rightarrow$   $\leftarrow$   $\uparrow$   $\downarrow$ .)  
Buchner(48): right  
Albert: Do you mean as shown above?  
Buchner(6): yes  
Albert: Good! I agree!  
Albert: What is the direction of the acceleration?  
Buchner(11): right  
  
Albert: Do you mean as shown?  
Buchner(7): yes  
Albert: Excellent! I agree.  
Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?  
Buchner(11): 3  
Albert: You say that the answer is 3.  
Albert: Good, I agree.  
Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?  
Buchner(18): speeding up  
Albert: Good! I agree with that.  
Albert: You have said that the car is speeding up. Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.  
Buchner(11): 2  
Albert: You say that the answer is 2.  
Albert: Good, I agree.  
Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.  
Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?  
(The x-axis has been drawn horizontally for convenience)  
Buchner(28): 1  
Albert: You say that the answer is 1.  
Albert: Good, I agree.

Dialogue continues. Press NEXT.

Albert: The distance travelled in a given time increases.

Albert: -----

Albert: Now for a summary of what we know.....  
Press NEXT.

Albert: So to sum up: We are considering a car which moves with constant acceleration.

Albert: During the early part of the motion, the acceleration is in the same direction as the velocity, so it is speeding up.

Albert: The x-component of velocity changes linearly with time.

Albert: -----

Albert: For any problem of this kind, it is important to extract all the useful information from the problem statement.....

Albert: So, what information is given in the problem statement? (Type in the values and units, e.g.  $m=3\text{kg}$ .)

Buchner (183):  $v_f=25\text{ m/s}$   $t=30\text{ seconds}$   
 $a=0.5\text{ m/s}^2$

Albert: You say that the final velocity is 25 m/s.

Albert: (That's the x-component of the final velocity.)

Albert: Good, I agree.

Albert: You say that the time is 30 s.

Albert: Good, I agree.

Albert: You say that the acceleration is  $0.5\text{ m/s}^2$ .

Albert: (That's the x-component of the acceleration.)

Albert: Good, I agree.

Albert: What are you asked to find?

Buchner (20):  $v_0$

Albert:

Albert: That's right!

Albert: That completes the descriptive part.

Press NEXT.

Albert: -----

Albert: Now to the solution of the problem.....  
(Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?

Buchner (35): write down an equation

Albert: Alright.

Albert: What do you wish to calculate?

Buchner (39):  $\Delta v$

Albert: Ok. The current goal is to calculate  $\Delta v$ .

Albert: On what does  $\Delta v$  depend or what quantities could be used to calculate it?

Buchner (18):  $a$  and  $t$

Albert: You say it depends on the acceleration.

Albert: Good! I agree!

Albert: You say it depends on the time.

Albert: Good! I agree!

Albert: Do you know a formula which relates  $t$ ,  $a$ , and  $\Delta v$ ?

Buchner (18):  $\Delta v=at$

Albert: You want to use  $\Delta v=at$ .

Dialogue continues. Press NEXT.

Albert: Ok!

Albert: Type in the value you get for  $\Delta v$ .

Buchner(12): 15 m/s

Albert: You say that the change in velocity is 15 m/s.

Albert: (That's the x-component of the change in velocity.)

Albert: Good, I agree.

Albert: What do you wish to do now?

Buchner(18): calculate  $v_f$

Albert: The value of  $v_f$  is given in the problem statement.

Albert: What do you wish to do now?

Buchner(17): calculate  $v_g$

Albert: Ok. The current goal is to calculate  $v_g$ .

Albert: On what does  $v_g$  depend or what quantities could be used to calculate it?

Buchner(16):  $\Delta v$  and  $v_f$

Albert: You say it depends on the change in velocity.

Albert: Good! I agree!

Albert: You say it depends on the final velocity.

Albert: Good! I agree!

Albert: Do you know a formula which relates  $v_f$ ,  $\Delta v$ , and  $v_g$ ?

Buchner(27):  $v_g = v_f - \Delta v$

Albert: You want to use  $v_g = v_f - \Delta v$ .

Albert: Fine!

Albert: Type in the value you get for  $v_g$ .

Buchner(16): 10 m/s

Albert: You say that the initial velocity is 10 m/s.

Albert: (That's the x-component of the initial velocity.)

