

Manouselis N., and Sampson D. (2003) Agent-based e-Learning Course Discovery and Recommendation: Matching Learner Characteristics with Content Attributes. International Journal of Computers and Applications (IJCA), Special Issue on Intelligence and Technology in Educational Applications, Volume 25, No. 1.

**AGENT-BASED e-LEARNING COURSE RECOMMENDATION:
MATCHING LEARNER CHARACTERISTICS WITH CONTENT
ATTRIBUTES**

Nikos Manouselis, Demetrios Sampson

INTERNATIONAL JOURNAL OF COMPUTERS AND APPLICATIONS,
SPECIAL ISSUE ON INTELLIGENCE AND TECHNOLOGY IN EDUCATIONAL
APPLICATIONS

Guest Editor: Dr. Vladan Devedjic

Corresponding Author:

Dr. Demetrios Sampson
Advanced e-Services for the Knowledge Society Research Unit
Informatics and Telematics Institute
Centre for Research and Technology – Hellas
42, Arkadias Street, Athens, GR-15234, Greece
Tel: +30-210-6839916/7
sampson@iti.gr

AGENT-BASED e-LEARNING COURSE RECOMMENDATION: MATCHING LEARNER CHARACTERISTICS WITH CONTENT ATTRIBUTES

Manouselis N., Sampson D.

Advanced e-Services for the Knowledge Society Research Unit
Informatics and Telematics Institute
Centre for Research and Technology – Hellas
42, Arkadias Street, Athens, GR-15234, Greece
{nikosm, sampson}@iti.gr

Abstract. In this paper an agent framework for discovery and recommendation of e-learning courses in agent-based learning environments is presented, means to model and store the learner model and the content attributes metadata information using international specifications and standards are studied, and two methodologies for constructing a matching mechanism to select courses that fit in the most suitable way the characteristics of the learner are introduced. Finally, the application of these mechanisms to the case of a learning community within the context of the NEMO project is shown, and the results are discussed.

Keywords: Intelligent agents for educational applications, Intelligent technologies and education, Student Modelling

1. Introduction

Throughout the world, researchers define a critical need in education and training: meaningful, coherent, modular, easy-to-use internet-based environments, for assembling, delivering and accessing educational resources customised to specific needs. The high rate of evolution of on-line learning platforms implies that on one hand, increasingly complex and dynamic educational on-line infrastructures need to be managed more efficiently and, on the other hand, new types of educational services and mechanisms need to be developed and provided. To meet the current needs, such services should satisfy a diverse range of requirements, as for example, personalization and adaptation [1].

Agent technology appears to be a promising approach to address the challenges of technology-enhanced learning. Intelligent agents appear to contribute important advantages for the scientific and educational computing. They begin to have an influence in different application fields of educational systems, assist the implementation of new training paradigms, and serve as assisting entities for both students and teachers in their computer-aided learning and teaching process [2]. Moreover, multi-agent systems are proving to have the potential to meet two critical needs accompanying the widespread adoption of content-rich, distributed information systems: become a fundamental enabling technology, especially in situations where interdependencies, dynamic environments and sophisticated control play a role; provide robust representational theories and very direct modeling technologies to help us understand large, multi-participant, multi-perspective social systems like information processing systems [3].

In the case of agent-based educational systems providing e-learning courses discovery and delivery to on-line learners, we can identify the need for providing the learners with courses (and, in the broader sense, learning content) that match their characteristics and preferences in the most appropriate way. In turn, this necessitates a fully specified matching procedure, based on two separate but equally important sets of parameters: the characteristics of the learner and the properties of the educational content. Such a matching procedure should be developed on three basic axes:

- The identification and representation of the interaction and educational needs of the learners;
- The identification and representation of the interaction and educational properties of the learning content to be communicated;
- A concrete mechanism for bringing together and matching the user characteristics with the content characteristics in such a way to discover and provide the most suitable e-learning courses depending on individual learner's needs and preferences.

