Towards a Methodology for the Design of Intelligent Tutoring Systems

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Abstract. The present article proposes a methodology for the construction of intelligent tutoring systems that can be applied to any case that implies the design of a system intended for training advanced engineering students in the operation and maintenance of mechanisms. The article offers premises for the design of the modules of knowledge domain, student and tutor, and describes control strategies implemented as meta-rules.

1 Introduction

Intelligent tutoring systems (ITS) started to be developed in the 80's, designed with the idea to provide knowledge with base in some form of intelligence in order to guide the student in the process of learning [Urretavizcaya, 2001; Sancho, 2002]. An intelligent tutor is a software system that uses techniques of artificial intelligence (AI) to represent the knowledge and interacts with the students in order to teach it to them [VanLehn, 1988]. To this definition, [Giraffa *et al.*, 1997] adds the consideration of different cognitive styles of the students who use the system according to Cern [2002]. In the 90's, with the advances of cognitive psychology [Norman, 1987; Gardner, 1988], neurosciences and the new paradigms of programming [Pressman, 2002; Pfleeger, 2002], ITS have evolved from a mere instructional proposal [Cruz Feliú, 1997] towards the design of environments of new knowledge discovery and experimentation [Bruner, 1991; Perkins, 1995; 2002] according to a constructivist vision of learning processes. In spite of these achievements, ITS have still not received a generalized adoption due to the complexity implied in its design, which has limited ITS practical application. The development of STI was stuck by the lack of maturity in the development of the human cognition area and therefore it was not possible to model it computationally since the complexity of the models involved required a high cost of calculation.

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2 Foundations for a Intelligent Tutoring Systems Methodology

2.1 Structure of the Intelligent Tutoring System

An Intelligent Tutorial System for training in the operation and maintenance of mechanisms consists basically of three models that communicate with one another [Kearsley, 1987]. With the purpose of obtaining a suitable operation of the ITS in reparation of mechanisms, the models of the mechanism, the student and the tutor must accomplish a suitable interaction. Therefore, it will exist a set of rules [García-Martínez and Britos, 2004] that define when and how these models are used. These rules constitute a meta-model in the sense that they control the basic models and their associate rules. The meta-model has the required functionality to activate and deactivate the basic models. As an example, the rules that can be expected to be contained in the meta-model may have the following form:

```
IF      The student has finished an specific item
AND     The tutor has little confidence in its own
        assessment on the student knowledge about that
        specific item
THEN    The tutor will interrogate the student exhaustively
        on the specific item
```

2.2 The Knowledge Domain Model

A model can be understood as an entity that copies the characteristics of an object, process or concept of the real world. In fact, a model is an abstract representation of some type of mechanism. It is abstract in the sense that it really does not exist, it is something that is created in the border of a computational program. In order to be able to construct a model of a mechanism, it must be possible to decompose the mechanism in its constituent parts. That is to say, the mechanism to be modeled must have identifiable parts in which it can be decomposed. This way, the behavior of the mechanism can be described through the behavior of its parts. This description includes from the intrinsic form of operation of each component up to the way in which a given component interacts with the others. In this work, qualitative models will be used more than quantitative, that is to say, that the relations among parts are described more in terms of the qualities of the constituent entities than of mathematical expressions that are representative of the operation way of these entities. This conception is more related with the way in which the human beings seem to approach the problems in their daily interaction with the every day world. In this way, a person can know when he or she is safe to cross a street without the need to construct mentally a mathematical model in order to calculate the trajectory of the vehicles that approach to him or her. The proposed methodology to model the knowledge domain when this one is referred to a mechanism consists of the following steps:

- Step 1. Identify the components which make up the mechanism

- Step 2. Identify the relations among the components of the model
- Step 3. Specify the rules of operation of the model
- Step 4. Evaluate the model

2.3 The Student Model

The design of the student model should be centered around the questions: What is desired that the student knows about the mechanism?. What types of knowledge must have a student to be able to solve a problem of operation or repair of the mechanism? [Barr & Feigenbaum, 1983]. It is evident that, in some way, the student must know how the mechanism works. The parts and components of the mechanism are the things that make it work.. Therefore, the student must have knowledge about:

- The components of the mechanism
- The operation of the components of the mechanism
- The interrelation between the components of the mechanism
- The operation of the mechanism

If a student chooses to examine a particular component, then it is assumed that the student knows something about that component. Given the context of the problem, the selection of a component is a kind of confirmation or disconfirmation that the student understands what the component does and how it relates to the operation of the mechanism. Every time the student checks, manipulates or examines a component, this tells what he or she knows or does not know about the operation of the mechanism. In order to make inferences about what the student knows, it is necessary to make assumptions about the meaning of student actions. These interpretations constitute the central part in the development of the student model in the design of an intelligent tutoring system:

Step 1. Identify the knowledge that the student has acquired concerning the components that integrate the mechanism.

