A prototype design for an expert system to identify pupils' misconceptions in science

Wan Salihin Wong Abdullah

University of Technology of Malaysia

Phil Wild

Loughborough University,
United Kingdom

ABSTRACT

In this paper we propose a link between research in diagnosing student misconception in science education and expert system technology. We will describe an attempt into researching and developing a prototype expert system as a supportive tool for classroom teachers. The two forms of rules in the knowledge base, the diagnostic rules and the questioning sequence rules, are illustrated with an example. The overall design framework chosen has taken into consideration the practicality of system adoption into present classroom settings. This system was developed using a commercial expert system shell, Leonardo. Results of an initial trial with school pupils and teachers are discussed.

Main conference themes: artificial intelligence
Educational areas: secondary education
Study topics: science/engineering
Secondary keywords: expert systems, knowledge representation

J. D. Tinsley et al. (eds.), *World Conference on Computers in Education VI*

INTRODUCTION

In a previous paper [1] we proposed a development which links research in diagnosing student misconceptions and the expert system technology. Specifically, we argued that:

- The diagnostic process is an important phase in classroom learning which has been emphasized by the requirements of the national curriculum.
- The normal practise of diagnosing in the classroom is through the use of questions and discussion. With the ever increasing demands on the time of the teacher a supportive way of handling the diagnostic process is sought.
- This process is regarded as something amenable to an expert system approach which means that knowledge and process can be formalized in a form which can be handled computationally.

In this paper we will describe the research and development of a prototype expert system as a supportive tool for classroom teachers in secondary science with the topic of motion and graphs being used for illustrative discussion.

In particular, we will discuss:

- the strategy of knowledge representation adopted in the prototype system;
- the architecture of the diagnosing system;
- the results of an initial trial.

This research project is funded by The Commonwealth Association of University under the Fellowship and Scholarship Plan and is being carried out in the context of developing nations such as Malaysia where the future direction is toward a more systematic and reliable school based testing. In implementing this vision in Malaysia there is a need for diagnostic expertise among normal classroom teachers which is still lacking. One possible solution is to employ the technological method which is concurrent with the Malaysian Ministry of Education plans to supply computers to all the secondary schools [2].

We proposed the use of expert system technology in this research because theoretically the diagnostic system requirements conform with the general uses of expert system technology as an instructional decision making tool. It can provide instructional feedback and provide a job aid for teachers as proposed by Jonassen and Grabinger [3]. Technologically the expert system provides advantages over previous attempts to use computers for diagnostic purposes:

- The availability of expert system shells on PCs makes distribution and use in the classroom easier.
- Compared to conventional programming the prototype knowledge base is easier to build and to modify capitalizing on sources of knowledge.

- An expert system provides an easier way to formalize and centralize the diagnostic knowledge.

THE EXPERT SYSTEM

McFarland and Parker [4] defined an expert system as a computer program which combines knowledge in the form of rules, and an 'inference engine' which uses the rules to draw inferences, or conclusions and recommendations, about a problem presented to the system.

Although expert systems have been designed in many different ways these all share the following certain basic components:

Knowledge base component: This part of the system stores the facts, rules or knowledge which are used by human experts in reasoning associated with a specific domain. Although there are several ways of representing the human experts knowledge, the most commonly used methodology is via production rules consisting of a set of conditions and corresponding actions. The general form is:

IF condition is satisfied THEN certain action is invoked.

Interface component: This part will facilitate communication between the expert system and the user. Normally it consists of an end user interface (e.g. a screen interface), a developer's interface (e.g. editing and debugging facilities) and an external program interface (linkage with external data or programs).

Inference mechanism component: This component is not usually accessible to an expert system designer, but rather is the 'black box' of the expert system. It contains the strategies (forward chaining and backward chaining) for controlling the selection and application of the rules in the knowledge base.

Global data component: This part keeps track of the problem by storing data, for example the user's answers to questions. During an execution of an expert system new facts are constantly being added, removed or modified as a result of the interaction between the user and the knowledge base.

The Design Framework

As in other application systems the initial step in prototype system design involves the formulation of the application requirement. There is no widely accepted approach, but we believe that most educators would likely agree to the following general design objectives and considerations. The system should:

- be efficient in terms of user input and program output;

- involve a certain amount of visual interaction with the user;
- be efficient and flexible in terms of allowing different topics to be diagnosed;
- be relatively easy to modify by allowing changes to be made as required;
- be practical and easily adopted into current classroom practise.