Albert: Good, I agree.

Albert: Well done! You have solved the problem.

Albert: Press NEXT to do another problem,  
or DATA to see ALBERT solve this one.

Press NEXT for another record for buchner.

Dialogue D-83:

This student found the problem very easy.

Rewitzky typing time: 193.9 s 10/14/86

Rewitzky(197): a motor car, initially moving with constant speed, undergoes a uniform acceleration of  $0.5 \text{ m/s}^2$  for 30 seconds. after this, its speed is 25 m/s. calculate its initial speed.

Albert: It is always useful to consider a problem qualitatively first.....

Albert: Press NEXT to continue.

Albert: In this section, we shall discuss the motion of the car in general terms. We will not use the values of any quantity.

Albert: So, this problem is about a car which moves. Does its velocity change during the period of interest?

Rewitzky(68): yes

Albert: Ok.

Albert: And that means.....

Rewitzky(89): the car undergoes acceleration

Albert: Right! There is an acceleration.

Albert: Acceleration is a vector and its direction is important. In order to talk meaningfully about the direction of the acceleration and other vector quantities in this problem we

Albert: (You can use the FONT key and w,d, etc. to get  $\rightarrow$ ,  $\leftarrow$ ,  $\uparrow$ ,  $\downarrow$ .)

Rewitzky(49): right

Albert: Do you mean as shown above?

Rewitzky(7): yes

Albert: Good! I agree!

Albert: What is the direction of the acceleration?

Rewitzky(24): right

Albert: Do you mean as shown?

Rewitzky(5): yes

Albert: Excellent! I agree.

Albert: Now, which one of the graphs above correctly shows how the acceleration of the car varies with time?

Rewitzky(19): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: Since the car is accelerating, the velocity is changing. Is it speeding up, or is it slowing down during the early part of the motion?

Rewitzky(28): speeding up

Albert: Good! I agree with that.

Albert: You have said that the car is speeding up.

Now please tell me which one of the graphs above correctly shows how the x-component of velocity changes with time.

Rewitzky(34): 1

Albert: You say that the answer is 1.

Albert: Good, I agree.

Albert: The car in this problem moves in a straight line. We may think of it as moving along the x-axis.

Albert: Which one of the three diagrams above correctly shows the positions of the car along the x-axis which are equally spaced in time?

(The x-axis has been drawn horizontally for convenience)

Rewitzky(51): 2

Albert: You say that the answer is 2.

Dialogue continues. Press NEXT.

Albert: Sorry, I do not agree with that.  
 Albert: In that one, the distance travelled in a given time decreases. That would mean it is slowing down.  
 So which one is it?  
 Rewitzky(15): 1  
 Albert: You say that the answer is 1.  
 Albert: Good, I agree.  
 Albert:  
     The distance travelled in a given time increases.  
 Albert: -----  
 Albert: Now for a summary of what we know.....  
         Press NEXT.  
 Albert: So to sum up: We are considering a car which moves with constant acceleration.  
 Albert: During the early part of the motion, the acceleration is in the same direction as the velocity, so it is speeding up.  
 Albert: The x-component of velocity changes linearly with time.  
 Albert: -----  
 Albert: For any problem of this kind, it is important to extract all the useful information from the problem statement.....  
 Albert: So, what information is given in the problem statement? (Type in the values and units, e.g.  $m=3\text{kg}$ .)  
 Rewitzky(127):  $a=0.5 \text{ m/s}^2$   
 $v_f=25 \text{ m/s}$   
 $t=30\text{s}$   
 Albert: You say that the acceleration is  $0.5 \text{ m/s}^2$ .  
 Albert: (That's the x-component of the acceleration.)  
 Albert: Good, I agree.  
 Albert: You say that the final velocity is 25.  
 Albert: You did not specify units, or your units were invalid.  
 Albert: You say that the time is 30 s.  
 Albert: Good, I agree.  
 Albert: (1 to go.)agree.  
 Rewitzky(29):  $v_f=25 \text{ m/s}$   
 Albert: You say that the final velocity is 25 m/s.  
 Albert: (That's the x-component of the final velocity.)  
 Albert: Good, I agree.  
 Albert: What are you asked to find?  
 Rewitzky(20):  $v_0$   
 Albert:  
 Albert: That's right!  
 Albert: That completes the descriptive part.