Step 2. Identify the understanding level that the student has acquired in relation to the functionality of the mechanism and how its components contribute to achieve it.

Step 3. Identify the strategies used by the student to solve the problem and to approach suitably the processes necessary to carry out the reparation of the mechanism.

2.4 The Tutor Model

The instructional model or model of the tutor [Sierra, 1999; Sierra *et al.*, 2001; 2003] is a representation of the methods that will be used in the intelligent tutor to provide information to the student. This model is complex because it is thought to direct the student in his or her process of learning and to carry out adjustments in this direction automatically as the student makes progress. In a practical sense, the following problem must be solved when the tutorial module of a system of intelligent instruction is constructed: the student is manipulating the domain model or mechanism and the student model is making inferences on the basis of these manipulations. The tutor must then make use of this information in order to provide useful information to the student. In a more general form, with the object of being able to correctly define the operation of the tutorial module, it must be possible to answer the following questions: When is it necessary to instruct? What type of instruction must occur? Therefore, the proposed methodological steps for the design of the tutor model are the following ones:

Step 1. Analyze the student model in order to clearly define which are the actions that he or she can perform.

Step 2. Interpret the actions defined in Step 1 in terms of the type of knowledge that the student must have in order to carry out these actions in a correct way.

Step 3. On the basis of the different types of knowledge identified in Step 2, determine the appropriate strategies of instruction so that the student incorporates significantly this knowledge into his or her cognitive structure.

3 An Example of Intelligent Tutoring System in Mechanism Reparation Domain

3.1 The Student Model

On the basis of the considerations carried out in previous theoretical analysis with respect to what the student model should be and the proposed steps in order to achieve it, the following rules are defined in order to describe how student actions can be modeled:

3.1.1 Assessing the Student's Understanding of the Mechanism Through a Single Student Action

An assessment rule can be expressed in terms of a subsumption analysis, which may be formulated as follows:

```
IF     in the model of the mechanism, the inferred path from
       source x (the point of examination or manipulation) to
       the target  y (the point where the fault occurs)
       subsumes a sequence of path elements from source x to
       target y

THEN   there is evidence supporting student knowledge of the
       inferred path of the mechanism.
```

3.1.2 Assessing the Student's Understanding of the Mechanism Through a Series of Actions

Concerning this aspect of analysis, the following rules can be formulated:

```
IF      a student's action examines a component in the model
        of the mechanism that is closer to the target in
        terms of physical distance and evidence
THEN    there is positive evidence that the student has
        knowledge of the mechanism
IF      a student's action examines a component in the model
        of the mechanism that is physically more distant and
        is adding negative evidence to the assessment of the
        student knowledge of the mechanism
THEN    there is negative evidence that the student has
        knowledge of the mechanism
```

3.1.3 Assessing the Student's Problem-Solving Process: Divide and Conquer

The rule can be formulated as follows:

```
IF      there is evidence (by showing that the student is
        manipulating components that belong to a different
        path of inference in the mechanism model) that a
        student is using a divide and conquer approach to
        problem solving
THEN    there is increased evidence that the student has
        understanding of some problem-solving methodology
```

3.1.4 Assessing the Student's Problem-Solving Strategy: Sequential Analysis

The following rule can be defined in terms of the possible paths of inference shown in the mechanism model:

```
IF      a student's sequence of actions follows a
        breadthwise, depthwise or spiralwise path through the
        mechanism,
THEN    there is evidence that the student is using a
        sequential strategy to diagnose the problem
```

3.1.5 Assessing the Student's Knowledge of Components

The rule covering this aspect of analysis can be stated as follows:

```
IF      a student examines component x
AND     then in sequence examines the sources of component x
        (the components that feed component x)
AND     then in sequence examines the sinks of component x
        (the components that are fed by component x)
THEN    there is evidence supporting that the student has some
        understanding of component x and its relation to other
        components
```