The technical requirements in order to specify ways to formally describe information related with all aspects of an e-learning architecture has internationally resulted in a number of standardization activities, aiming to define common learning technologies specifications and standards. Without such international standards, it will be difficult for key players in the field, such as, universities, corporations, and other organizations around the world to assuring the interoperability of their learning objects or other instructional technologies. The Learning Technology Standards Committee (LTSC) of the Institute of Electrical and Electronics Engineers (IEEE) was formed in 1996 to develop and promote instructional technology standards [4]. In Europe, the Alliance of Remote Instructional Authoring and Distribution Networks for Europe (ARIADNE) was in progress with the financial support of the European Union Commission [5]. At the same time, the Instructional Management Systems (IMS) Project [6] was initiated in the United States. Each of these and other organizations (e.g. the Advanced Distributed Learning Initiative (ADL [7]), the European CEN/ISSS Learning Technologies Workshop [8]) began developing technical standards to support the broad deployment of learning technologies. Many of these initiatives have representatives on the LTSC group. In line with the three axes defined before, the specifications that correspond to each of the guidelines driving the project are the following:

- **Learner modelling:** existing specifications enable the common description of learner-related information with metadata structures based on XML (i.e. the IMS Learner Information Package / LIP and the IEEE Public and Private Information for Learners / PAPI specifications).
- **Content description:** existing specifications enable the common description of learning objects with metadata structures based on XML (i.e. the IEEE LearningObject Metadata / LOM, IMS Meta-data, ADL Shareable Courseware Object Reference Model / SCORM specifications).

In this paper, we introduce a generic agent-based framework for discovering and recommending e-learning courses to on-line learners. Based on this agent framework, we describe the basic roles and functionalities of such a system, specify how the learner profile is constructed using the IMS LIP model and how the e-learning courses can be formally described using the IEEE LOM standards. Then, we introduce two general mechanisms for user characteristics and content attributes matching, engaging a rule-based expert shell and a multi-criteria decision making model. Finally, an example application of the proposed mechanisms in the case of one of the learning communities of the NEMO project is examined, and the conclusions made from this application are stated.

2. Agent-based educational environments

There are currently two major strands in the application of agent technologies in educational environments. The first is the use of artificial tutors / trainers for assisting educational and vocational procedures. The so-called 'pedagogical agents' are usually virtual characters that inhabit virtual learning environments, and possess advanced means of communication and interaction with the user - for a survey, see [9]. The second considers engaging agent terms

analysis and agent-based infrastructures for developing complex educational environments, with many participating actors. This strand mostly focuses on the multi-agent aspect of complex e-learning systems, benefiting from characteristics as communication, collaboration, distributed problem solving, formulation of virtual communities and efficient and effective educational content publishing, brokering and delivering through the Internet.

A multi-agent architecture for an Intelligent Tutoring System with multiple strategies is described in [10]. This work mostly focuses on the presentation of the inner structure of the agents in order to deal with the implementation of different strategies for learning by simulating different roles in the learning process (i.e. the role of the co-learner, the role of the tutor or the role of the disturber). A generator of pedagogical strategies has been implemented in Smalltalk, and two prototype user interfaces are set up for controlling monitoring the agent functionalities for the typical situations and for the assignment of specific tasks. The system agents are rather different versions of one pedagogical agent than a multi-agent society with communication and coordination capabilities.

In [11] a collaborative on-line learning system for open and distance learning that tries to respond to the requirements of an efficient and motivating learning process, is presented. This is a multi-agent system, where human and artificial agents collaborate in order to achieve a learning task. Each learner is endowed with his/her own digital personal agent, monitoring user actions and responsible for retrieving pre-existing solutions for given types of problem and managing communication and interactions with the user. Moreover, a Tutor Agent tries to partially replace the human tutor during the student interactions with the system, serving as an artificial tutor. The Tutor interacts with the learner following various styles of teaching. In several cases, the Tutor engages the help of an Information Agent that supports the analysis of the problems, by retrieving and filtering information from specified sources that can range from learning materials available in the system to the entire Internet. The human tutors have also their personal agents, but without the function of creating the learner's profile or history. There is no information about the internal structure, the communication protocols or the implementation details of the system.

In [12] an agent-based infrastructure for supporting collaboration in an on-line learning environment is proposed, based on software agents that engage the 'collaboration profile' of each learner, in order to search for potential collaboration partners, identify collaboration services to be used, and to monitor collaborative activities. There are four types of agents supporting this infrastructure: the Group Agents performing tasks related to search and invitation processes; the User Agents associated with all users in the environments; a set of mobile agents as the Search and Invitation agents for searching user profiles in local databases and interacting with the corresponding User agents; the Activities agents, concentrating and generating information important about the activity and participation levels of the collaboration group members; finally, the Advisor agents performing most of the tasks related to group and members knowledge monitoring and making recommendations based on the members profiles and the information related to the group activities. There is no clear definition of the communication, coordination and implementation issues of the agent-based infrastructure, except from an indication that the system is implemented in Java 2 and the mobile agents have Voyager 3.2 as their base platform.