Press NEXT.

Albert: -----  
 Albert: Now to the solution of the problem.....  
 (Remember, symbols used are:  $v_0$   $v_f$   $x$   $t$   $a$   $m$   $F$   $v_{av}$  and  $\Delta v$ .)

Press NEXT.

Albert: How would you like to start?  
 Rewitzky(44): with the equation  $v_f=v_0+at$   
 Albert: You want to use  $v_f=v_0+at$ .  
 Albert: What do you wish to calculate?

Dialogue continues. Press NEXT.

Rewitzky(13):  $v_B$   
Albert: Ok. The current goal is to calculate  $v_B$ .  
Albert: You want to use  $v_f = v_B + at$ ....  
Albert: Ok!  
Albert: You need to rearrange the formula.  
Rewitzky(20):  $v_B = v_f - at$   
Albert: You want to use  $v_B = v_f - at$ .  
Albert: Fine!  
Albert: Type in the value you get for  $v_B$ .  
Rewitzky(21): 10 m/s  
Albert: You say that the initial velocity is 10 m/s.  
Albert: (That's the x-component of the initial velocity.)  
Albert: Good, I agree.  
Albert: Well done! You have solved the problem.  
Albert: Press NEXT to do another problem,  
or DATA to see ALBERT solve this one.

Press NEXT for another record for rewitzky.

Appendix G

Students' comments about ALBERT

## Appendix G

### Students' comments about ALBERT

Listed here is a representative selection of comments made by the students in response to each of the questions. Some comments were very similar, e.g. those about breaking the problem into a number of steps. Where duplication occurred, only one comment is shown. A few comments were unintelligible. They have also been omitted.

QUESTION 1. Is ALBERT different from other computer lessons (PLATO programs) which you have used? If so in what way?

"'ALBERT' is different in that, instead of merely requiring you to do calculations and answer questions, 'ALBERT' takes you through the reasoning process behind the methods and formulas until you arrive at the final answer."

"Can give ALBERT a problem to help one solve - useful for tutorial problems, solving old exam paper problems. Does not give the student problems which increase in complexity. A brighter student can use it instead of asking a lecturer without having to wade through easy exercises first."

"Yes, it makes you solve the problem in such a way that you have to think about the subject matter."

"Yes, it is not rigid in problem solving compared to other PLATO programs."

"Yes, it asks you how you would like to solve the problem and doesn't wait until you try pot luck guesses to get on the right track or reject everything you type in until you find the set way to solve the problem."

"Yes, it does not simply have a set of questions that the user goes through. But the user can type in the problem that he personally finds difficult."

"ALBERT helps by 'participating' instead of just saying 'correct' or 'wrong try again'. He asks questions and covers all aspects of the problem with the student before starting to solve it."

"Not really except ALBERT requires far more feedback in other word ALBERT requires you to give him the information to work with and most other computer lessons lead you through discussion which is already there."

-----

QUESTION 2. Do you feel that you learned anything while using ALBERT? If so what? (Please try to be specific.)

"I have learned to think about what I am actually trying to find and to visualise what is happening, instead of looking at the information given and trying to remember which formulas I know to include all of them."

"I can never remember the equations of motion but found I was able to derive them easily with ALBERT'S help. It is useful trying to work out the equations."

"It has taught me to ask myself questions about a certain problem before trying to solve it. (Not just to 'plug in' values into a formula.)"

"Personally ALBERT has definitely taught me to order my thoughts while solving a problem, also the route you choose with which to solve the problem is accepted by ALBERT, unless of course its impossible. There is no set way which ALBERT wants to do it."

"Yes, the section that I completed helped me to break the problems down into pieces, and not try and solve it all at once."

"Yes. Understanding of the problem was improved. It helped me to think what I was doing and not just substitution into formulas."

"No. The section covered is very familiar to me and I found no problems in finding the answers to those questions attempted."

-----

QUESTION 3. Do you think that ALBERT can teach students how to solve problems? (Please try to give reasons for what you say.)

"Yes I do. ALBERT definitely improves the approach to problems. All it requires is to work through the theory section first and to think clearly about what is actually happening and what we are required to find. ALBERT forces you to do this."

