DEVELOPMENT OF AN INTELLIGENT TUTORING SYSTEM OF GENERALIZED SUPPORT FOR DIFFERENTIATED LEARNING

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Abstract

In this work we present a computational system for learning support called SAGE (Sistema de Apoyo Generalizado para la Enseñanza Individualizada) designed to offer a teaching plan for each student according to their skills and knowledge based on a taxonomy of learning objectives. To achieve it, a content map and the Bloom's Taxonomy were used. The content map organizes subjects from the general to the particular through a Morganov-Heredia matrix where dependencies are established and the existent relationships between the course subjects are represented. The representation of skills and knowledge is based on the first four cognitive levels from Bloom's Taxonomy, it is obtained from a diagnostic test and updated according to the advance of the students. The system consists of three models that were created according to the object-oriented methodology: the student model, the teacher model and the interface model. The student model takes the lessons and consults their evaluations, the teacher model registers students to the course and follows up on their progress, and the interface model provides a simple interaction with the users, keeping the student's attention during the lessons and facilitating the query of information to the teacher. Our final system is content-free, integrates some support tools like games and practice exercises and allows students and teachers to check the progress of the course by comparing the scores with the group average, showing positions inside the group, median and standard deviations, as well as charts that show progress from one chapter to another. We also propose three improvements for the system: a clustering analysis to the cognitive characteristics of the students for determining grouping profiles, the Bayesian Knowledge Tracing method based on those profiles so that progress depends on the probabilities of students having the required knowledge but failing in the test or not having the knowledge and guessing the answers and the substitution of Bloom's Taxonomy by Marzano's Taxonomy since the last one takes into account important aspects as metacognition as a first approach to learning.

Keywords: Intelligent Tutoring Systems, Bloom's Taxonomy, Individual Teaching, Marzano's Taxonomy, Bayesian Knowledge Tracing.

1 INTRODUCTION

The use of computational systems as helping devices for instructional strategies started since the 50s [1]. Some of their objectives were: teaching computer programming, use of software, strategies for problem resolution, and educational games designed to make learning an enjoyable experience. The first computational systems that promoted the learning concepts were named as Computer-Aided Instruction (CAI) which showed a text with questions to the student and they had to provide a brief answer and a set of instructions to let the system continue with the next questions. The answers provided by the student were evaluated by the system according to specific patterns, this way the student programmed their own path during the revision of the material.

During the 70s some Artificial Intelligence (AI) techniques were added to CAI design [2] such that a new type of tutoring systems named Intelligent Computer-Aided Instruction (ICAI) was born. The development of ICAI allowed the introduction of teaching material to analyze student's performance after the application of the individual tutoring strategies. At the end of the 70s, ICAIs were rebranded as ITS (Intelligent Tutoring Systems).

ITS are dynamic and adaptive systems for personalized instruction based on students' characteristics and behavior that result from the union of knowledge from various fields such as: AI, cognitive psychology and educational research [3]

The architecture of an ITS is composed by four modules:

- Domain model: It contains knowledge about the subjects that must be learned. It is also called Knowledge model.

- Student model. The use of student models in ITS arises because these systems must work with uncertain and incomplete information about the students. The process of instruction is adapted to the students' needs.
- Instructional model. It defines the teaching and tutorial strategies. It is also called Teacher model or pedagogical module.
- Interface model. Is the media that allows the interaction between the user and the computational system.

Problems concerning computer-aided education have been addressed almost exclusively by computer specialists, who, although they dominate their field, do not know what specific problems may arise when integrating these new technologies into processes for educational purposes.

We have implemented a system in which we integrate computational tools with a taxonomy of educational objectives. Our emphasis is on the design and development of the modules involved in the teaching-learning process that allow interaction with the student and the teacher.

2 METHODOLOGY

SAGE's design was carried out in two steps: the design of the system, in which decisions were made about the environment in which the system will be implemented and the design of objects, in which the models developed during the analysis were refined. Three models were developed according to the object-oriented methodology: the student model, the teacher model and the interface model. A content map and the Bloom's Taxonomy were used to organize the courses and to implement progress control through them according to their skills and knowledge.

2.1 System models

Every model was designed in three steps, first with a static structure where the classes that compose it must be identified, then with a sequence of interactions between objects, which allows us to identify what each class does and finally with a representation that shows how the data is transformed when going through processes. Below we have a description of each model:

2.1.1 Student model

It consists of three sub-modules: the initial student model that is generated from the results of the diagnostic test, the standard student model that is generated from the results of the group at the end of the lessons, and the ideal student model that the teacher proposes at the beginning of the course based on the percentage of performance required for their students.