A multi-agent architecture for a web-based adaptive educational system can be found in [13], providing a distributed system architecture, a communication protocol used by the agents, a distributed learning algorithm, a conflict resolution mechanism and a distributed decision-making algorithm. A large number of agents are used for user modelling, since each service is allocated to one type of agents – with most important the interface, coordinator, and advisor agents. The interface agent is responsible for interaction with the user, elicitation of user requests and presentation of the educational material. The coordinator agent is responsible for translating the user requests into application-dependent data, and for translating the

information gathered after the request is served to a form comprehensible by the interface agent and the user. The advisor agent is responsible for delegating tasks to the agents that can serve the requests, controlling thus the workload of the system. The system engages the KQML agent language for communication between the agents, and the message content is represented in KIF.

I-Help ([14],[15]) is a distributed multi-agent collaborative environment for peer help. It is designed to assist learners as they engage in authentic problem-solving activities and works by locating resources (both on-line and human) that are particularised to a learner's help request. On the surface, I-Help resembles a simple environment for sharing messages in public and private discussion; the underlying infrastructure contains numerous personal agents that communicate with each other and with application agents of various sorts, learner models that are spread across the many agents in the system, and inference mechanisms to process the learner models and locate appropriate helpers. I-Help was initially designed to meet with three basic requirements: accessibility, dependability and scalability. The first was met by engaging web technologies, and providing access to the system using a simple web browser; the second by enquiring that the services offered are available, reliable, secure and safe at all times; the third by ensuring the possibility of the system to scale up and support more users and in a wider variety of contexts. The system is based on the MAGALE (Multi-AGent Adaptive Learning Environment) multi-agent architecture [16], developed on Java and CORBA and using agent communication based on KQML.

In [17] a computational model of distance learning is introduced, based on a socio-cultural approach that privileges collaboration as a form of social interaction. The model is designed as a multi-agent society contains a number of agents: the PDZ (Proximal Development Zone) agents that are responsible for observing the real development of the students and propose activities which would make their real capacities (Real Development Level) as close as possible to the desired ones (Potential Development Level); mediating agents, responsible for the interface between the system and the student, carrying out all tasks of interface and communication with the user; the semiotic agents, assisting in introducing external stimulation (instruments and signs, according to the socio-cultural theory); the social agent having a knowledge of all PDZ agents of the system, establishing the integration of the society and constructing models of student groups; finally, the human agents, establishing social relationships to each other according to personal characteristics and personalities. The system developed using Java, and engages KQML for agent communication.

The Baghera platform presented in [18] is a web-based multi-agent architecture for learning environments, claiming to be taking a different approach in computer modelling and conception of learning environments: taking into consideration collaboration between human and artificial agents, diversity of conceptions in learners' knowledge, and education as a result of interaction among the participating agents having different and complementary abilities. The Baghera multi-agent architecture was analysed and designed using a specialized agent-oriented methodology (AEIO [19], and was realised using the JatLite package (Java Agent Template Lite, <http://java.stanford.edu>). Agent communication is in accordance with the FIPA-ACL specifications ([20]).

Most of these systems, and several others not described above ([21], [22], [23], [24], [25], [26]) in one extend or another cover the collaboration aspect of a e-learning environment, but not dealing with the problem of locating knowledge resources, and selecting those most appropriate for each learner according to his/her needs and preferences. Moreover, most of these systems do not deal with the formalization aspect of the communicated knowledge (either the learner profiles or the learning content); this results to a serious lack of reusability of resources and of interoperability between similar systems.

In the following sections we are going to focus on the problem of discovering e-learning courses in an agent-based environment where content providers publish offers, learners publish requests and broker agents mediate in the discovery and matching procedures. Examining the technical implementation of such a system is beyond the scope of this paper therefore we will only present a generic framework for the problem. Much concern will be given in representing the needs and preferences of the learner, the attributes of the online courses, and the definition of the matching procedures.

