An Intelligent Tutoring System Architecture for Competency-Based Learning

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Abstract. An Intelligent Tutoring System (ITS) aims to customize teaching processes dynamically according to student's profile and activities by means of artificial intelligence techniques. The architecture of an ITS defines its components where the pedagogical model is crucial, because the ITS complexity will depend on its scope (specific or generic). Our interest is focused on generic ITS that are very complex due to the fact that could be applied to different educational domains. This contribution proposes an architecture for ITS that uses a Competency-based learning pedagogical model, in order to manage the complexity and make them easier to understand, together a diagnosis process for such a type of systems.

Keywords*:* Intelligent Tutoring Systems, Competency-based education, knowledge representation.

1 Introduction

An ITS provides direct customized instruction or feedback to students in their learning processes by means of Artificial Intelligence (AI) techniques, mainly for knowledge representation, managing a teaching strategy like an expert both in the teaching and pedagogical domains in order to diagnose the student learning status. Hence the system should offer solutions, actions, processes that support the student learning process [1].

Due to the fact that, the ITS deals with the teaching purpose about an educational domain such as a course, a module, a subject, etc., together pedagogical criteria [2], they can be classified as *generic* or *specific*. The latter uses pedagogical criteria suitable for a specific educational domain, being such systems limited to just one domain. However the former deals with a multi-domain view and should be able to adapt its criteria to cover different teaching domains and make easier the learning process to the students.

Even though a generic ITS is more flexible, it is also more complex and such complexity implies problems as:

Model comprehension: It is difficult to build a system that joins different theoretical frameworks, evaluation criteria, knowledge representations, heuristics, etc.

Implementation: the model configuration and the interpretation of the different parameters might sometimes become confuse.

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To solve the previous problems this contribution introduces a novel generic ITS architecture and its diagnosis process whose pedagogical model is the Competency-Based Education (CBE) [3], [4], [5]. The joint of ITS and CBE involves innovations in the components, processes and relationships by introducing new features regarding the components of an ITS to fit the CBE model in with it. We will present the knowledge representation of the domain, the student model and the diagnosis process according to the CBE. This architecture provides the teacher a platform that facilitates the implementation of customizing training proposals and tools that improve the performance of generic ITS.

The contribution is organized as follows, Section 2 reviews the main features of an ITS architecture. Section 3 presents the concepts and principles of competency-based education (CBE). In section 4 is introduced the proposal of an ITS model based on competences (ITS-C) and its diagnosis process. Finally we point out some conclusions.

2 Intelligent Tutoring Systems

An ITS is a dynamic and adaptive system for personalized instruction based on the students' characteristics and behavior that involves a combination of various fields such as: AI (expert systems, Bayesian networks, fuzzy logic, etc.), cognitive psychology and educational research. To achieve its objectives the design of an ITS must include an architecture that supports the associated processes. This section reviews a general architecture of an ITS, its knowledge representation and eventually it is presented a classification of ITS according to their scope and pedagogical criteria.

2.1 Architecture

In [6], [7] is defined the general architecture of an ITS by four components: i) domain model, ii) student model, iii) pedagogical model and iv) interface model. These components interact each other to accomplish different functions.

These components are described in further detail below according to [8] and [9]:

Domain model or what is taught? It contains knowledge about the subjects that must be learned. Anderson in [10] asserts that the more knowledge in a domain model the more powerful. The domain models can be classified in:

Black box model: It does not require an explicit coding of underlying knowledge. The domain model has been previously encrypted, being of interest their behavior.

Model based on the methodology of expert systems: It follows the same steps of an expert system. It involves extracting knowledge from experts and decides the way in which it will be codified and implemented.

Cognitive model: The domain model is obtained by abstracting the way in which humans make use of knowledge. This type of model is most effective from a pedagogical point of view, though implementing effort is higher.

