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Methodology for Developing an Intelligent Tutoring System Based on Marzano's Taxonomy

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***Abstract*—**The Mexican educational system faces diverse challenges related with the quality and coverage of education. The development of Intelligent Tutoring Systems (ITS) may help to solve some of them by helping teachers to customize their classes according to the performance of the students in online courses. In this work, we propose the adaptation of a functional ITS based on Bloom's taxonomy called *Sistema de Apoyo Generalizado para la Enseñanza Individualizada* (SAGE), to measure student's metacognition and their emotional response based on Marzano's taxonomy. The students and the system will share the control over the advance in the course, so they can improve their metacognitive skills. The system will not allow students to get access to subjects not mastered yet. The interaction between the system and the student will be implemented through Natural Language Processing techniques, thus avoiding the use of sensors to evaluate student's response. The teacher will evaluate student's knowledge utilization, which is equivalent to the last cognitive level in Marzano's taxonomy.

***Keywords*—**Intelligent tutoring systems, student modelling, metacognition, affective computing, natural language processing.

I. Introduction

THE Mexican educational system faces diverse challenges associated with the quality and coverage of the education, graduation rate, and population diversity. The Education Sector Program 2013-2018 [1] acknowledges that the objective of achieving an education with sufficient quality has not been accomplished, that desertion rates are still high, mainly at the superior level, and that the study materials are not diverse enough. On the other hand, the development of Information and Communication Technologies (ICTs) will allow to increase the online education offer and to diversify the educational care models even when ICTs still has a long way to be fully developed.

Within this context, the integration of ICTs allows the use of different media to transmit knowledge as well as the flexibilization of the educational process Teaching - Learning methods to the educational environment so it becomes crucial. The concept of Virtual University appeared after the innovations offered by ICTs changing traditional pedagogical models through Distance Education, a remote educational model based on the creation and development of different methodological strategies and study materials to enable an adequate relationship between the elements inside the educational model. This modality encourages and is based on autonomous, individual and group study processes.

Technological resources appear as powerful learning facilitators: they allow the student to work with various information networks permanently updated; to get an individual connection with any part of the world; to solve problems collaboratively; to get information about their own progress, to process big databases, and they allow the teacher to monitor the students individually. One of these technological resources is the ITS, which result from the interaction between cognitive psychology, artificial intelligence and computer systems. An ITS is a computational system which uses artificial intelligence techniques to help the Learning-Teaching process in an adaptive way, its main functions include: to provide activities in accordance with the knowledge and skills of the student to foster significative learning, and to provide personalized feedback to stimulate the performance of subsequent tasks, thus avoiding frustration and discouragement due to unknown errors [2].

ITS offer multiple ways of incorporating technology to teaching and they offer the opportunity to change the educational field, however, it is important to think in terms of integration. The pedagogic and didactic principles that support the educational processes must provide the necessary space to incorporate the tools provided by technology looking for the development of better learning and teaching ways. At the same time, it is necessary to define which tasks are more feasible to be automatized and which tasks can be left to the teacher, thus helping to reach a high quality educational process.

This work proposes a methodology to update an ITS named *Sistema de Apoyo Generalizado para la Enseñanza Individualizada* (SAGE) [18]. The project aims to add a shared control between the student and the system over the navigation within different activities, thus fostering metacognitive skill improvement and monitoring the affective status of the students providing indicators that will provide information to the teacher to the continuous improvement of the classes.

II. Related Work

In recent years three major research lines have been developed within ITS field. Table I shows some examples of works related with every line:

1. Determination of suitable difficulty levels for each

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student, identifying the ideal level of complexity that each task must have. Some works have been used Bayesian Networks for identifying differences in reading and use of concepts among students and for studying the effects of student-machine shared control in the selection of reagents [3], [4], Artificial Neural Networks for determining the level of difficulty of the tasks of a process [5] and Formal Analysis of Concepts for determining the appropriate type of feedback to solve the tasks of a process [2].