3. Agent-based Framework

The general requirements of an agent-based system for brokering of e-learning courses are the following:

- This is a system where learners will be connected in order to get access to learning material (educational content). At this point we consider the learning material to be structured in the form of full e-learning courses, but it can also be viewed as learning objects that can be synthesized into full courses according to the learner needs – this perspective falls beyond the scope of this paper.
- This is a system where content providers will be connected in order to publish learning material. That is, to describe the e-learning courses they have created and publish offers to the rest of the users of the system.
- This is a system that can provide learner modelling and content modelling services. To be more specific, in this architecture we wish to provide the learner with a recommendation service, based on the parameters of the learner model and the description of the educational content. The modelling services can be either provided by the general mediating agents or by specialized tutor agents dedicated to such pedagogical processes.
- This is a system that is able to monitor, control and automatically provide directory naming and matching services to the users participating. Each user can be uniquely identified and addressed to.

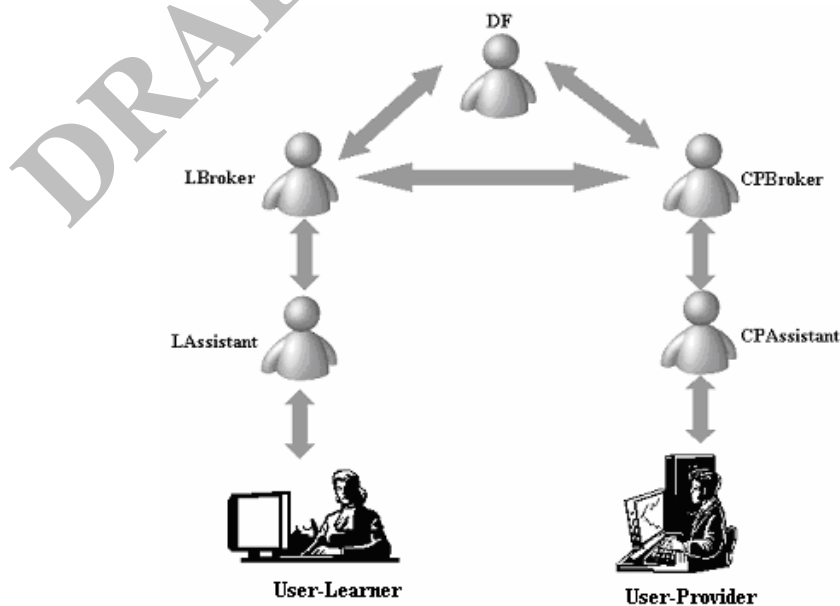


Figure 1: The agent-based e-learning framework

A generic architecture for agent-based course brokering is defined to represent the three main roles participating in the e-learning process: the Learner, the Content Provider and the Administration Authority. The agents participating in this framework (Figure 1) are the following:

- **The Learner Assistant.** The LAssistant is the agent located at the user side, responsible for all interactions of the learner with the system. The LAssistant formulates the learner requests to messages understandable from the other agents of the system, and presents the search results in forms of recommendations to the learner. The LAssistant also creates the learner model, covering so part of the services that in a more generic framework would possibly belong to a specialized Tutor Assistant Agent. In the problem we are studying, these functionalities that can be sufficiently covered by the LAssistant agent.
- **The Learner Broker.** The LBroker is the agent responsible for publishing the learner requests to the other broker agents, receives the existing offers for educational content, and evaluates them upon the learner needs and preferences.
- **The Content Provider Assistant.** The CPAssistant the agent located at the content provider side, responsible for formulating the descriptions of educational courses into offers and messages understandable from the rest of the system. The CPAssistant is responsible of the elicitation of the user requirements in a user efficient and comprehensive way using an appropriate user interface. Similarly with the case of the LAssistant, the content modelling functionalities can be assumed to be carried out by the CPAssistant instead of engaging a specialized Tutor Assistant agent.
- **The Content Provider Broker.** The CPBroker is the agent responsible for publishing the content provider offers to the rest of the broker agents. The CPBroker engages the e-learning courses descriptions in order to publish offers either to all LBrokers in general, or specific LBrokers that might be interested in particular.
- **The Directory Facilitator.** This facilitator agent provides mediating services, by informing agents about other agents of the broker repository and their availability. That is, the Facilitator (or Matchmaker agent) maintains a directory of agent names, addresses and services, and a database of all requests and offers, and is responsible of forwarding offers from CPBrokers to requesting LBrokers and vice-versa. The Facilitator is not responsible of making any decision regarding the suitability of the offered courses; it rather simply forwards those offers that seem to be matching some simple constraints (as subject keywords) and lets the selection to be carried out by the broker agent.