Student Model or who is taught? It also implies what the student knows or does not know about the domain. The use of student models in ITS arises because these systems must work with uncertain and incomplete information about the students [11]. Many

ITS infer this model from the student's knowledge about the domain model. The process of instruction is adapted to the students' needs. The structure that stores the student's knowledge status is *his/her own model*, while the update process is called *diagnosis of the student*. Holt et al. [12] extend the classification presented in [13] about the student model proposing the following approaches:

Overlay Model: It represents the student's knowledge about the domain. The student's behavior is compared with an expert. The differences are assumed as gaps in knowledge of the learner.

Differential model: It defines the student's knowledge in two categories, expected knowledge that student should know and expected knowledge that should not know. This approach modifies the previous one representing explicitly the differences between expert's and student's knowledge.

Disturbance model: In this model, student's knowledge is not considered a subset of the expert's knowledge, but it is possible that the student knows some knowledge in different quantity and quality regarding the expert.

Instructional Model or how is it taught? It defines the teaching and tutorial strategies. We highlight three tutorial features that should have an ITS [14]:

- Control on the representation of knowledge to select and sequence the parts that should be supplied to the student.
- Ability to answer students questions about his/her instructional objectives and contents.
- Strategies to determine when the student needs support and how to select the appropriate help.

Interface: It supports the man-machine interaction. Additional efforts are needed to develop this element of the architecture, to make it intuitive and transparent to the student. Burton identifies key issues in the interface design [15]: wishing representation aspects of the domain, level of abstraction and accuracy of representation, order in the presentation of contents, proofing and support tools and assistance, level of control performed by the tool.

Different Intelligent Tutoring Systems are using the advantages offered by Internet, such as Haskell-Tutor [16], WHAT [17] (Web-Based Haskell Adaptive Tutor), ActiveMatch [18], etc.

2.2 Knowledge Representation

An ITS organizes an educational proposal according to pedagogical criteria. These criteria determine the knowledge representation in the domain model, student model and its update process. A common knowledge representation adopted by an ITS is a hierarchical network where nodes are concepts and related concepts are connected by arches or arrows. Generally, this structure may take the form of semantic networks, conceptual maps or Bayesian networks [8], [9]. The relationship among nodes can be of different types: aggregation, part-of, etc.

2.3 Classification of ITS

The customization of the teaching process for each student according to his/her necessities by an ITS is based on the use of training proposals and domains of knowledge (subject, capabilities, professional roles, etc.). Every training proposal is based on the design of a curriculum which might use different approaches that are driven by their teaching and learning views. Consequently the designers must assume pedagogical criteria that underlie the ITS.

The ITS can take different views to implement the pedagogical criteria according to its educational scope that generates a classification into *specific* and *generic* ITS:

1. *ITS for specific domain:* It uses pedagogical criteria suitable for just one specific educational domain, such systems are limited to that educational domain. Therefore, a specific ITS assumes pedagogical criteria adapted to a specific domain, whenever the designer is an expert or worked closely with an expert in the domain model, and the associated processes. This type of ITS does not present problems of implementation, because they suit the specific domain, achieving generally satisfactory results. Some examples are: ELM-ART (Episodic Learner Model Adaptive Remote Tutor) [19], ActiveMatch [18], WHAT (Web-Based Haskell Adaptive Tutor) [17], etc. The main problem of this type of ITS is that its implementation is limited to a single domain.
2. *ITS for generic domain:* An ITS for generic domains is designed to provide a framework to design and implement training proposals for multiple educational domains. Because of this, it could arise a problem when the teacher must adapt various components of the curriculum design to the specifications of the domain model and student model (which will depend on how knowledge is represented in these models). Another issue is the difficulty of producing correct interpretations of the parameters provided by the ITS, especially those ones that use heuristics for student's diagnosis. Some generic ITS are: TANGOW (Task-based Adaptive Learner Guidance on the Web) [20], ALICE (Adaptive Link Insertion in Concept-based Educational System) [21], etc.

3 Competency-Based Education (CBE)

This section reviews concepts about CBE that is the educational model used in our proposal.

