

Elicitation of Knowledge with and for 'Intelligent' Tutoring Systems

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Abstract

It will be argued that ITS's are not primarily of practical use but that they rather are instrumental in bringing about advances in the understanding of learning and hence in the design of optimal teaching strategies. The basic assumption underlying the idea that ITS might be a better vehicle for instruction than traditional teaching is, that for each individual there exists an optimal teaching 'remedy' once a very specific cognitive 'diagnosis' has been made. Thus cognitive diagnosis is a crucial problem. In order to reduce the search space of potential diagnoses that could explain the student's cognitive behaviour, heuristics based upon research in mental models is necessary. During the development of an ITS for thermodynamics at the University of Amsterdam research had to be done simultaneously on the prevailing mental models and misconceptions in this domain. Results will be briefly discussed. Not only the actual cognitive state of the student and the recent intervention history are thought to be important but also certain personality traits might relate to an optimal (form of) teaching interaction. Traditional Aptitude-Treatment Interaction research is also based upon this notion. ITS's, once in their operational phase, can be used as instruments in ATI- research. In contrast with the traditional approach, the research can be done with subjects who, apart from their specific personality structure and/or cognitive style, have specific cognitive states (eg. misconceptions). Together with the fact that the interaction using an ITS is better controlled this might result in effect sizes that are considerably larger and findings that could be interpreted easier in terms of theories of individual learning. Current research at the University of Amsterdam, using an 'intelligent' simulation environment, focuses on the interaction of the amount of structure in the instruction with some personality traits in pupils with well-established misconceptions.

1.Objectives of the Computer Coach project

The original goal of the project 'a Computercoach for Thermodynamics' at the University of Amsterdam was to implement a prototype 'Intelligent' Tutoring system for testing in the classroom. However the development of this computer coach turned out to be more difficult than expected. Actually the original goal fragmented into a number of fundamental research projects which might be typical for the proposition that this kind of project stimulates relevant educational research often resulting in the elicitation of knowledge from expert teachers (using the ITS under construction) and from students with regard to common misconceptions.

The project started about 4 years ago and was concluded in 1986 (Bierman & Kamsteeg, 1987). It was a part of a large endeavour to study the acquisition of knowledge in formal domains like Physics. The focus of this larger global project

is on how people learn to solve problems and the main research method was the analysis of thinking aloud protocols produced by subjects while they are solving problems. To aid the researcher in the analysis of these protocols a program was written that was able to solve thermodynamic problems like the ones presented to the subjects. This program could be seen as a model of an obedient problem solver and the thinking aloud protocols of an obedient subject should highly correlate with the trace produced by this program (Jansweijer et al, 1982). It was proposed that by adding a few components dealing with the didactics of teaching the program would be suitable as an 'intelligent' computer coach. The difficulties encountered yielded a number of secondary research goals like 'the development of an electronic scratchpad', research on mental models of heat and temperature and elicitation of didactic knowledge from expert-teachers. These topics will be treated extensively later in the paper.

2.Design of the Computer Coach

The architecture of the computer coach was built around this program as can be seen in figure 1.