As it is understood from the agents' functional description, the task of selecting and recommending appropriate e-learning courses is delegated to the broker agents – the LBroker and the CPBroker. Both types of broker agents undertake the responsibility of making a decision on which e-learning courses offered in the proposed system are suitable for specific learners according to the learners' needs and preferences. In order to do so, they have to engage both learner and content modelling, so that matching between the user characteristics and the content characteristics can be carried out. For this purpose, we introduce a formal modelling of the learners and the corresponding description of the e-learning courses, in order for the broker agents to communicate offers and requests for e-learning courses. We do not address any aspects regarding the intelligence of the assistant agents (LAssistant and CPAssistant) apart from their modelling capabilities (as proactiveness, reasoning etc) since this is beyond the scope of this paper; we assume that the assistant agents are able of getting the information needed for modelling the learners and the content with the use of appropriate interfaces, supporting the flow of communication between the users (located anywhere) and the broker agents (located at the agent system side), and presenting the recommendation results to the learners.

4. Learner Modelling

From one point of view, a learner model is a single description of a user maintained by some application to judge the user's level of experience, understanding of domain content, mastery of tasks, preferences, attitudes, or cognitive styles [14]. From a richer perspective, the user model also contains the parameters that drive the personalization features in a system; the parameters that are taken into consideration when different forms of similar presentation material are available at the same time, and the system has to decide which to select for the specific user [27].

It is important thus to define and store the learner model (or the learner profile) in a formalized and globally reusable manner, in order for the system to easily model, maintain, access, and modify the user related information. There are global standardization efforts currently working towards this direction, the definition of data models applicable to learning architectures that require user modelling; in this Section the IMS Learner Information Packaging model [28] is presented, as the means to package learner information to the point that the resulted data covers the broad range of information that may be used by different systems to support the learner's activities and is ready for exchange between disparate systems. There are eleven main categories in the information tree of IMS LIP. These primary data structures, as specified by IMS, are the following:

- **Identification:** The identification learner information contains all of the data for a specific individual or organisation. This includes data such as: name, address, contact information, agent and demographics.
- **Goal:** The goal learner information consists of the description of the personal objectives and aspirations. These descriptions may also include information for monitoring the progress in achieving the goals. A goal can be defined in terms of sub-goals. A different 'goal' structure is used for each entry.
- **Qualifications, Certifications and Licences (qcl):** The qcl learner information consists of the qualifications and licences awarded to the learner, i.e. the formally recognised products of their learning and work history. This includes information on the awarding body and may also include electronic copies of the actual documents. A different 'qcl' structure is used for another qualification, etc.
- **Activity:** The activity learner information consists of the education/training, work and service (military, community, voluntary, etc) record and products (excluding formal awards). This information may include the descriptions of the courses undertaken and the records of the corresponding assessment. A separate 'activity' structure is used for each entry.
- **Competency:** The competency learner information consists of the descriptions of the skills the learner has acquired. These skills may be associated with some formal or informal training or work history (described in the 'activity') and formal awards (described in the 'qcl'). A different 'competency' structure is used for each competency through an external reference mechanism.
- **Transcript:** The transcript learner information is used to store the summary records of the academic performance at an institution. This information may contain an arbitrary level of detail and so there is no proscribed structure for a transcript.
- **Accessibility:** The accessibility learner information consists of the cognitive, technical and physical preferences for the learner. Disability, eligibility and language capabilities. These describe the learner's capabilities to interact with the learning environment.
- **Interest:** The interest learner information consists of descriptions of hobbies and other recreational activities. These interests may have formal awards (as described in the associated 'qcl'). Electronic versions of the products of these interests may also be contained. Each interest will be described within its own 'interest' structure.

- **Affiliation:** The affiliation learner information is used to store the descriptions of the organisation affiliations associated with the learner. These affiliations may include education groups, e.g. classes, cohorts, etc.
- **Securitykey:** The securitykey learner information is used to store the passwords and security codes that are to be used when communicating with the learner. A different 'securitykey' structure is used for each key and class of key.
- **Relationship:** The relationship learner information is used to store the description of the relations between the other core data structures. All of the relationship information has been removed from the other structures to enable these to be collected at a single place. This structure may also be used to describe mapping relationships to be used by the communicating systems.