2.1.2 Teacher model

The teacher registers all students with their personal data and their corresponding keys, so that when a student wants to enter the system is identified through this key. In addition, the teacher can follow the development of the course to check that the lesson is correctly formed, can keep track of the students consulting statistics and reports on grades, performance and progress of students throughout the course.

2.1.3 Interface model

The interface provides a simple interaction between the users, maintaining the attention of the student when taking the lessons and facilitating the query of information to the teacher.

2.2 Content map

In order to articulate and structure the elements of the thematic index, dependencies must be established and the relationships between the topics of the course must be represented. Thus, an adequate organization of the knowledge to be transmitted will be achieved and properties that will make the content of the course solidly structured to achieve greater retention and assimilation will be identified.

To achieve those goals we used a content map based on the technique of Morganov-Heredia [4] that organizes knowledge from the general to the particular, through a table where the dependence between the different subjects is represented. In this way, if the student wants to consult a later topic that is not related to the one they are currently studying, they can do so, but if there is a dependency

between topics, they will not be allowed to see it. Figure 1 shows an example of a dependency table, in the first column the lesson identifier is shown, in the following three the lessons are arranged according to the chapters, topics and subtopics, in the last column the dependencies between lessons are shown (if there is no dependence relation a “-1” appears).

id_tema	capitulo	tema	subtema	depende_de
0	0	0	0	-1
1	1	0	0	-1
2	1	0	0	-1
3	1	1	0	-1
4	1	1	0	-1
5	1	1	0	-1
6	1	2	0	-1
7	1	2	0	-1
8	2	0	0	-1
9	2	0	0	-1
10	2	0	0	-1
11	2	1	0	8,9,10
12	2	1	0	8,9,10
13	2	1	0	8,9,10
14	2	2	0	11,12,
15	2	2	0	11,12,
16	2	2	0	11,12,
17	2	2	0	11,12,
18	2	2	1	15,16,
19	2	2	1	15,16,
20	2	2	1	15,16,
21	2	2	2	15,16,
22	2	2	2	15,16,
23	2	2	2	15,16,
24	2	3	0	8,9,10
25	2	3	0	8,9,10

Figure 1. Example of a dependency table.

2.3 Bloom’s taxonomy

Benjamin S. Bloom et al [5] found that behavior is composed of three main dimensions: cognitive, affective, and psychomotor. They also proposed a taxonomy for the educational objectives in the cognitive domain which operationalizes theoretical recommendations and put them inside a thinking process hierarchy which helps to select, describe and evaluate what is going to be taught. To provide a structure to the cognitive domain, the authors divided them in six categories:

- Knowledge: Involves all those actions that consist on memorize, the student repeats the communication in the same way it was presented to him/her.
- Comprehension: Is to understand the message inside the communication process. The student must interpret the message or identify the same information that was presented to him/her but in their own words.
- Application: Is the transference of acquired knowledge to similar or almost new situations, this means, to make generalizations. Application involves knowledge possession as well as the ability to put it into practice.
- Analysis: Is to fraction knowledge in their constitutive elements so the relative hierarchy of ideas appears clearly and the existent relationship among them is expressed explicitly.
- Synthesis: Include all actions in which the student combines various elements to create an original product. It means the reunion of the elements and parts to form a whole.
- Evaluation: Consists in judging if a determined set of knowledge satisfies or not a specific criterion. It means also the comparison between to contents with a determinate purpose, through the reasoning process.

Table 1 shows a proposal to evaluate those levels through different types of questions. SAGE uses the first four levels of Bloom’s Taxonomy.

3 RESULTS

The system was implemented through the Visual Basic language, a relational database managed by Microsoft Access was used for data storage, and the Crystal Reports tool was integrated for report generation. Below we describe some characteristics of our final system:

Table 1. Correspondence between strategies and cognitive levels

Type of question	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Brief answer	✓	✓				
Completing	✓	✓				
Multiple option	✓	✓	✓	✓		
Matching	✓	✓				
Alternative answer			✓	✓		
Arranging	✓					
Essay			✓	✓	✓	✓

3.1 General Content-Free Architecture

A general architecture was defined contemplating the separation of the teaching elements and the database that store the content of the subject. This has the advantage that the same architecture can be used to assist in the instruction of different subjects, as long as these subjects meet the following characteristics:

- Descriptive structured information
- Procedural information
- Information suitable for be classified according to Bloom's Taxonomy

Our methodology was applied to a physics course for high school. The different types of sources that we have were classified as follows to define the cognitive levels of Bloom's taxonomy:

- Definitions as knowledge
- Text as comprehension
- Exercises and formulas as application
- Examples and descriptions as analysis

3.2 Diagnostic test

When students enter the system for the first time, they must present a diagnostic test to detect their abilities and deficiencies in terms of the four cognitive levels that will be stimulated by the system: knowledge, comprehension, application and analysis. This serves as the basis for generating the initial student model. The test consists of ten questions, randomly selected from the question bank, stored in the corresponding table.