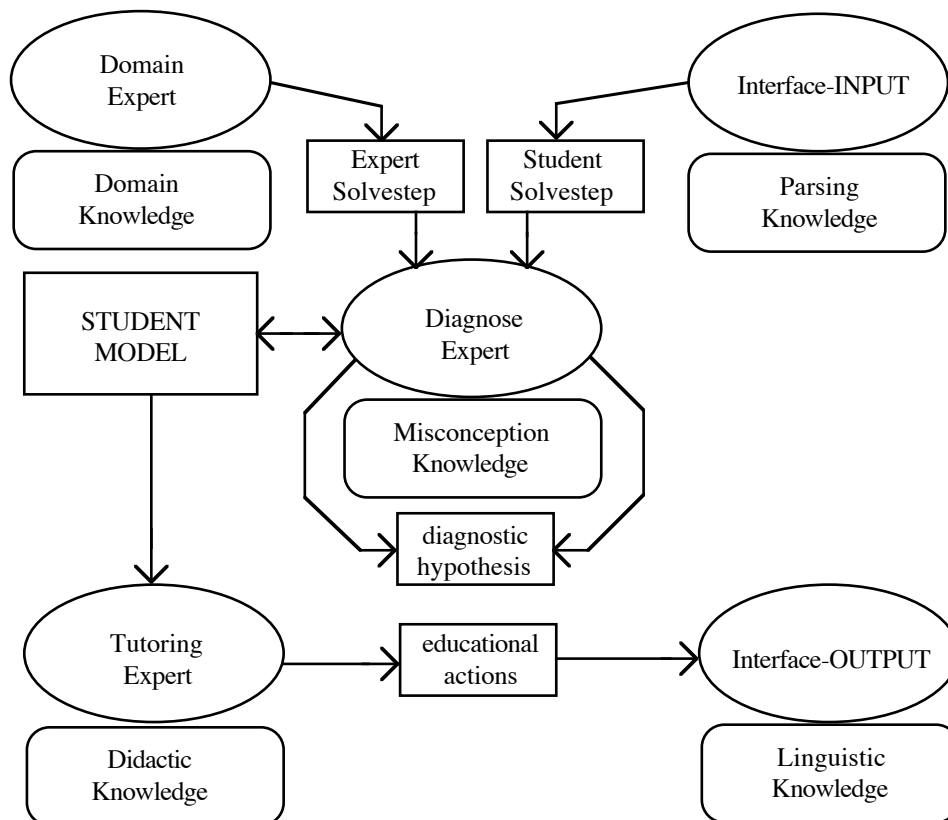


figure 1: the architecture of the computer coach.

On top of this architecture there is a component which either selects the next problem or decides that the pupil has learned enough.

The system consists of four components. Each of these components performs a separate function.

2.1 The domain expert

The domain expert component is the original 'obedient problem solver'. This component accepts a problem text as input; consecutively it solves the problem, producing a 'mental trace'. This trace is also called 'norm' trace because of the underlying educational goal that the pupil should eventually confirm to this solving norm. From the beginning of the project on, the intention has been to localize all knowledge pertaining to the domain of thermodynamics within this component. The reason being that a similar computer coach for a different domain could then be constructed by replacing nothing but the domain expert.

2.2 The diagnose expert

The function of the diagnose expert is to generate hypotheses about the reason for deviating cognitive behaviour on the part of the pupil. A further important task is to maintain and update a model of the pupil. One way of doing this is estimating, for each knowledge item that the domain expert has access to (factual knowledge, procedural knowledge as well as knowledge about solving strategies), the mastery level of the pupil. In this approach the current knowledge of the pupil is seen as a subset of the eventual knowledge he should come to possess. The pupil model is therefore an incomplete, but apart from that, identical copy of the expert model. This kind of pupil model is called 'overlay model', because (apart from the missing elements) it exactly covers, as it were, the expert model (eg. viz. Goldstein, 1982).

In domains, such as physics, about which one may assume that a pupil already has some (possibly incorrect) knowledge to begin with, it is furthermore necessary to keep track of the incorrect knowledge (misconceptions, incorrect mental models) the pupil has. Since this is knowledge an expert generally does **not** have, it does not fit in an 'overlay model' but must be represented separately, for instance in a list of misconceptions ('bug catalog') or by extending the overlay model with pointers to incorrect knowledge (eg. Brown & Burton, 1978).

The aforementioned function of generating hypotheses about deviating pupil behaviour is performed in the context of such a pupil model. That is, the likelihood of a certain hypothesis is deduced on the basis of information in the pupil model.

2.3 The tutoring expert

The task of the tutoring expert is to decide upon an optimal instructional intervention with respect to the diagnosis. In this task also, the pupil model plays an important role. Apart from the cognitive aspects of the pupil model, personality features of the pupil can be taken into consideration in deciding upon an optimal instructional action. The personality trait 'negative fear of failure', for example, can play a part in deciding whether to give many or few procedural hints.

2.4 The interface

A (user) interface is that part of a computer program which takes care of the interaction between the user and the rest of the program. In our case this means that the actions the pupil performs at the computer terminal have to be translated into a form that can be used by the diagnosis expert. That is, motor actions have to be interpreted as reflections of cognitive actions. Reversely, instructional interventions of the tutoring expert have to be presented to the pupil in the form of one or more comprehensible sentences.

3. Secondary Research goals

3.1 Implicit vs. Explicit Knowledge

A major difference between this kind of CAI and the more traditional frame-based CAI is the fact that the didactic knowledge in this latter type of CAI is implicit in the program (for instance in the branching decisions or in remedial texts) whereas in ITS's the didactic decisions are based on explicit didactic knowledge.