Building a knowledge base

The main steps are analysis of past research literature in pupil misconceptions and building the rules base.

Analysis of past research literature in pupil misconceptions

We used the topic of motion and graphs as an example. The 'expert knowledge' consisted of examples of the common misconceptions reported in the literature.

- There is evidence that pupils tend to use a 'position' criterion when comparing the speeds of two objects. That is, when two objects were next to one another (at the same position) pupils said that they were moving at the same speed.
- Pupils also tend to interpret graphs based on the general pattern of the lines on the graph without examining other factors in detail.

Building the rules base

This knowledge base contains a collection of rules. In this prototype system there a two rules: diagnosis and questioning.

The diagnosis rule is essential in defining the parameters and the logical relationship between parameters. A parameter is a domain fact which in this application takes the form of the pupil's answer to the question. A rule defines the relationship between the parameters.

As an example to illustrate the simplified working of an expert system consider a knowledge base with these rules:

Rule 1 :

IF the user is reasoning that two objects are moving at the same speed when they are next to one another (at the same position)

THEN the user is using a 'position' criterion.

Rule 2 :

IF the user interprets the slope of straight lines on a distance-time graph as a change in speed

THEN the user has a misunderstanding that the slope of straight lines on the graph indicates a change of speed.

When the system is executed, it will request the facts or answers it needs (IF part of the rule) in order to make a decision (THEN part of the rule). After the users has provided the answers, the inference mechanism of the expert system will use both the rule set and answers to questions for searching the right decision.

For the above example the general questions will be:

- Is the user reasoning that two objects were moving at the same speed when they were next to one another (at the same position)?
- Is the user reasoning that there is a relation between the slope of a straight line and a **change** in speed?

Obviously it is not practical for the system to ask the user this in the form as stated above. We need to refine and modify the user interface and elaborate the condition part of the rule. Here the format of the common multiple choice question is applicable. By making the system as close as possible to the normal classroom testing pupils will not feel threatened when they use the system.

An expert system shell which only allows a simple text output as a way to prompt for a user answer, is not adequate for this application; the system should display graphical data for better understanding of the question. In the prototype system a modified version of the user interface has been implemented as follows:

- The question text is stored outside the main program in a question data file or question bank. It will be retrieved by the main program as required to be displayed on the screen. This strategy provides a convenient way to edit or change the questions or to cater for questions of other topics.
- The question diagram is shown together with the relevant question text on the screen.
- There is an allocated area for prompting the user's input with the ability to check the user's input and to display input error messages.

The questions used in the question bank for the above example are listed in Fig. 1. To refine the rules for the listed questions the knowledge representation for the prototype system is described in a tabular matrix as shown below (Tables 1 and 2).

As an example the form of rule derived from the tabular matrix (Table 1) might be:

IF	speed is increasing when slope is ascending
and	speed is decreasing when slope is descending
and	speed is constant when slope is horizontal
THEN	show descriptive 1A

Descriptive 1A is a descriptive feedback on the conception of the pupil in the specific area. This form of rule can be extended to include all the options as listed in the tabular matrix.

Table 1 Tabular matrix for question 1

Rule	*Parameters*			*Feedback*
	Slope Ascending	*Slope Descending*	*Horizontal*	
Rule 1 : Speed	increasing	decreasing	constant	Descriptive 1A
Rule 2 : Speed	constant constant constant		Descriptive 1B	
Rule 3 : Speed	decreasing	increasing	constant	Descriptive 1C

Table 2 Tabular matrix for question 2

Rule	*Parameters*		*Feedback*
	Same speed ?	*When is it ?*	
Rule 1	yes	t = 3 units	Descriptive 2A
Rule 2	yes	t other than 3 units	Descriptive 2B
Rule 3	no	-	Descriptive 2C

The second kind of rule is the questioning rule. The order of questioning is based on a branching strategy: the question displayed by the system is based on the answer to the previous question. This will eliminate unnecessary waste of time in answering more questions in an area obviously understood and will also reduce the possibility of confusion among the users. For this prototype system a simple branching strategy of the form If-Then is used, e.g.:

```
IF          display_Question_1 is done
and         answer_Question_1 is 'A'
THEN        display_Question_2

IF          display_Question_1 is done
and         answer_Question_1 is 'B'
THEN        display_Question_3
```

- This diagnostic system was implemented in Leonardo, a rule-based shell which runs on PCs. The system is user friendly and relatively easy to use.