3.3 Statistics

It is important for both the teacher and the student to have an easy way to analyze and interpret the results. In this case, it was decided to show some statistical values with which the student and professor can see the development of the course, in relation to the grades, performance and tools used.

Through the statistics of grades of different tests and performance at different cognitive levels, students will be able to observe their progress during the course. Figure 2 shows one of the performance statistics, which belongs to the application level, where the change of this level from one chapter to another is observed through bar graphs. In addition, the average and standard deviation of the group are shown.

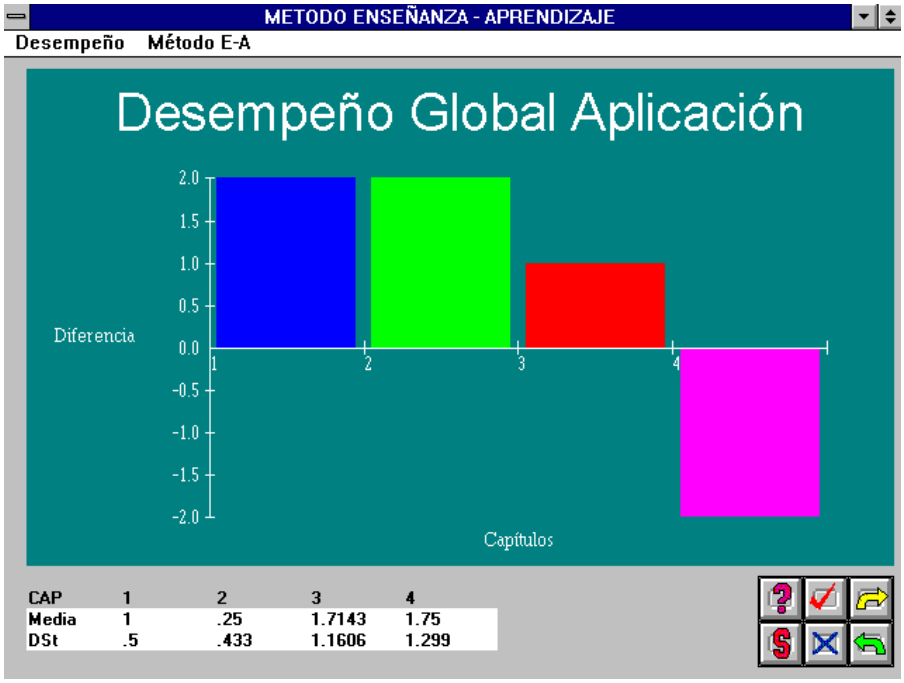

Figure 2. Performance screen of a student.

In the same way that it is important for the students to see their performance, for the teacher it is of vital importance to keep track of the group in general or of a specific student, for this it is possible to have access to statistics and reports that will allow to see the grades of the students, their performance and the location of the students within the course.

The teacher can consult the performance of each student through the chapters, either by means of bars that represent the changes in performance from one chapter to another, or the grades of each chapter while the mean and the standard deviation of the group appear, as shown in Figure 3. Additionally, the teacher can see the information in the form of a report, in a table where the grades by chapter of all the students are shown.