In the early stages of the computer coach project it became clear that there was no formal source of information with regard to this explicit knowledge, the process of individual cognitive diagnosis, nor of the relation between diagnoses and optimal tutorial interactions. The majority of educational research concerns the classroom situation, i.e. its results are rather unspecific in as far as individual students are concerned. For instance the traditional Aptitude-Treatment Interaction research generally uses large groups with students selected on the basis of personality traits but not on the basis of specific cognitive deficiencies. Also theories of learning are generally too unspecific to derive a coaching strategy from (Kamsteeg, 1984). According to Anderson (1985) his ACT-theory is an exception and one might infer from his theory that the student should be kept as close as possible to the correct solution path.

The lack of information regarding didactic knowledge stimulated us to start a number of small projects each of them potentially having some practical use in the more traditional environment of the classroom (Looy,1987 ; Malhas,1986 ; Stehouwer, 1986).

3.1.1 Field Research

With regard to the question of optimal tutorial interventions we initiated field research asking teachers for common cognitive problems that they encountered in the classroom and also which action they undertook to relieve such a problem (Malhas, 1986). This field research yielded lists of problems ranging from inadequate support knowledge like insufficient knowledge of algebra, to more complex problems like the aforementioned heat-temperature confusion. However, the list of tutorial actions that was elicited from these teachers was rather short. The most popular action was 'explain it again'. During this research it became rather apparent that most teachers were primarily interested in getting the pupils ready for the exams instead of having them understand physics in a more fundamental way. against this background one might wonder whether Physics on the pre-university curriculum is of any use. However, we also received a few nice examples of Socratic dialogues which would be valuable in an ITS but might also be communicated to other teachers of thermodynamics. On the whole we were forced to conclude that we had to elicit didactic knowledge from teachers with experience in individual coaching rather than from classroom teachers. This was done using a methodology called MUSPA.

3.1.2 The MUSPA, individual knowledge elicitation research

This methodology has been extensively described elsewhere (Bierman & Kamsteeg, 1987). The essence of the method is to create a hybrid system of the unfinished computer coach and the human coach working together while coaching the students problem solving. The set-up is given in figure 2.