IMS LIP models are created and stored using the XML standards [29]. In order to verify the XML profiles' validity according to the IMS specification, LIP uses XML schemas. To further ease the packaging of learner information, LIP employs an extensive set of vocabularies to help predefine commonly used elements. Additions though are allowed, and these vocabularies are subject to extensions/additions based on external feedback. Vocabularies can evolve without impacting the LIP specification. Each element of the LIP model contains other sub-elements in a hierarchical structure finally concluding to the values of the parameters of the learner profile. Those parameters are the numerous criteria that affect the selection of an e-learning course and cover all aspects of the user's learning experiences, preferences, attitudes, mastery of tasks and cognitive styles.

For the purpose of this paper, we will adopt a learning style modelling based on the Honey & Mumford model [30] and stored in the LIP data model. The learner by answering the Honey & Mumford's learning styles questionnaire (LSQ) provides the information needed for the Honey & Mumford model to return the four parameters of the model: one value from '0' to '100' for each cognitive style category (Figure 2). The learner model can be therefore formulated in two ways: (a) either by classifying the learner in the dominant category; or (b) directly from the values returned by the LSQ. In the first case, the user is characterized by a single descriptor (e.g. 'Activist') and this is the case for a number of systems that use Honey & Mumford modelling -e.g. the INSPIRE [31]. Nevertheless, (a) is rather a sub-case of (b), since the two models are equivalent if the learner is characterized with a multi-attribute model containing '1' in the dominant category and '0' in the rest. Obviously, a multi-attribute modelling of the learner is more consistent and more realistic. An example of including such a description in a LIP compliant model is presented in the Table 1.

Modelling of the learner in the agent-based framework is carried out by the Learner Assistant agent. The user is called to answer to appropriate questionnaires (or import the LIP model previously constructed in a similar application). For the specialized parameters of the learner model (as the learning style) specially designed tests and questionnaires have to be used (e.g. the Honey & Mumford LSQ). Such special tasks, as it has been previously mentioned, could be also carried out by a separate, specialized Tutor Assistant Agent (incorporating several Tutor-related functionalities as defining several parameters of the learner's profile) but this falls beyond the scope of this paper.

Identifying the user learning and interaction needs and specifying the learner related characteristics in a format optimum for storing, managing and communicating them in a reusable and interoperable way, is the first axis on which the matching procedure will be developed. The second one is the definition and formal specification of the learning content's educational and interaction properties. In the next section we will address this problem, introducing the concept of 'learning objects'.

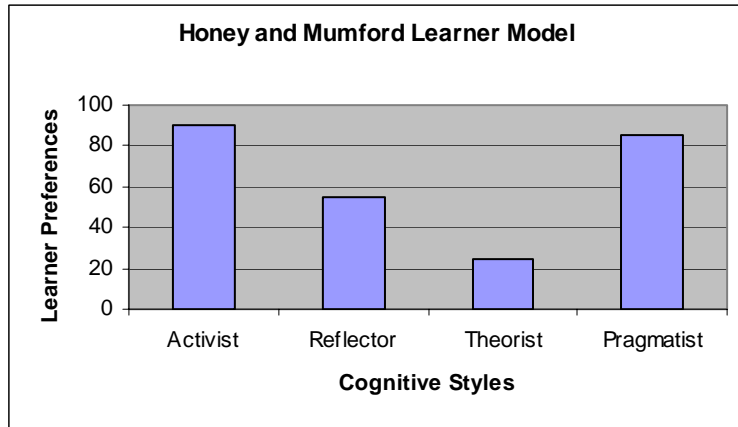


Figure 2: An example learner’s model after a LSQ is processed. It provides a measure of how the learner ‘scored’ in every category

LIP ELEMENT NAME	EXPLANATION	VALUE
Accessibility.preference.ext_preference.Honey-Mumford.Activist	Cognitive Preference according to the Honey & Mumford model for the Activist category.	90
Accessibility.preference.ext_preference.Honey-Mumford.Reflector	Cognitive Preference according to the Honey & Mumford model for the Reflector category.	55
Accessibility.preference.ext_preference.Honey-Mumford.Theorist	Cognitive Preference according to the Honey & Mumford model for the Theorist category.	25
Accessibility.preference.ext_preference.Honey-Mumford.Pragmatist	Cognitive Preference according to the Honey & Mumford model for the Pragmatist category.	85

Table 1: An extension of the Accessibility.Preference element of the LIP model, for expressing the learning style of the user. The scores derived from the LSQ comprise the learner’s model, stored in the appropriate elements (values 0-100).