The CBE is an emerging curriculum model that tries to satisfy the demands of learning contexts, by the developing competencies, enabling students to act in a complex world in constant transformation, [3]. A competence is the ability to perform effectively in a given situation, it is based on knowledge but it is not limited to it [22]. Competences are complex knowledge and represent the know-how to integrate conceptual, procedural and attitudinal knowledge.

The current importance and relevance of the CBE is showed in Tuning Educational Structures in Europe [5], The contribution of universities to the Bologna process and the Tuning Latin America project. Tuning serves as a platform for developing reference points at subject area level. These are relevant for making programmes of studies (bachelor, master, etc.) comparable, compatible and transparent. Following it is described some key processes and concepts of the CBE such as the curriculum design based on competences and its descriptors.

3.1 Curriculum Design Based on Competences (CDBC)

The Curriculum Design Based on Competences (CDBC) is the process that performs a training proposal based on CBE. The training proposal is organized according to competency norms that are benchmarks to evaluate the performance achieved by students. Such norms contain a set of descriptors that reflect good professional practices that guide the development of competences. The validity of competency norms should have agreed among social actors as government, industry, education system, etc. [4].

3.2 Descriptors of CDBC

The basis of representation of the domain model and student model are the descriptors of the CDBC. Here we revise the set of descriptors that reflect good professional practices and guide the development of competences that integrate competency norms.

Competency unit (cu): It is a main function that describes and groups the different activities concerning the role or profile chosen.

Competency element (ce): It is the disaggregation of a main function (cu) that aims to specify some critical activities. A function (cu) can be specified by one or more competency elements (ce), according to its complexity or variety.

Evidence of performance (evd): It checks if a process is performed according to best practices.

Evidence of product (evp): It is a descriptor of tangible evidence in the results level, when the best practices have been used.

Evidence of knowledge (evk): It is a descriptor about scientific-technologic knowledge that allows the user understands, reflects and justifies competent performance.

4 An Architecture for an Intelligent Tutoring Systems Based on Competences (ITS-C)

In this section is introduced the proposal for the architecture of a generic ITS based on competences (ITS-C) that facilitates the overcoming of the implementation and comprehension problems presented by generic ITS.

It is necessary to establish a link between the use of ITS and the pedagogical model based on competences. To do so, we propose an architecture for ITS-C (Fig. 1 shows graphically) that extends the components of the general architecture presented in Section 2.

In the following subsections the domain and student models together the diagnosis process are further detailed to show the novelties and elements of the new architecture to be consistent with the CDBC approach.

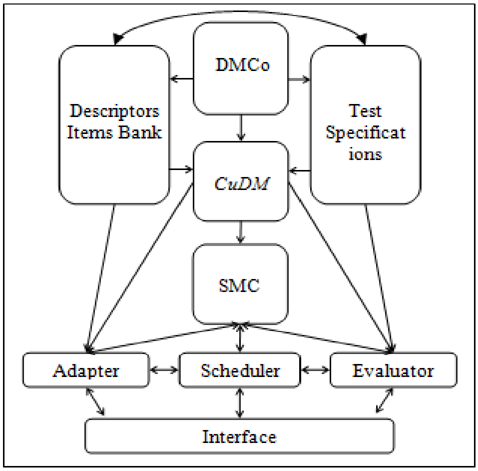

Fig. 1. An ITS-C Architecture

4.1 Domain Model

It contains the expert's competency profile in a knowledge domain. In an ITS-C it consists of four components:

1. *A domain model of competency (DMCo)*: It is represented by a semantic network whose nodes are competence units (*cu*), competence elements (*ce*), descriptors (*evd, evp, evk*) and their relations. In an ITS-C the DMCo does not represent expert's knowledge but the competency profile that is obtained from the functional map and the competency norms.
2. *A curriculum domain model (CuDM):* It rearranges the DMCo according to a teaching strategy that defines the competences associated to a professional profile to perform in different situations. The CuDM is a module based structure, developed from the CDBC of a educational purpose, being each module (M_i) the unit that defines the contents, activities and objectives to learn the necessary skills for solving problems in a professional area. Such skills are inferred from a competence elements whose descriptors are associated to a bank of items used to specify tests that allow the evaluation of a module.
3. *A set of descriptors*: The descriptors associated with the *ce* of the didactic modules are *evd, evp,* and *evk*, that belong to a bank of items.
4. *A bank of problems*: It is associated to the modules of the CuDM and the test specifications provided by the teachers.

