MEDEA: an Open Service-Based Learning Platform for Developing Intelligent Educational Systems for the Web

Mónica TRELLA, Cristina CARMONA, Ricardo CONEJO
Departamento de Lenguajes y Ciencias de la Computación, Universidad de Málaga.
{trella, cristina, conejo}@lcc.uma.es

Abstract. As a consequence of the increasing importance of distance education there is a growing interest in the application of intelligent techniques to existing web-based educational systems. Many researchers are focusing their efforts on reusing high quality educational software and material to take advantage of their sound theoretical foundations and effective teaching strategies. In this paper, an open learning platform for the development of intelligent web-based educational systems is presented. MEDEA[1] is a service-based learning platform that allows using intelligently different integrated learning systems for instruction purposes. To achieve this task, MEDEA provides a common student model and an instructional planner. Learning resources are integrated as web services. Systems developed with MEDEA guide students in their learning process but permit free navigation to better suit their learning needs. The learning platform has been instantiated and evaluated by developing with satisfactory results two intelligent web-based systems for the study of Logic and Agrarian Economy

Introduction

Most of existing adaptive and intelligent web-based educational systems (AIES) are the result of research efforts focused on a particular pedagogical task, learning domain or teaching strategy, such as, for example, ELM-ART [16], or AlgeBrain Tutor [1]. Although less common, we can also find educational web-based tools for generic domains, like CATGlobal [12] or DCG [15]. Given the availability of all these tools, educators and course designers might wish to integrate some of them as resources of their own systems. For example, a teacher might use DCG to develop the instructional material of a LISP AIES, ELM-ART as a drill-and-practice environment for acquiring problem-solving skills, and CATGlobal as a sound evaluation of a student's knowledge. In most cases the systems' modularity is limited, and therefore reusability is almost impossible unless the system is used as a whole.

There are several examples of systems that try to integrate external software components as resources of their own systems. The first attempts can be found in Koendinger [12], Brusilovsky [6], or DeBra [10], who connected two independent systems and defined standard protocols to communicate them. More recently, systems like ActiveMath [11] or KnowledgeTree [5], based on the integration of web-educative services, are being developed.

Therefore, it seems that the next step in the integration of AIES is the definition of learning platforms that allow the creation of intelligent systems offering domain-independence, extensibility and resource reusability and interoperability. Our contribution in this direction is

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MEDEA[2] which is an open learning platform for the development of AIES, based on existing tutorial web systems. MEDEA allows teachers to develop their domain specific web-based systems, and to this end provides curriculum sequencing, student diagnosis techniques, and selection of teaching tasks, whereas the execution of these pedagogical tasks (examples, exercises, tests, etc.) is performed by external tutorial systems (MEDEA *instructional resources*). Unlike AHA, ELM-ART sequels and other architectures, the MEDEA platform is defined to allow the integration, at runtime and even at the cognitive level, of any web-based tool that could be encapsulated as a web service that accomplishes a communication protocol. MEDEA is not based on a fixed set of components; and it is not a particular solution for the integration of two given systems.

1. How MEDEA works

This section is devoted to the description of MEDEA from the student's point of view. Perhaps the best way to illustrate how MEDEA works is to compare it with the behaviour of a personal educational advisor. Imagine that a disoriented student arrives at an educational institution where personal advisors are available. In a personal interview, the student and his/her personal advisor discuss his/her background, interests, preferred learning styles and other relevant educational information. As a result, the advisor can make an informed recommendation of the most suitable courses and teachers available. The personal advisor, who also stays in permanent contact with the student's teacher, keeps a record of his/her results. MEDEA performs this process of educational advising and coaching. Table 1 compares the procedures used for such a process in both learning contexts, and shows that for each action on the part of the educational advisor there is a corresponding action in MEDEA. Useful conclusions (for MEDEA's design) can be drawn from this table: actors of each action are identified, and its inputs and outputs are established.

Table 1. Educational advising in traditional learning and in MEDEA.

	Traditional learning			**MEDEA**		
Instructional step	**ACTOR**	**INPUT**	**OUTPUT**	**ACTOR**	**INPUT**	**OUTPUT**
Asking for advice to study a subject	Student	Subject		Student	Domain model	
Selecting the most adequate topic	Advisor	Student's academic records	Next topic to study	Instructional planner	Student knowledge model	Next topic to study
		Student's personal features			Student attitude model	
Selecting the most adequate teaching style	Advisor	Preferred learning style	A teacher	Instructional planner	Student profile	An instructional resource
		School staff			Instructional resources	
Performing the instruction	Teacher	Message from the advisor, including target topic and other relevant information	Student's results	Instructional resource	Message from the planner, including target topic and other relevant information	Student model of the instructional resource
		Teacher's learning material			Instructional resources' learning material	
		Teacher's syllabus			Instructional resources' domain model	
		Student's background (previous sessions)			Instructional resources' student model	
Updating student knowledge state	Advisor	Student's results from the teacher	Updated student's academic records	Student model	Partial student model from the instructional resources	Updated student model

[2] MEDEA (*Methodology and Tools for the Development of Intelligent Teaching and Learning Environments*)

2. The Architecture of MEDEA

MEDEA is composed of a domain-independent *kernel* and a set of *instructional resources* (IR). Fig. 1 illustrates the architecture and its modules, which will be described in more detail in the following subsections.