Question 1

The motion of an object is shown as a distance-time graph as in the diagram.

1(a) In diagram 1(a), the graph shows that the speed of the object is
A. increasing
B. decreasing
C. constant

1(b) In diagram 1(b), the graph shows that the speed of the object is
A. increasing
B. decreasing
C. constant

1(c) In diagram 1(c), the graph shows that the speed of the object is
A. increasing
B. decreasing
C. constant

Question 2

Two balls 1 and 2 move at CONSTANT speeds on separate tracks.
The position occupied by the two balls at the SAME TIME are shown in the DIAGRAM 2 by identical numbers.

2(a) Do the two balls ever have the same speed on the tapes shown ?
A. yes
B. no

2(b) When do the two balls have the same speed ?
A. when t = 3
B. when t = 4
C. when t = 5

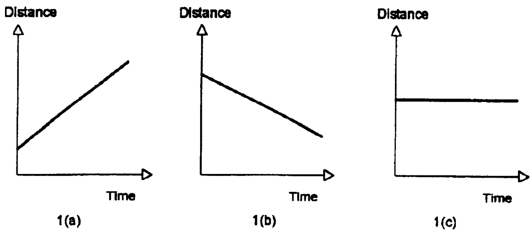
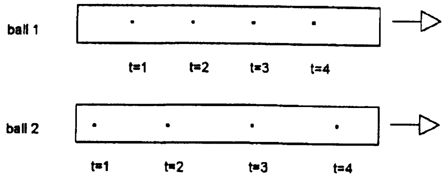


Diagram 1



[starting point is NOT shown]

Diagram 2

Fig. 1

The following extra features of Leonardo are used extensively in the prototype system:

- a graphic package for drawing of simple diagrams;
- access of external files;

an extensive procedural programming language to support complex design.

The structure of the prototype system

The prototype system consists of four main parts:

The initialisation unit: This starts the system by linking to the external question bank, displaying a welcome screen and then prompting for a user name.

The input unit: This displays a series of questions which branch according to the user's answer to the previous question. The user is required to press a key corresponding to the choices provided by the question. If there is a mistake in user's input, the system will remind the user then wait for a new input.

The diagnosis unit: Every time the user gives an answer to a specific question, the system will add a parameter into the system's global data component. Based on the collection of user's answers the system invokes every rule in the knowledge base of the system matching these with the corresponding models of misconception.

The output unit: This provides the results of the diagnosis to the user. Three output alternatives are provided: hard copy print, show on screen or print to file.

The complete structure of the system is shown in flowchart form in Fig. 2.

EVALUATION OF THE SYSTEM

The evaluation of the prototype system consists of two main parts. One is the initial verification of the system before the field trial. The other one is the validation of the system when used by pupils and teachers. The evaluation is directed toward determining whether the system can reach the proper conclusions. It also provides a way for testing and demonstrating the capabilities of the system.

Several important analysis results found are:

- This study confirmed the existence of the misconception found in previous studies.
- One interesting phenomenon is the existence of contradictory ideas in the student's conceptions. These contradictory ideas result in the failure of the system to suggest any specific model.
- This study suggests that the program can make a reasonable diagnoses, at least for the majority of the sample.

In order to evaluate the user satisfaction a questionnaire was constructed containing numerous questions relating to a number of factors such as accuracy, content, reliability, etc. Several teachers were asked to go through the system and then gave their feedback on the questionnaire. The initial responses from teachers showed that:

- the user interface part of the system is very satisfactory;
- the system in general succeeded in diagnosing student's misconception in the specific domain;
- the branching capability of the system is very helpful;
- in general they were satisfied with the accuracy and outcomes of the questions used in the system.

CONCLUSION

In this paper we have discussed a prototype diagnostic system which was built using expert system technology. The results from the trial suggest that the system is capable of diagnosing pupil's misconceptions as planned. As this is only a first attempt there are several more aspects to be examined:

- Can this expert system diagnosis strategy be easily transferred to another topic in the domain?
- Is the knowledge base inside the program adequate or is there still a need for additional 'knowledge' to provide a deeper link between the various forms of misconception diagnosis rules? Can these deeper links accommodate the various contradictory ideas in pupils' conceptions?
- Can the program be expanded so that the process is totally independent of teacher involvement. In other words, can the system provide feedback without teacher help?
- Can this program be used as a research tool for further work in the area of science misconception?

situations and combinations are taken into account in a particular domain. Several aspects of system verification were carried out:

- A flow diagram for checking the completeness of the system for any missing rules.
- Manually check of the rules in the knowledge base for any inconsistency in the system's structure.
- A check that the rules are free of syntax errors.