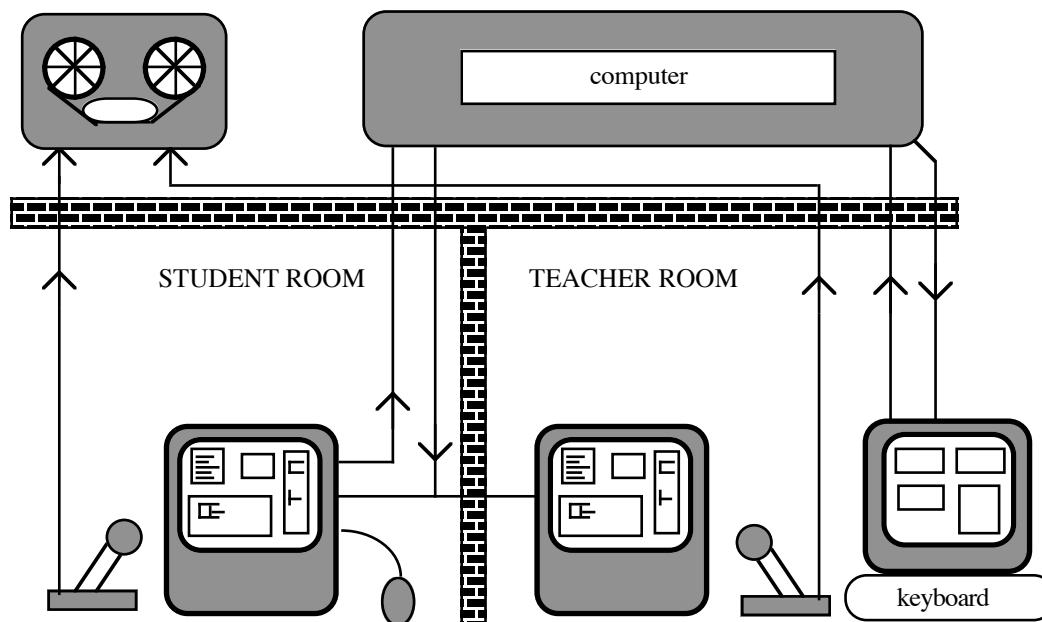


figure 2: The MUSPA experimental set-up

This approach yields three protocols: one from the student, one interaction-protocol and one from the teacher. The thinking aloud protocol produced by the human teacher is analyzed carefully in search for im- or explicit didactic knowledge (eg. coaching strategies). This didactic knowledge is subsequently implemented in the computer coach and a new test cycle begins. In the more final stages the human coach is able to follow the reasoning of the computer coach on his terminal and his thinking aloud task gradually shifts into a criticizing aloud task. In this way substantial didactic knowledge was elicited. For instance some teachers used a strategy of generating hints which became more and more specific (Bierman & Kamsteeg, 1987). This MUSPA technique is useful for the development of any knowledge based system meant to run within the context of an ongoing dialogue since it also represents a crucial test on the design of the user-interface.

3.2 Enhanced Band-width of Communication

With regard to diagnosis it was necessary that the motor actions of the student at a terminal should be parsable in terms of cognitive actions. To that purpose we developed a graphic user interface called the 'scratchpad' using PCE-Prolog, an object oriented extension to the Prolog-language (Bierman & Anjewierden, 1986). The student is forced to make all his notes on the machine itself. The most interesting feature of this interface is the ease with which the contents of the scratchpad can be parsed symbolically. For instance it takes only a few lines of code to find out whether the student did recognize that a given problem was a

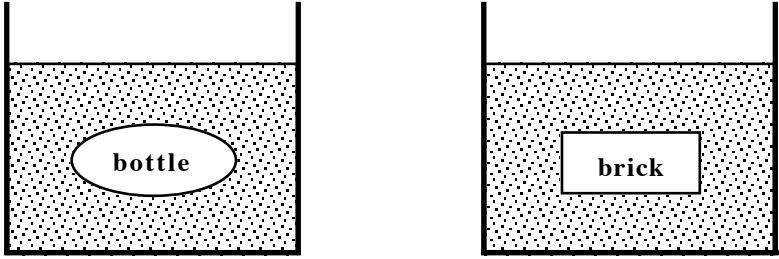
dynamic one. Of course the 'scratchpad' is not a fundamental educational finding, but this largely technical spin-off of our project is directly usable in traditional CAI-programs.

3.3 Mental Model research

A more fundamental aspect with diagnosis is caused by the fact that the malrule approach fails in the domain of thermodynamics. The malrule approach to diagnosis is essentially the search for a piece of false or lacking (procedural) knowledge that could explain the deviating behaviour of the student. This approach has originally been explored by Brown and Burton (1978) for simple arithmetics (subtraction). They showed that for a majority of the incorrect behaviour it was possible to single out (combinations of) malrule(s) that could simulate this particular behaviour.

For complex domains, like physics, this approach is not feasible since the search space is too large. The number of cognitive procedures which are activated before a correct solution is found is an order of a magnitude larger than for subtraction. Even when diagnosis is done on intermediate steps there are too many potential malrules that could explain an incorrect step. Therefore we need some heuristics (rules of thumb, eg. telling which cluster of malrules is most probable) to reduce the search space. This need triggered a research project into different mental models which are present in the domain of thermodynamics and their respective probability of occurrence (Stehouwer, 1986). Mental models might on the surface level be detected as patterns of error rather than single errors.

To illustrate the type of knowledge we gained from this project it is necessary to give some more details. A number of qualitative questions were submitted to about 200 students. A typical question is given in figure 3:



A brick and a bottle with water of the same weight have both a temperature of 50° C. The bottle is heated for 15 minutes until 100° C. The brick is heated for 30 minutes also until 100° C. Both objects are plunged into two identical containers with water. If the temperature of the objects is decreased till 50° C. the temperature of the container is measured.

What container has the highest temperature?
 a. with bottle b. with brick c. identical

Explain WHY?

figure 3: example of qualitative (mental model) question

The subjects were not only requested to mark the proper alternative but they were also asked to justify their answer. From these justifications we were able to derive a taxonomy of mental models concerning the concepts of heat and temperature. At the core of the incorrect models is the general idea of heat as a particle (figure 4).