"Yes, it leads the students into solving the problems for themselves without just showing them the answer when they get it wrong."

"Yes. It helps you work through a problem and discover how to solve it. It lets you work in your own way and so arrive at an answer."

"Yes I do because firstly you can choose which problem you want to solve and ALBERT leads you very systematically through the problems which I find a great advantage especially if ALBERT becomes so developed that any problem can be entered and solved."

"Yes. Because it doesn't just supply an answer, ALBERT forces its' user to think through a problem in the logical sequence needed to answer these problems in exam situations."

"Yes, as it helps the students to break down the problems using each piece of information which normally is overlooked."

"Yes. It gives you a basic network for solving any problems, analyse (thoroughly) find what values you're given, find formula that applies and solve."

Yes, helps student to think logically through the problem and makes the student decide where to start."

-----

QUESTION 4. What did you like most about ALBERT?

"The little encouraging comments when something was right - the conversation-like approach makes it much less impersonal which is what I normally don't like about computers."

"Being able to check my method with the correct method. Easy to use and understand. Can input the standard of problems I am having difficulty with."

"The way it conversed with you about the problem."

"The whole approach to problem solving. First discussing qualitatively the problem then determining what must be found etc."

"The freedom which you have in answering the question."

"Feedback."

"Can do problems of your own level and don't have to struggle with the set PLATO examples that are sometimes above one's standard."

"ALBERT, potentially, can solve the problems you wish to solve."

"If you need the answer, you just push help."

"That I could type in any problem that I wanted."

"Individual problems could be solved."

"ALBERT speaks nicely, explains his results or deductions clearly and helps the student rather than merely correcting him."

"It helps one to think clearly about the problem."

"Easy to understand."

"It gave me a reason to "play" on the computers and they fascinate me."

-----

QUESTION 5. What did you like least about ALBERT?

"The fact that it was quite time consuming, especially in the beginning when things went wrong."

"The laborious typing of the problem statement."

"The fact that it was limited only to linear motion problem."

"Not enough variations on symbols, units etc."

"Occasional confusion with typing problems but that's got more to do with computers than with ALBERT."

"ALBERT has a limited vocab and can get very muddled at times which makes problem-solving long winded at times but it's not a major problem."

"Although a certain amount of dialogue is possible, ALBERT has a very restricted vocabulary and this makes it difficult to communicate with him."

"It took too long."

"The problem, that it doesn't always accept everything you type in i.e. the units have to be spaced, lines of certain length etc."

"Sometimes it went too slowly. When I already knew the answer. Rather frustrating at times. Typing errors also caused problems."

"He doesn't always give an immediately useable formula (one must work out other factors by using another formula before using ALBERTS)."

"Time consuming and frustrating when one can't get to the end of the problem without going through numerous steps."

"Time taken is too long. Can't read whole formula if there are spaces."

-----  
QUESTION 6. How could ALBERT be improved?

"Most of the problems we initially encountered seem to have been modified already eg. use of the arrows was a great help instead of typing "horizontal" etc. ALBERT doesn't recognise some English words but if the usual expressions and phrases are used he seems to cope, and I realize that it would be impossible for him to have a limitless vocabulary."

"If your answer is incorrect you should get a hint on how to continue, i.e. what to consider as the next step, to solve problems after allowing the student about 2 or 3 tries otherwise one feels like giving up."

"It could be given a greater vocabulary giving it a greater personality thus more enjoyable to work with."

"I can't think of any improvements. It would be nice if it could be expanded to help with other sections of Physics."

"To include rest of the Physics syllabus."

"Complexity and subjects could be added."

"I'd like to be able to do any type of problem on it."

"Development so that ALBERT can solve any problem entered into the computer."

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## Software Sources

CONDUIT

P.O. Box 388

Iowa City, IA 52240

Cross Educational Software

1802 N Trenton St

Ruston, LA 71270

Intermediate Physics Simulations

R.H. Good

California State University

Hayward, CA 94542

Strassman Computer Services

55 Talmadge Hill Road

New Canaan, CT 06840

University of the Witwatersrand

Department of Physics

1 Jan Smuts Avenue

Johannesburg

Vernier Software

2920 S.E. 89th St

Portland, OR 97225

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