4.2 Student Model Based on Competences (SMC)

In an ITS-C the student model of competence (SMC) stores the student's information and its representation in the diagnosis process, by using an overlay model in the semantic network of the CuDM, to evaluate the competences associated to each competence elements (*ce*) belonging to a module M_i (Fig. 2 shows graphically).

The nodes *evp, evd* and *evk* store a probability distribution $P(\theta_{evp} = |\vec{u}_i)$, $P(\theta_{evd} = |\vec{u}_i)$, and $P(\theta_{evk} = |\vec{u}_i)$ corresponding to the level of competency of the student in the respective node. Being θ the student's level of technical-scientific knowledge about the descriptor for a response pattern $\vec{u}_i$ obtained from the responses provided by the student in the test T_s.

Once the components of the CuDM are determined the elements involved in the diagnosis are defined:

1. The items bank associated to the *evk, evp* and *evd* of each *ce;*
2. The tests, T_s, associated to the *ce;*
3. Test specifications that determine the methods for selecting items, end criteria, etc.

Each node ce_i will compute the student's technical-scientific knowledge level about it, θ_{ce_i} (see equation (3)) that aggregates the probabilities for evk_i, evd_i and evp_i that reflects the student technical-scientific knowledge.

Once the distributions of the nodes, ce_i, have been obtained the level of competency for a module M_i is estimated by averaging the values of the respective elements of competence (ce_i).

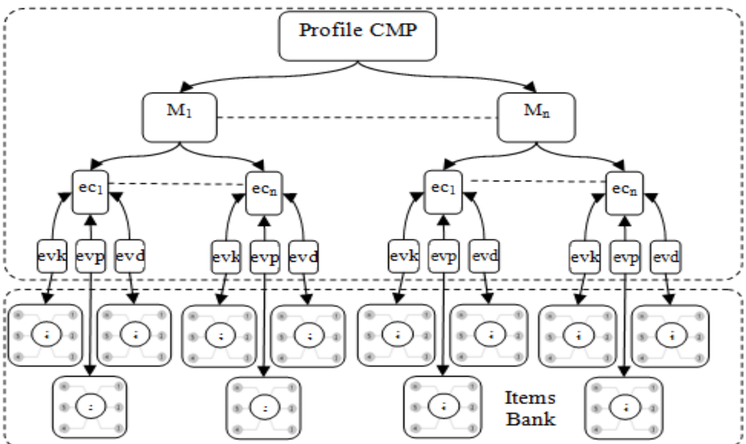

Fig. 2. Modules of a CuDM

4.3 Diagnosis Process Based on Competences

The diagnosis process estimates the level of competence achieved by the student in the didactic modules, M_i, to update the SMC. To do so, our model uses Computerized Adaptive Tests (CAT) [9] with a discrete and non parametric response model that is able to evaluate items with multiple answers. Its main components are:

1. *A response model associated to the items*: It describes the student expected performance according to his/her estimated knowledge. In our case we use the response model based on the Item Response Theory (IRT) [9].

2. *Bank of Items*: The better is its quality the more accurate will be the CAT to achieve the learning objectives. Each item Q_i is associated to the descriptors (evd, evp or evk) that solve, Q_i. And every choice to solve Q_i has assigned a characteristic curve of option (CCO) obtained by a calibration process based on the Ramsay algorithm [23]. Also the model defines the characteristic curve of response (CCR) and of Item (CCI). The former represents the probability that the student answers a given choice according to his/her knowledge and the latter the probability that he/she answers Q_i correctly. Each CCO is represented by a probability distribution noted as, $(\vec{u}_i|\theta_t)$, where each component of distribution represents the probability that the student selects the response pattern $\vec{u}_i$, given their level of competence θ_t.
3. *Initial level of Knowledge:* The initial knowledge estimation is crucial because it determines the CAT for each student.
4. *Criterion for selecting items:* the adaptive mechanism of CAT selects the items that should be solved by the students.
5. *Stop criterion*: The test should end when the student achieves a level of knowledge fixed a priori, though there are other criteria such as a maximum number of items is achieved, etc.