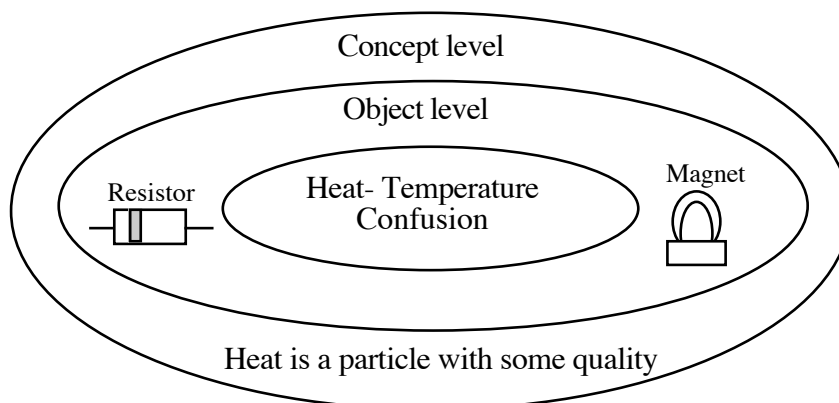


figure 4: Postulated Mental Models underlying the Heat-Temperature confusion

Around this fundamental metaphor we found out that object property could be

labelled as magnetic-like or resistance-like with regard to heat-transfer. 'Magnetic' thinkers would say that objects that are heated easily will lose their heat difficultly, while 'Resistant' thinkers would say that objects that are heated easily will lose their heat easily. Finally we found protocols that indicated some model describing the relation between an object and its surroundings. This relation was described in terms of the quality of heat transfer. Generally this quality would reflect itself in the **time** needed to heat an object embedded in a heat bath. Some people had the idea that slow heating implied a low quality of the heat (i.e. the heat-'particles' to have a low temperature), while others had the reverse idea. We called them 'Battery' thinkers and 'Simmer' thinkers.

These hypothetical models were tested by presenting a number of simple qualitative questions directly related to these models using the same subjects. For instance, the following question was asked:

If an object plunged into a container with water causes this container to increase its temperature by 10° C , the object will have lost 10° C.

It turned out that the 'thinkers' who combined the Resistant and the Battery model were very consistent in their use of this model, where other thinkers were more inconsistent. Although the Resistant-Battery model is physically incorrect, it very often yields the correct prediction in daily life. For the other, less stable models it appears that they are highly context dependent and probably it is not justified to label those as mental models which would suggest some form of stability (van Looy, 1987). Although we embarked on this research to find heuristics that could help us in the diagnosis of errors for our ITS's it must be obvious that these findings can be valuable in the classroom too!

3.4 Student Models

In order to explore the knowledge to be represented in the student-model we reanalyzed the teacher protocols gathered with the MUSPA methodology, specifically looking for im- or explicit references to the student inferred cognitive state. We only found rather superficial remarks dealing with global impressions of the human coach (Kamsteeg & Bierman, 1988). Thus the question arises if it is necessary to have a very specific student model. Collins (1987), for instance, seems to believe that there are a large number of educational heuristics each of which supposedly would improve the teaching. None of these heuristics were dependent on the specific type of student. Kelly (Kelly, Martinak & Sleeman, 1987) found empirical evidence that a deep cognitive diagnosis does not necessarily result in better teaching.

4. From teacher to student

4.1 Why is individual tuition superior to collective teaching?

Although not very much comparative research has been done on the teaching results obtained through human versus computer coaching, the preliminary conclusion might be that classroom teaching yields the worst results and individual human tuition the best results. Computerized teaching falls between the two. Thus the conclusion must be that the individual human teachers do possess knowledge that is lacking in the computer coaches. A possible candidate might be the specific knowledge concerning the cognitive state of the student, the above mentioned student model. The whole idea of individual tuition being better than collective teaching is based upon the idea of individual differences which might require different teaching actions. And although virtually each article on ITS stresses the need for a good student model, most computer coaches only maintain a very superficial student model. However, from our student-model research, it appears that human teachers do not use specific student-models.

The fact that CAI yields better results than the classroom teacher might be explained by the behaviouristic heuristic that immediate feedback is better for every student independent of his/her cognitive state.