Validation of the system

The validation process involved thirty secondary science pupils from two local schools. The responses from the pupils were stored in a unique text file based on the pupil's name. A simple analysis was carried out on these responses and the results are discussed below.

During the trials it was observed that pupils did not have any difficulty in working through the program. It is thought that this is partly due to their previous general experience with using computers. In fact the pupils seemed to enjoy the new experience.

The analysis of the pupils' responses is shown in Tables 3 and 4. The data in Table 3 (for question 1) show that the system successfully detected 9 pupils who have a correct conception, 16 pupils who showed a misconception of what the slope of the graph represented, and 5 cases of contradictory or nonconsistent ideas.

Table 3 Pupils' responses for question 1

Questions			
1(a)	*1(b)*	*1(c)*	*Total*
a	b	c	16
c	c	c	9
c	b	c	3
a	c	c	1
a	a	c	1
Total			30

Table 4 Pupils' responses for question 2

Questions		
2(a)	*2(b)*	*Total*
a	a	12
b	-	18
Total		30

The data in Table 4 (for question 2) showed that only 12 pupils answered question 2(b). In this adaptive structure only those pupils who answered 'A' for question 2(a), were given the chance to answer question 2(b). Again the data in the table show that 12 pupils applied an idea which used the 'position' criterion as suggested in the literature.

Several important analysis results found are:

- This study confirmed the existence of the misconception found in previous studies.
- One interesting phenomenon is the existence of contradictory ideas in the student's conceptions. These contradictory ideas result in the failure of the system to suggest any specific model.
- This study suggests that the program can make a reasonable diagnoses, at least for the majority of the sample.

In order to evaluate the user satisfaction a questionnaire was constructed containing numerous questions relating to a number of factors such as accuracy, content, reliability, etc. Several teachers were asked to go through the system and then gave their feedback on the questionnaire. The initial responses from teachers showed that:

- the user interface part of the system is very satisfactory;
- the system in general succeeded in diagnosing student's misconception in the specific domain;
- the branching capability of the system is very helpful;
- in general they were satisfied with the accuracy and outcomes of the questions used in the system.

CONCLUSION

In this paper we have discussed a prototype diagnostic system which was built using expert system technology. The results from the trial suggest that the system is capable of diagnosing pupil's misconceptions as planned. As this is only a first attempt there are several more aspects to be examined:

- Can this expert system diagnosis strategy be easily transferred to another topic in the domain?
- Is the knowledge base inside the program adequate or is there still a need for additional 'knowledge' to provide a deeper link between the various forms of misconception diagnosis rules? Can these deeper links accommodate the various contradictory ideas in pupils' conceptions?
- Can the program be expanded so that the process is totally independent of teacher involvement. In other words, can the system provide feedback without teacher help?
- Can this program be used as a research tool for further work in the area of science misconception?

This study has shown in an objective way the potential of applying expert system technology for diagnosing pupils' misconceptions in science education. A substantial saving in terms of teacher's time and energy can be realized if this system can be used in the classroom decision making process.

REFERENCES

1. Abdullah, W. S. W. and Wild, P. (1994) *Expert systems used in the identification of misconceptions and assessment in school science: a review and proposed development.* British Journal of Educational Technology, **25** (1) pp. 29-40.

2. Shariffadeen, T. M. A. (1991) *Information Technology and Education—The Emerging Malaysian Scenario.* Proceeding of the National Symposium on Educational Computing, 19-21 November 1991, pp. 2-19.

3. Jonassen, D. H. and Grabinger, R. S. (1990) *Levels of Processing in Building Expert Systems*, in Cognitive Tools for Learning. (eds Kommers, P. A. M., Jonassen, D. H. and Mayes, J. T.). Nato ASI Series, Vol. **81**.

4. McFarland, T. D. and Parker, R. (1990). *Expert Systems in Education and Training.* Educational Technology Publications, Englewood Cliffs, New Jersey.