TABLE I
RECENT WORK ABOUT ITS

Line	Objectives	Techniques	Works
Determination of difficulty levels for each student	Identify differences in reading and use of concepts among students	Bayesian Networks	[3]
	Study the effects of student-machine shared control in the selection of reagents	Bayesian Networks	[4]
	Determine the level of difficulty of the tasks of a process	Artificial Neural Networks	[5]
	Determine the appropriate type of feedback to solve the tasks of a process	Formal Concept Analysis	[2]
Modelling student's knowledge and interaction using natural language processing	Knowledge construction based on the dialogue with a machine	Semantic Networks, ontologies and NLP	[6]
	Model of the user's cultural heritage	Semantic Networks, ontologies and NLP	[7]
	Implementation of educational assistants that interact with students	Semantic analysis and NLP	[8]
Monitoring student's emotional states	Adapting hypermedia environments and motivate metacognition	Eye tracking	[9]
	Determine affective responses to specific problems	Facial recognition and measurement of the skin conductance	[10]
	Monitoring of emotional responses and levels of difficulty during reading	Acquisition of photoplethysmographic signals	[11]

TABLE II
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			✓	✓	✓	✓

2. Modelling of student's knowledge through semantic networks and ontologies, using Natural Language Processing (NLP) techniques as a medium of interaction. Examples of these works include knowledge construction based on the dialogue with a machine, modeling of the user's cultural heritage and implementation of educational assistants based on artificial intelligence that are in charge of interacting with the students solving their doubts [6]-[8]
3. Monitoring of students' emotional states. In these studies it is common the use of techniques that incorporate additional devices that function as sensors, some examples are: eye tracking for adapting hypermedia environments and motivate metacognition [9], facial recognition and measurement of the skin conductance to determine affective responses to specific problems [10], and acquisition of photoplethysmographic signals for monitoring of emotional responses and levels of difficulty during reading [11].

An ITS was developed at Tecnológico Autónomo de México (ITAM) [18] in 1995, best known as SAGE. This system is based on the use of a content map where knowledge is organized from the general to the particular and where the subject dependencies are shown in a table. This allowed to join and order the elements of the subject index inside a structure, in order to define the relations between the subjects of the class and to allow them to navigate between lessons without risking a student to get a lesson dependent on concepts that he/she has not learned yet. Lesson planning is based on Bloom's Taxonomy [12]. This tool describes the levels that a student must reach to learn concepts belonging to some area of knowledge. Levels are: a) knowledge, b) comprehension, c) application, d) analysis, e) synthesis and, f) evaluation. Table II shows the proposed strategies to reach each cognitive level. From them, SAGE takes the first three: knowledge, understanding, and application.

This paper intends to take SAGE as a starting point to propose an ITS. This system would incorporate elements of all three axes mentioned above: the first axis, determine the relevant levels of difficulty for each individual, will be developed through the modification of the sequence of the activities that belong to a virtual course. To achieve this, a control shared between the student and the ITS will be developed in order to stimulate the development of student's ability to assess his/ her own progress. From the second axis, the use of natural processing language techniques as a mean of interaction is resumed to achieve the objective of the third axis: to monitor the emotional status of the students through text. The works cited in the third axis have used sensors and have reported good results; however, their use has some disadvantages: most of the time, it is necessary to use non-conventional devices [13] and the presence of them could have a negative effect over students' responses.

This work will be based on Marzano's taxonomy [14], which includes metacognition and consciousness of the self, levels excluded from Bloom's taxonomy.

III. Selected Taxonomy

Marzano and Kendall [14] stated that the objective of Bloom's taxonomy was to develop a coding system, whereby teachers could design learning objectives using a hierarchical organization, which proved to be a useful tool for assessment based on objectives because of the level of detail that the tool provides to define the goals. However, one of the most common objections against the use of this tool is the oversimplification of the nature of thought. This approach helped to spread the idea that learning can be represented with a behaviorist, simple and one-dimensional model instead of a multidimensional and constructivist one which is more accurate. The biggest criticism to Bloom's taxonomy is that it conceives a simplified separation between levels according to their difficulty. Because of this, Marzano and Kendall proposed a hierarchical order which is not based in terms of difficulty, but 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 of the task, the probability of success, the present motivation to accomplish it, 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, as well as strategies to fulfill these goals. Later, the cognitive system deals with information processing and the analytical operations such as inference, comparison, and classification. Finally, the success of the task depends on the knowledge that the student has about it [14].

Marzano's taxonomy organizes the previous process in six levels of mental processing where the fifth and sixth levels correspond to metacognition and self-system. Metacognition comprises the tasks of goal planning and self-regulation and self-system comprises the tasks of evaluation of motivation and emotional state. The four remaining levels correspond to the subcomponents of the cognitive system: retrieval, comprehension, analysis, and knowledge utilization. Table III shows correspondence between systems, levels and tasks in Marzano's taxonomy.