3.1.6 Assessing Student Use of the Troubleshooting Guide

The rule in this case can be enunciated as follows:

```
IF      the number of times that the student uses the
        troubleshooting guide follows a downward trend over
        time,
THEN    there is evidence that the student's knowledge of
        problem solving and the mechanism is increasing over
        time
```

3.1.7 Assessing Student Repetitive Actions

In this case, the following rule can be formulated:

```
IF      the count associated with the performance of any action
        is over a specified threshold
OR      the sequence of actions results in an identifiable
        pattern of actions
THEN    there is evidence that the student is repeating actions
```

3.2 The Tutor Model

The preceding section described a student model containing seven rules. These rules can be roughly classified as shown in Table 1. The partitioning of the rules into three categories allows the instructional model to address three distinct kinds of knowledge and assist students while they are interacting with the tutor [Pozo, 1998; Pozo Municio; 1999]. As Table 2 shows, tutoring or instructional strategy can be organized around these classifications.

Rule	Description	Classification
R1	Infer knowledge of the mechanism from a single student action	Mechanism Knowledge
R2	Infer knowledge of the mechanism from a series of student actions	Mechanism Knowledge
R3	Is the student using a divide and conquer problem-solving strategy?	Problem-solving Knowledge
R4	Is the student using a sequential problem-solving strategy?	Problem-solving Knowledge
R5	Does the student understand components?	Component Knowledge
R6	Is the student using the troubleshooting guide?	Problem-solving Knowledge
R7	Is the student performing repetitive actions?	Mechanism Knowledge / Problem-solving Knowledge

Table 1. Student Model Rule Classifications

Rule(s)	Classification	Instruction
R5	Component Knowledge	Provide the student with instruction about the function of a specific component
R1, R2	Mechanism Knowledge	Provide the student with instruction about how the mechanism works and the relationship between components
R3, R4, R6, R7	Problem solving knowledge	Provide the student with instruction about problem solving methods that would be useful

Table 2. Summary of Student Model Rule-Based Instructional Strategy

This organization of student model rules and their relation to instruction assumes that these three kinds of knowledge are important in the process of diagnosing and repairing mechanisms. Of course, other kinds of knowledge might be appropriate for other kinds of domains and problems. Based on the idea that the data from the student model is an indication of a particular problem, a series of instructional model tutoring rules may be formulated:

Rules referred to *Component Knowledge*

```
IF      the student model indicates there is a possibility
        the student has a deficit of component knowledge
AND     the assessment is above a specified threshold
THEN    provide first-level instruction to the student about
        relevant components

IF      the assessment is above a second specified threshold
THEN    provide second-level instruction to the student about
        relevant components
```

Rules referred to *Mechanism Knowledge*

```
IF      the student model indicates there is a possibility
        the student has a deficit of mechanism knowledge
AND     the assessment is above a specified threshold
THEN    provide first-level instruction to the student about
        relevant portions of the mechanism

IF      the assessment is above a second specified threshold
THEN    provide second-level instruction to the student about
        relevant portions of the mechanism
```

Rules referred to *Problem Solving Knowledge*

```
IF      the student model indicates there is a possibility
        the student is problem solving using a sequential
        approach
AND     the assessment is above a specified threshold
THEN    provide instruction to the student about alternative
        methods of problem solving

IF      the student model indicates there is a possibility
        the student is problem solving by continuously
        referring to the technical reference
AND     the assessment is above a specified threshold
THEN    provide instruction to the student about using the
        technical reference manual less

IF      the student model indicates the possibility that the
        student is performing repetitive actions
AND     the assessment is above a specified threshold
THEN    provide instruction to the student about trying
        different actions to avoid repeating the same actions
```

4 Conclusions

The main contribution of the present communication can be seen in the guidelines given for the construction of intelligent systems to instruct and train students in the operation and repair of mechanisms. The scope of the article goes beyond the methodologies suggested in the bibliography for the construction of intelligent tutors, entering in the details of the effective implementation of this kind of systems.
The motivating effect of technology in education is verified when it is correctly applied to the generation of relevant experiences of learning. In addition, the use of simulations -and mainly with respect to the operation and maintenance of mechanisms- will allow that students trained with these technologies develop suitable mental models with high possibilities of transference to real contexts and situations. Nevertheless, it is highly recommendable that the proper techniques of educational research are applied to evaluate the effectiveness of the proposed tool, which totally justifies the formalization of later studies in this direction.

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