4.2 Cognitive Aptitude Treatment Interaction-research

But then again how do we explain human individual teachers outperforming computer coaches? Is it the subtle interaction between personality trait and educational treatment? None of today's CAI systems has implemented knowledge that takes personality traits into account. Generally, Aptitude Treatment Interaction research does not show very strong effects (Snow et al, 1980). Thus, at first sight this hypothesis might be far fetched. However it should be mentioned that ATI research is generally evaluated by using rather global measures from pre and post treatment tests. This means that these findings tell us something about one specific treatment for students with one specific trait irrespective of their particular cognitive deficiencies. This brings us to the current research at the University of Amsterdam. Here we might use ITS's to select students with specific cognitive deficiencies and then study the ATI for this specific cognitive state. In our research 'Resistor-Battery' thinkers are selected and placed in either a structured or an unstructured learning environment. This environment is a computer simulated lab which is constructed using AI-techniques (see figure 5)

figure 5: the HEAT-LAB for 'Socratic' experiments

Student might either explore or be well guided (in a Socratic way) in this lab. We will examine the interaction of these treatments with the personality trait 'fear of failure' as determined by a personality test. Students are requested to think aloud during their sessions. These protocols will enable us to trace down the moments of insight yielding the switch from the wrong mental model to the correct mental model. We hope that this type of research which combines aspects of modern cognitive and more traditional ATI-research will eventually yield theories of learning that are specific enough to be of value in individual teaching.

5. Conclusion

In order to build an artificial teacher we should first understand the craft of teaching (Ohlsson, 1986). This self-evident truth was confirmed again in our effort to implement a computer coach for thermodynamics. Different aspects of this craft were subsequently the subject of smaller research efforts. Special attention was

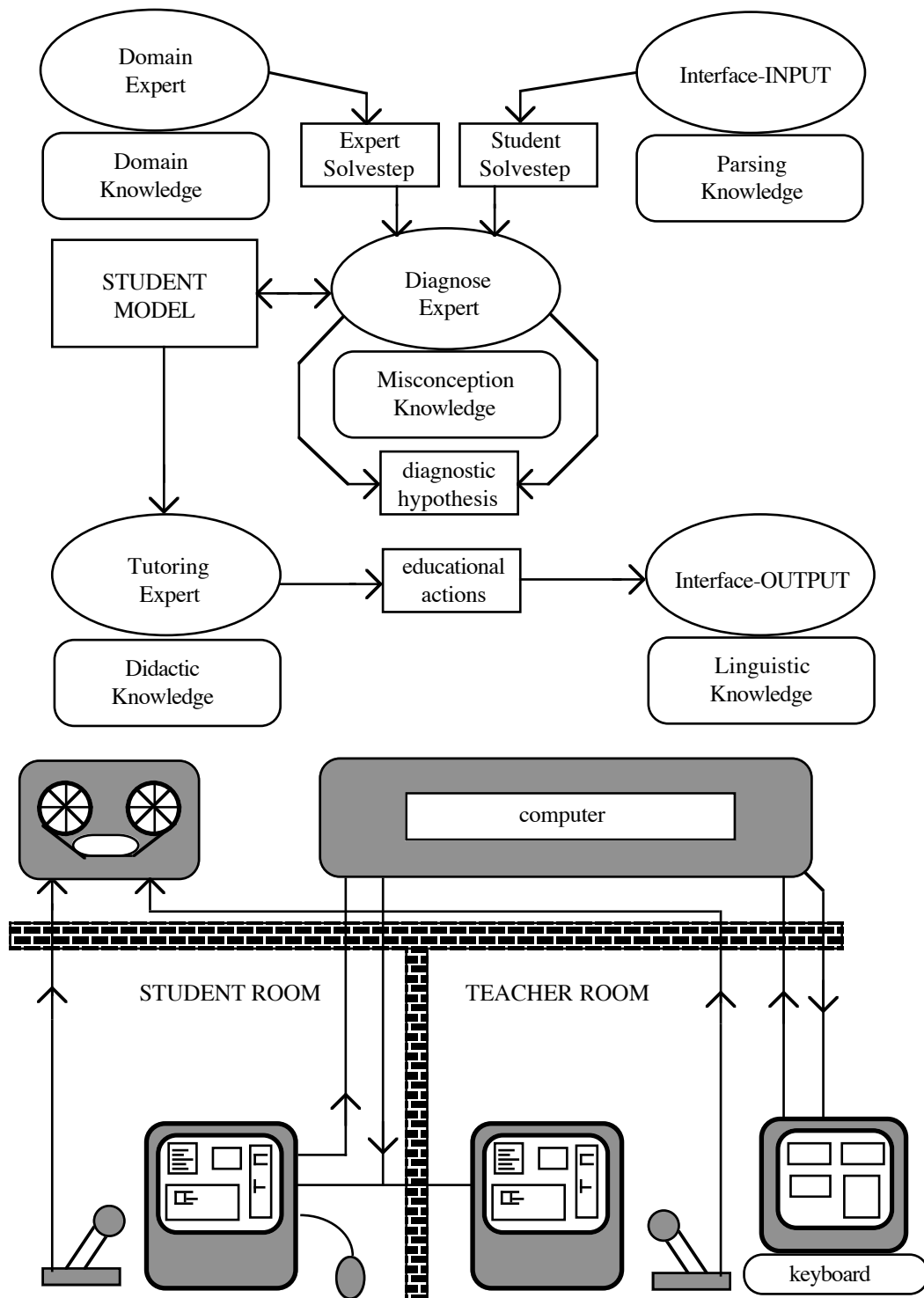
given to the elicitation of knowledge concerning the craft of teaching from expert-teachers. However we found this a very inefficient route to take. This might be due to the difficulty to find teachers who are experts in individual coaching. Or it might be that this didactic knowledge is so 'automated' that is not possible to elicit it using techniques based upon the analyses of thinking aloud protocols. Whatever it may be, our conclusion was that we need another approach to find the optimal teaching interventions for each specific coaching context. It has been realized that an 'Intelligent' tutoring system in fact is at least the implementation of a complete theory of individual learning. So it appears that a more fundamental approach to the problem of the lacking didactic knowledge is through the study of individual learning. Thus recent research focusses on the student rather than on the teacher. This does not imply that 'intelligent' tutoring systems are only for the very far future (after we have found the ultimate theory of individual learning). There is a growing feeling that there might be a set of didactic heuristics which is of a more general nature, or in other words, less context (specific student model) dependent. These heuristics represent a part of the didactic 'intelligence' of the teacher. Implementing them in a computer coach would result in a coach which might classify the learner into one of a few global categories and use this classification to base its strategies on.