5. Content Modeling

Learning objects currently lead other candidates for the position of choice in the next generation of instructional design, development, and delivery, due to their potential for reusability, generativity, adaptivity, and scalability [3]. As learning object it is considered any entity, digital or non-digital, that may be used for learning, education or training. The IMS Meta-data [32] and IEEE LOM [33] standards (we will commonly refer to them as LOM due to their very slight differences) specify a conceptual data schema that defines the structure of a metadata instance for a learning object. The metadata instance for a learning object describes relevant characteristics of the learning object to which it applies. Such characteristics can be grouped in general, lifecycle, meta-metadata, technical, educational, rights, relation, annotation, classification categories. The conceptual data schema specifies the data elements of which a metadata instance for a learning object is composed. We can distinguish 9 categories in the LOM specification:

- **General:** groups the general information that describes the learning object as a whole.
- **Lifecycle:** groups information related to the history and current state of this learning object and those who have affected this learning object during its evolution.
- **Meta-metadata:** groups information about the metadata instance itself (rather than the learning object that the metadata instance describes).

- **Technical:** groups the technical requirements and technical characteristics of the learning object.
- **Educational:** groups the educational and pedagogic characteristics of the learning object.
- **Rights:** groups the intellectual property rights and conditions of use for the learning object.
- **Relation:** groups features that define the relationship between the learning object and other related learning objects.
- **Annotation:** provides comments on the educational use of the learning object and provides information on when and by whom the comments were created.
- **Classification:** describes this learning object in relation to a particular classification system.

The LOM standard defines a set of meta-data elements that can be used to describe learning resources. This includes the element names, definitions, datatypes, and field lengths. The specification also defines a conceptual structure for the meta-data. The specification includes conformance statements for how meta-data documents must be organized and how applications must behave in order to be considered LOM-conforming. The IEEE LOM Draft Standard is intended to support consistent definition of meta-data elements across multiple implementations, but does not (at the time of this writing) include information on how to represent meta-data in a machine-readable format, necessary for exchanging meta-data. On the contrary, IMS developed a representation of the meta-data information in XML. There are slight differences between the IEEE and IMS Metadata specifications, therefore the XML binding of IMS can be used for the description of learning object according to LOM.

In the case of discovering e-learning courses for learners, the specification of the content properties as a LOM model can provide the attributes upon which each offered e-learning course is evaluated for its suitability. For example, in study the case of the learning style suitability of an e-learning course according to the Honey & Mumford model, the course can be described in a single attribute way, as:

```
TypeOfContent="SuitableForActivists" ,
```

or with an equivalent multi-attribute description in the following way (we will describe why such a multi attribute description is necessary in the following section):

```
SuitabilityOfContentForTheorists= "NotSuitableAtAll";
SuitabilityOfContentForActivists= "Perfectly suitable";
SuitabilityOfContentForReflectors= "NotSuitableAtAll";
SuitabilityOfContentForPragmatists= "NotSuitableAtAll";
```

We can therefore describe the suitability of a course for each category of learners with a value from the set ["Not suitable at all", "Not very suitable", "Moderately suitable", "Very suitable", "Perfectly suitable"]. This is a multi-attribute modelling (description) of the content that can be integrated as an extension of the LOM elements in the way shown in Table 2.

LOM Element	Sub-element	Data type	Values
Educational	SuitabilityForTheorists	Vocabulary (enumerated)	Not suitable at all
	SuitabilityForActivists	Vocabulary (enumerated)	Perfectly suitable
	SuitabilityForReflectors	Vocabulary (enumerated)	Moderately suitable
	SuitabilityForPragmatists	Vocabulary (enumerated)	Not suitable at all

Table 2: The proposed LOM extensions for describing a learning object regarding its suitability for the Honey & Mumford learning style categories.

Content modelling in the proposed agent framework is a task carried out with the help of the Content Provider Assistant agent, although a separate Tutor Assistant Agent can carry out - similarly with the case of learner modelling- specific specialized tasks. The CPAssistant agent needs to utilize a specially designed metadata authoring interface to create the XML files (as the EM² tool [34]) or import existing metadata files for the e-learning courses that have been previously created in a similar application and are LOM conforming.

6. The Proposed Matching Mechanism

At this point, the technical basis for the development of a matching procedure for agent-based online course discovery and recommendation has been formally specified. The real complexity though for the designers of e-learning systems arises when they try to match subject matter with learner characteristics. Such a matching procedure involves all these parameters as input and also requires a proper matching mechanism. In the following paragraphs we address this problem in two ways: using a rule-based expert shell, and using a multi-criteria decision making model for the broker agents.