During the administration of a test, the student's knowledge is estimated each time that responds a item. The updating of the distribution of knowledge of the student is carried out using an adaptation of the Bayesian method proposed by [24] that updates the knowledge distribution as follows:

$$P\left(\theta_{ev_t}|\vec{u}_1,..,\vec{u}_i\right) = \begin{cases} \left|P\left(\theta_{ev_t}|\vec{u}_1,..,\vec{u}_{i-1}\right)Po(\vec{u}_i|\theta_t)\right| & if\ Q_i\ asseses\ evd_t, \\ & evk_t\ or\ evp_t. \\ P\left(\theta_{ev_t}|\vec{u}_1,..,\vec{u}_{i-1}\right)\ in\ other\ case. \end{cases} \quad (1)$$

Where $P\left(\theta_{ev_t}|\vec{u}_1,..,\vec{u}_i\right)$ is the a priori student knowledge estimation on evd_i, evp_i or evk_i; and $Po(\vec{u}_i|\theta_t)$ the CCO for the option of the response pattern.

After the updating of the distribution of the nodes *evk*, *evd* and *evp* of the student, the system can estimate the level corresponding to the distribution by using one of the two choices introduced in the CAT [9]:

Expectation a posteriori (EAP), the value corresponding to the level of knowledge is the average of the distribution of probabilities. Formally:

$$EAP\left(P(\theta_{ev}|\vec{u}_n)\right) = \sum_{k=0}^{k-1} kP(\theta_{ev} = k|\vec{u}_n), \quad (2)$$

where *k* represents the knowledge level.

Maximum a posteriori (MAP), the level of knowledge value corresponds to that with the biggest probability assigned, i.e., the mode of distribution. Formally:

$$MAP\left(P(\theta_{ev}|\vec{u}_n)\right) = max\,P(\theta_{ev} = k|\vec{u}_n) \quad (3)$$

The competency level θ_{ce_i} in ce_i is computed by using the values of the nodes evd_i, evp_i and evk_i.

$$\theta_{ce} = k_d P(\theta_{evd} = k_d|\vec{u}_n) + k_p P\left(\theta_{evp} = k_p\middle|\vec{u}_n\right) + k_k P(\theta_{evk} = k_k|\vec{u}_n) \quad (4)$$

where $k_d P(\theta_{evd} = k_d|\vec{u}_n), k_p P\left(\theta_{evp} = k_p\middle|\vec{u}_n\right)$ and $k_k P(\theta_{evk} = k_k|\vec{u}_n)$ are the probability regarding the descriptors *evp, evd* and *evk* and *k* the competency level.

The diagnostic algorithm used is an adaptation of the proposed for CAT [9].

For each answered item the algorithm updates the $P\left(\theta_{ev_t}\middle|\vec{u}_i\right)$ of *evk*, *evd* or *evp*, and checks the stop criterion if it is fulfilled then the value θ_{ce_i} of the ce_i is calculated and updated (by using equation (4)) otherwise it is selected the following item (based on the selection criterion of items established in the test specifications) of the test, repeating the process until fulfills the stop criterion. In [2] we carried out an evaluative study of the algorithm successfully.

5 Conclusions

We have introduced innovations in the architecture of an ITS by presenting a new representation of the domain model, student model, and the diagnostic process based on the pedagogical model Competency Based Teaching (CBT) that is an emerging educational model with a promising the future in global education. Therefore the proposal of an ITS-C architecture based on the principles CBE is a quite interesting because the teachers incorporate into their practice the principles of CBE.

The use of CBE provides a better understanding of ITS-C architecture at the time of its implementation, thus overcoming the problems of ITS architectures based on other pedagogical models.

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