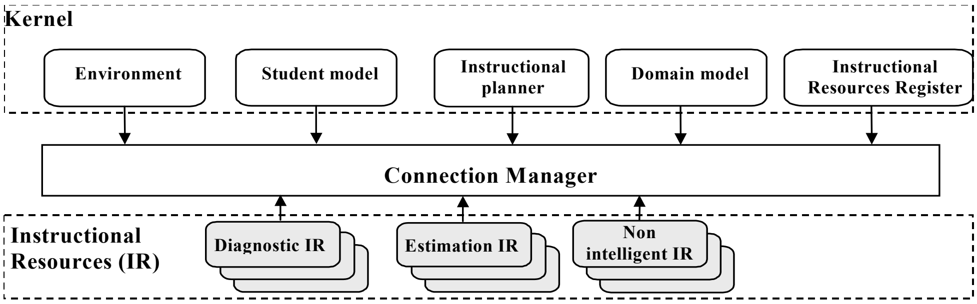

Fig. 1. The Architecture of MEDEA

2.1 Instructional Resources

These are external educational systems for concrete pedagogical tasks (electronic books, simulation systems, assessment tools, etc.). From the point of view of MEDEA, an instructional resource has 1) its own domain model, 2) a development interface for content authoring, 3) a student interface, and 4) its own student model, (which contains the relevant information to be passed to MEDEA).

MEDEA defines three types of instructional resources (IR): 1) *Diagnostic Intelligent IR*, which use some diagnosis process to establish the student knowledge level (i.e. a test system), 2) *Estimation Intelligent IR*, which use heuristics (mainly based on student interaction observation) to estimate the student knowledge level (i.e. an electronic book that stores the percentage of visited pages) and 3) *Non Intelligent IR*, which are systems that do not have a student model and consequently have no need of inferring it (for example a simulation).

Instructional resources offer the following services to the kernel system modules: 1) *init*, initiates the execution of an IR session, 2) *end*, concludes the pedagogical task and requests the *student model updating* service (2.2.3), 3) *new user*, creates a new student model in the IR, 4) *student model*, returns the IR student model.

2.2 Kernel

The MEDEA kernel includes those resources needed for a) guiding student through the curriculum, and b) selecting additional educational tasks for domain learning. These resources are described below.

2.2.1 Environment

It represents the student interface and includes a set of controls (links and buttons) that allow students to a) execute a pedagogical task, b) request an instructional plan or c) consult and modify the student model.

2.2.2 Domain Model

It stores the knowledge about the subject. The standard domain representation in web-based educational systems is the semantic network model [4]. The domain is defined by: a) a semantic network of concepts and the relations between them, and b) the pedagogical knowledge required for the instruction. In order to allow data interchange, OXML (Ontology eXtensible Markup Language) has been used. In this context, it is important to note that the domain is being modelled for pedagogical purposes, and therefore it is not strictly necessary to represent all the possible relations [2]. Thus, only four relations have been included: two of them are pedagogical (*prerequisite_of* and *subtopic_of*) and the other two are classical relations in an ontology definition (*subconcept_of* and *part_of*).

2.2.3 Student Model

MEDEA's student model composed of a *Student Knowledge Model* (which represents what the student knows about the subject) and a *Student Attitude Model* (which represents other student features that are relevant for the instructional process).

MEDEA's student knowledge model is an overlay model divided into four layers: (1) the *estimated model*, which represents what the system guesses about the student's knowledge based on his/her interaction; (2) the *verified model*, containing data obtained from evaluative components; (3) the *inferred model* from the *prerequisite* relationships; and (4) the *inferred model* from *part-of* relationships. The inferred layers are currently supported by two independent Bayesian networks (see [8] for a more complete description and an empirical evaluation with simulated students).