TABLE III
Systems, Levels and Tasks in Marzano's Taxonomy

System	Level	Tasks
Cognitive	Retrieval	Retrieval
Cognitive	Comprehension	Integrating, symbolizing
Cognitive	Analysis	Matching, classifying, analyzing errors, generalizing, specifying
Cognitive	Utilization	Decision making, problem solving, experimenting, investigating
Metacognitive	Metacognitive	Specifying goals, process monitoring, monitoring clarity and accuracy
Self-system	Self-system	Examining importance, efficacy, emotional response and overall motivation

IV. Proposal

When comparing both taxonomies, we noticed that the first five levels of Bloom's taxonomy: knowledge, comprehension, application, analysis and synthesis, have complete correspondence with the cognitive system described by Marzano and Kendall. Only the sixth level, which corresponds to evaluation, might have a relationship with the metacognitive system, however, this level just evaluates the result of the process, without including the goals creation mechanism and the planning of to achieve them. Finally, there is no level on Bloom's taxonomy that corresponds to the self-system.

Based on the above, by proposing Marzano's taxonomy as a foundation for the ITS, we can assure that SAGE included the first three levels of the cognitive system (retrieval, comprehension, and analysis) because the system is based on the first three levels of Bloom's taxonomy (knowledge, comprehension, and application) and it have been explained that those levels are equivalent [15].

SAGE does not include the higher levels of Bloom's taxonomy since, according to the authors, the implementation of those levels require the use of natural language processing techniques, point beyond the original scope of the project [18]. The use of those techniques will allow us to monitor students' emotional response and motivation, thus including the last level of Marzano's taxonomy which corresponds to the self-system. To explore the emotional response through text analysis tools such as: Knowledge-Based Techniques [16], Multinomial Naive Bayesian [17], Support Vector Machines [17] and Deep Learning Neural Networks [16] could be used.

The content map included in SAGE will be complemented with a progress control shared between the system and the student [4], so a self-assessment will be constantly requested to evaluate the level of domain of the tasks required for the current level. Then, the system must show the achieved performance and allow or deny the student to move forward in accordance with the estimated and the real performance. It is important to show this difference to the students because if these computations are made without informing them about the accuracy of their estimations, their metacognitive skills will not be developed. For this reason, the fifth level of Marzano's taxonomy that equals the metacognition system is included via the shared control.

The automation of the fourth level of Marzano's taxonomy, which corresponds to the use of knowledge, will require automatic evaluation of texts or techniques of advanced image processing algorithms to implement, since it will be necessary to extract and interpret the information that is going to be evaluated in disjoint documents. The complexity of this task is high for the machine while for the teacher is almost intuitive. On the contrary, the metacognitive and self-system levels are tasks that require a considerable amount of effort by the teacher while the machine can get help from the aforementioned techniques to perform that monitoring in a personalized way. Based on the above, we have decided to leave the level of utilization of knowledge totally in the hands of the teacher. Table IV shows how the different levels of Marzano's taxonomy were assigned.

TABLE IV
ASSIGNATION OF MARZANO'S TAXONOMY LEVELS

System	Level	Assignation
Cognitive	Retrieval	SAGE
Cognitive	Comprehension	SAGE
Cognitive	Analysis	SAGE
Cognitive	Utilization	Teacher
Metacognitive	Metacognitive	New ITS
Self-system	Self-system	New ITS

V. CONCLUSIONS

This article describes the proposed development of an ITS which includes the monitoring of students' metacognitive and emotional aspects through a progress control shared between the student and the system, and techniques of natural language processing. The starting point of this work is a system that is based on knowledge, understanding, and application tasks related to information processing.

Marzano's taxonomy allows considering the following aspects: self-evaluation, planning and motivational and emotional responses. The objective of encouraging students to know their progress and to provide information to the teachers about the way students respond to the activities is achieved by using Marzano's scale. This will allow continuous improvement of the different course based on objective criteria.

To monitor the metacognitive skills and the emotional and motivational responses is more complicated for the teacher than assessing and providing feedback to his/ her students' learning evidences. On the other hand, it is easier for machines to monitor in a concurrent way the progress of students, to compare their results with students' estimations about their progress using various computational tools to track the emotional and motivational aspects, and to recognize necessary patterns to evaluate the content of the course to generate appropriate feedback. For these reasons, our proposal puts the teacher as responsible of monitoring the last level of the cognitive system. This is an example of how technological tools can be used as aids within the educational activity and how a practitioner might delegate some tasks to the machine to focus on others.

The customized progress methodology and the indicators obtained regarding emotional states must be evaluated by a panel of experts in psychology and pedagogy. A satisfaction survey will be applied to the users, students and teachers after they use the system.

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