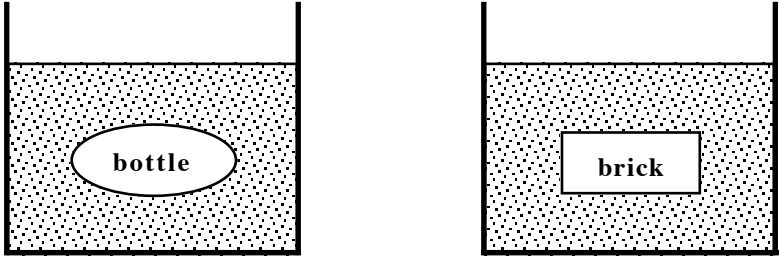
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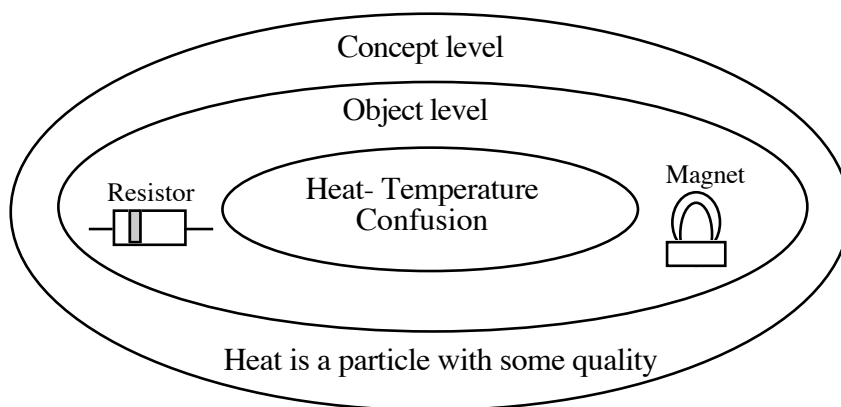


Figure Captions

figure 1: the architecture of the computer coach.

figure 2: The MUSPA experimental set-up

figure 3: example of qualitative (mental model) question

figure 4: Postulated Mental Models underlying the Heat-Temperature confusion

Biographies

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