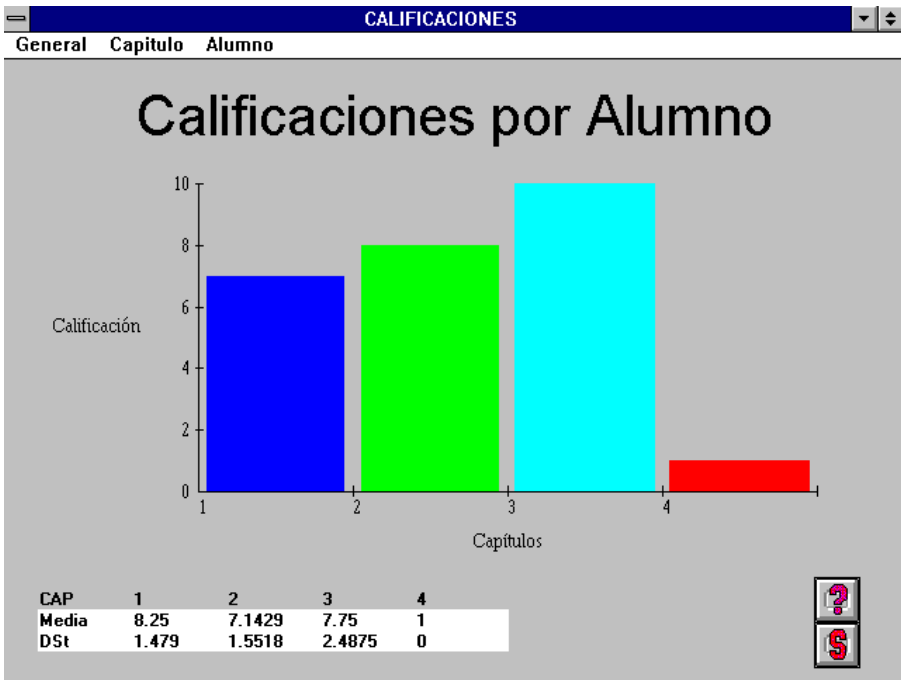

Figure 3. Performance screen for the teacher.

3.4 Additional tools

Within any learning system, it is important to use tools that help the student improve their performance. In SAGE, two tools were included for this purpose: practice exercises and games.

3.4.1 Practice exercises

At any time, the student can choose to perform practice exercises, when the subject includes them. Helping directly to improve the students' abilities. The system has the table of exercises, where exercises of the different chapters are stored so that the student can consult them.

3.4.2 Games

The inclusion of games was considered because, generally, after a certain time the student tends to lose concentration. With this, the students are given the opportunity to get distracted a little, since when they enter the game option they can only stay in it for a short time and they will not be allowed to select this option again until the next session. The game that was incorporated into the system is the hangman.

4 CONCLUSIONS

There is no taxonomy of educational objectives valid for all schools and all cases. This is mainly due to the fact that the methods of teaching and learning evolve day by day and cover different aspects of the processes involved. Even though Bloom's Taxonomy is not the only proposal, it allowed us to show the possibility of algorithmically organizing a teaching systematization model, to integrate it into a computational system. A clear advantage of this approach is that the teacher not only puts emphasis on the material that will be exhibited, but also throughout the development of the course, from the planning of the course to the evaluation, which takes place at the end of the course, of the students' performance as of his own.

One of the major contributions of SAGE is that it works as a skeleton that supports the integration of content from a wide range of courses. For this, the tables are filled with information corresponding to the topics of the subject under study, which must have information that can be classified within the different cognitive levels of Bloom's taxonomy.

Another important characteristic of SAGE is the ideal student model, this model represents a point of reference so that the system can determine that both the student (comparing this model with the percentages obtained) and the group (by comparing the percentages of the ideal student model with those of the standard student model), approaches the objectives established by the teacher.

Some teachers express the fear that computers will end up displacing them, while others believe that to be able to use the machine in their educational task it is necessary to obtain a specialization in the area of computing. We consider it of great importance to point out that neither one nor the other occurs. On the one hand, the teacher is irreplaceable, the more intense the use of computers, the more emphasis is placed on the role of the teacher as leader and driver of the students' academic activities; that is, the machine must be seen as a means to facilitate the transmission of a new knowledge cluster. On the other hand, the appearance of new computational tools has allowed designing and implementing friendly interfaces that require a minimum knowledge of computation of both the teacher and the students.

5 FUTURE WORK

To improve our system we propose the substitution of Bloom's taxonomy for Marzano's taxonomy [6] that includes a hierarchical order which is not only based in terms of difficulty, also in terms of the control that some processes have over others. The model presents three mental systems: self-system, metacognitive system, and the cognitive system. When the execution of a new task is required, the self-system is responsible for assessing the importance, the probability of success, the motivation and the emotional response to the task. Depending on these factors the task is accepted or rejected. When the task is selected, the metacognitive system is responsible for the creation of goals to be achieved, later, the cognitive system deals with information processing. The cognitive system is composed of four levels: retrieval, comprehension, analysis, and knowledge utilization, that are organized in a similar way to the first levels of Bloom's taxonomy [7].

A clustering analysis of the cognitive profiles of the students [8] is also proposed, so that, in addition to taking into account the results of the diagnostic tests, the student model will include information on

thinking styles, learning styles, sensory representation systems, etc. The clustering analysis could provide us with key information to include in SAGE different types of reagents according to the characteristics of the students.

Finally, we propose the use of Bayesian Knowledge Tracing method [9] to adapt the navigation routes of each student by calculating the probability that knowledge and skills have been acquired. This is based on the calculation of four probabilities: that a skill is learned prior to take the lesson, that a skill be learned after an opportunity to take the lesson, that a student will guess correctly if a skill is unlearned and that a student will make a mistake if a skill is learned. According to [10], the clustering analysis described above could be useful to estimate these parameters

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