The student model includes the *student model updating* service, that updates the student model whenever the student performs a pedagogical task, that is, every time that an *instructional resource* is executed. *Diagnostic IR* can accurately evaluate student's knowledge about some domain topics. This information then goes to the verified knowledge model. The evaluation of *Estimate IR* is mainly based on student observation. In this case, the available information is used to update the estimated knowledge model. *Non intelligent IR* do not evaluate students in any way, so the student model updating service just informs that the student has executed that task.

2.2.4 Instructional Planner

This module provides guidance during the learning process. The adaptation during instruction is divided into two sub-processes: *microadaptation* and *macroadaptation* [14]. Microadaptation refers to which knowledge unit should be selected next, and macroadaptation determines how to present the selected knowledge.

In MEDEA, microadaptation is carried out by the instructional planner, and consists in selecting not only the concept to be studied but also the most adequate instructional resource to teach said concept. These tasks represent, respectively, the *focus concept* and the *focus pedagogical task* services. The implementation of specific instructional theories (macroadaptation) related to a concrete domain or to a particular pedagogical strategy/task (adaptive assessment, example-based learning, dialog-based reasoning, etc.) is the responsibility of the instructional resources.

When designing a planning procedure valid for any domain, it is difficult to draw conclusions from related work because many ITS sequencing techniques are strongly domain dependent and are based on heuristic rules obtained from the experience of teachers. However, our study of related work has allowed us to identify a set of generic pedagogical facts which will be considered as design principles in MEDEA:

- An adaptive system must reduce the negative effects of a hypermedia system: cognitive overload and disorientation. MEDEA satisfies this need by means of a planner algorithm to help students choose an instructional path.
- The system must allow students to build their own knowledge structures by freely choosing the instruction sequence (constructivism). MEDEA offers curriculum sequencing, although it also allows free navigation.
- The teacher must be able to fix some sequences of the instructional path by defining prerequisites.
- Too many interruptions in the learning process can provoke discouragement and boredom[3]. MEDEA will only assess students when an important difference between estimated and verified student models is detected.
- There are two kinds of strategies to select the next concept: a) selecting the concept studied more recently until the student has learned it, or b) choosing concepts that have not been visited recently. The first one can cause boredom and consequently make the student to quit. The second one can provoke dispersion of the instructional focus and disorientation. An equilibrium between these two strategies has been reached in MEDEA by means of applying the following rules: a) the concept selected as instructional focus must belong to the topic being studied; b) the system must insist on a concept only if the student is about to learn it; and c) when selecting a concept, the interest shown by the student in learning this concept is taken into account.

2.2.5 Connection Manager

This is the module that manages all the requests and responses between MEDEA's services. This communication has been considered from two different points of view: as a distributed software problem and as a conceptual semantic issue.

From the implementation point of view, the communication problem has been achieved by using Web Services (WS). WS are software components located somewhere on the Internet that are accessible through standard protocols. The syntax to call a web service can be described using a standard XML-based language: WSDL (Web Service Description Language). A WSDL document describes what a service does, how it can be accessed, and where it is located, so that different clients can understand automatically how to interact with it. The connection manager is able to communicate with the instructional resources using the description provided in the WSDL file by the IR developer.

As mentioned above, there is also a semantic perspective of the communication problem, beyond implementation. The integration of different systems must be transparent for the student; the platform must show a unique view of the curriculum and a unified student model that summarises all the data from the component student models. To this end, relationships between the concepts of MEDEA's domain models and its components (Fig. 2) must be established. Different ways of representing student knowledge on each concept (binary, discrete, and real) and procedures for automatic type conversions have been implemented.

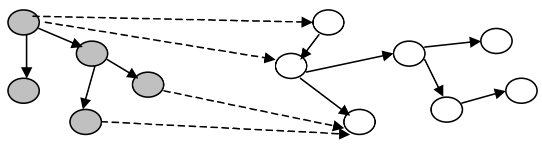

Fig. 2. Establishing the relationships between the domain models

3. Developing an AIES with MEDEA

MEDEA provides tools for the development process of an AIES. The first step consists in building the model for the subject domain. For each concept in the domain, the teacher must provide information about it, such as a name and a difficulty degree (high, medium, low), and also some data regarding its assessment: type (binary, discrete, real) and minimum value for the concept to be considered as learned. The learning material for the subject must be developed using the authoring tools of each instructional resource. This allows teachers to reuse material previously created or to develop material using their preferred tools.

The next step consists in selecting instructional resources that will be used in the AIES. Registration of an IR is performed by the resource developer, who provides the technical aspects needed to establish the connection with MEDEA. These data are used to generate a WSDL file. Once a resource has been registered, any interested teacher can use it.

As each instructional resource is also an AIES, it has its own domain model. For each selected resource, the teacher has to establish the relationships between both domain models. Once this step has been completed, the AIES is available for students through MEDEA's interface.

4. The evaluation of MEDEA

The first step in MEDEA's assessment platform consists in instantiating it to test resource interoperability. The aim is to obtain an AIES where all the resources work properly to achieve a common goal.

This formative assessment process has been accomplished in two phases. In the first phase, two educational tools (SIGUE[3] [7] and SIETTE[4] [9]) have been registered as MEDEA's instructional resources (Section 4.1). The second phase consisted in the development of two AIES: one for the study of Logic and another for Agrarian Economies. Due to limited space, section 4.2 only describes the Logic AIES, but the two courses are available through MEDEA'S interface. Independently, the accuracy of the student model in MEDEA has been tested using simulated students with satisfactory results (reported in [8]).

4.1 The integration of SIGUE and SIETTE as instructional resources in MEDEA

Most web AIES have at least an electronic book and an assessment tool, and therefore two domain independent tools were selected in order to cover this minimum functionality in MEDEA: SIGUE and SIETTE.

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[3] http://www.lcc.uma.es/sigue

[4] http://www.lcc.uma.es/siette

SIGUE is an authoring tool for developing and deploying adaptive courses using existing web pages. SIGUE makes estimations of their knowledge based on the percentage of pages visited for each.

SIETTE is an adaptive web-based assessment system. It implements *Computerized Adaptive Tests* (CATs) based on a psychometric theory called Item Response Theory (IRT).

The developers of SIGUE and SIETTE cooperated in the component integration task. The steps needed to carry out this integration task are:

1. Implementing the *instructional resource services* listed in Section 2.1. These procedures were deployed as web services. (This step will require most of the integration effort, depending on the modularity and accessibility of the resource).
2. Providing (through a web form supplied by MEDEA) location and execution parameters of the resource web services to automatically generate the WSDL file.

According to the resource developers involved in this experiment, the main advantages of the MEDEA platform are: a) easiness of use; and b) modularity, which allows adding/removing resources without affecting the rest of the system.

4.2 The development of an AIES on Logic within the MEDEA framework

Our collaborators in this phase were teachers of Logic at the University of Malaga. The work of these teachers consisted in performing the steps described in Section 7.

The result of all this process is a Logic AIES accessible through MEDEA's student interface. The domain model has 37 concepts and 70 relations. The syllabus is composed of six main topics: *Introduction*, *Formal syntax*, *Formal semantics*, *Symbolization*, *Arguments and Calculus*. Each of them contains diverse subtopics.

The domain models in SIGUE and SIETTE (used to develop the course web pages and the test items, respectively) were defined by different teachers. These models were quite similar, but did not fully coincide with MEDEA's domain model; therefore teachers had to establish the correspondence between them.

The results of this experiment showed that the tools available for the development of AIES in MEDEA were considered useful for the corresponding tasks: SIGUE allowed the reuse of pre-existing material and SIETTE provided the AIES generated with a powerful and sound assessment tool. From the teacher's point of view, MEDEA helped in the time-consuming task of developing an AIES from scratch and was considered especially useful if pre-existing material exists and is to be reused.

5. Conclusions

MEDEA is an open learning platform for the development and deployment of adaptive and intelligent web-based educational systems. It is composed of the traditional modules of AIES architecture plus a set of external web-based educational systems (instructional resources).

MEDEA's main goals were to provide teachers with a tool to develop an AIES by taking advantage of other existing material and software, and to give students a learning environment in which they have a personal educational advisor that guides and supports their learning process. Experimental results indicate that both goals have been achieved.

MEDEA offers educators curriculum sequencing, teaching task selection and student model management. The instructional process is adapted by the instructional planner (which decides which knowledge should be selected next and how it should be taught), while the teaching tasks are left to the instructional resources.

This paper presents a general vision of the MEDEA platform. In order to evaluate its suitability, two components were integrated and then two AIES have been developed.

However, this formative assessment process should only be considered as a first step in the evaluation of the system. Once the architecture has been validated, the next step is to evaluate the system from the student's point of view. Though we are aware that the results of this evaluation will strongly depend on aspects that lie much beyond the MEDEA project (such as the quality of teaching material, strategies, evaluation processes, behaviour of the components, etc.), such results will be very useful for the process of refining and improving MEDEA.

Apart from these very important assessment issues, further research work in MEDEA is planned in different directions, such as a) implementing different instructional planners with teaching strategies adapted to particular subject domains, b) semantic description of the behaviour of each instructional resource, c) exploring how the use of intelligent agents can improve how MEDEA works, and c) applying automated reasoning techniques to use the log files to improve the system's behaviour.

A prototype of MEDEA (in Spanish) is operating at http://www.lcc.uma.es/medea

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