6.1 Rule-based Modelling

The most common way to include intelligence into agents is based on tools and techniques from Artificial Intelligence (AI): knowledge representation, predicate logic, reasoning, and rule-based expert systems. IF-THEN rules have become the most popular form of declarative knowledge representation used in artificial intelligence applications, and consequently to agent-based ones [35]. There are several reasons for this: knowledge represented as IF-THEN rules is easily readable and understandable, in contrast to knowledge represented in predicate logic. Each rule can be viewed as a standalone unit of knowledge of information in a knowledge base. New knowledge can be easily added, and existing knowledge can be changed by simply creating or modifying individual rules. Rules are also easily manipulated by reasoning systems, either by 'forward chaining' (producing thus new facts) or by 'backward chaining' deducting whether statements are true or not [36]. Such an expert system consists of three main elements, a knowledge base containing the IF-THEN rules and known facts, a working memory containing derived facts and data, and an inference engine containing the reasoning logic used to process the rules and data.

In the context of the problem under study and the discussed agent framework, the broker agents that select e-learning courses can engage the rule-based expert shell in the following way:

- 1) Users' characteristics and e-learning content attributes are modeled according to the prescribed way.
- 2) The Learner Broker agents include a knowledge base with a set of rules connecting the user characteristics and the content attributes in the form way: IF CharacteristicOfUser= 'this' THEN TypeOfContent = 'that'.
- 3) Every time a learner requests a certain type of e-learning course, the Learner Broker agent receives a number of offers from the CPBroker agents that match the initial requirements of the request (i.e. match the subject keywords).
- 4) The LBroker filter all received offers using the rules of the knowledge base in order to satisfy the constraints posed by the specific request.
- 5) The solutions that satisfy the constraints are returned to the Learner Assistant and are recommended to the user.

Although rather a simple and effective matching mechanism, the rule-based approach has also several disadvantages too. For example, there is no ranking of the recommended courses or other way of measuring the differences of the qualifying solutions; once an offer satisfies the

problem constraints, it is considered equal with the other recommended solutions and there no measure of suitability among the qualifying offers. In order to deal with such handicaps, we introduce a multi-attribute modelling of the matching problem, reformulating it into a decision making one.

6.2 Multi-criteria Decision Making (MCDM) Modelling

According to Roy [37] the general methodology of modelling decision making problems includes four steps, from the definition of the object of the decision to the activity of the decision aid:

- i. Defining the object of decision, that is the set of potential actions and the problematic of the decision.
- ii. Studying the parameters influencing decision and defining a set of criteria that will help to model the decision maker's behaviour. This step regards modelling a consistent family of criteria, assuming that these criteria are non-decreasing value functions, exhaustive and non-redundant.
- iii. Modelling comprehensive preferences and operationally aggregating evaluations. The decision maker is asked to express his global preferences on a reference set A_R , taking into consideration the evaluations of the reference actions in A_R on all criteria. This previous experience (expressed by the evaluations on the actions in the reference set) is then utilized to predict the evaluations of the actions belonging in the real set A .
- iv. Investigating and developing the recommendation through the activity of decision aid. The formal procedures designed to acquire and process the information that will lead to the solution of the decision problem.

In the problem under study, the decision is regarding the selection of suitable e-learning courses from the offered ones. It is a decision to be made by the learner, but a large part of it is delegated to the LBroker. Therefore, the LBroker receives the available offers, evaluates them according to the learner's preferences and presents the most suitable ones to the learner, along with an indication of this suitability (a total utility measure).

The first step of the modelling methodology includes definition of the decision variables in a form of a consideration set A . This set includes all available e-learning courses, which will be evaluated by the decision maker (in this case, the LBroker). What is called 'the problematic of the decision' is the definition of what kind of evaluation or choice does the decision maker want to make upon the different objects available in set A ; in the case of broker agents recommending an e-learning course, we assume that the decision problematic is "ranking of actions".

In order to evaluate the actions of set A , the LBroker engages a number of criteria that are defined as 'the suitability of each type of content attribute for the corresponding learner profile parameter'. The suitability is no longer defined as an "IF CharacteristicOfUser= 'this' THEN TypeOfContent = 'that' " rule but as non-decreasing value functions, exhaustive and non-redundant. Each criterion must be defined on A as it follows:

$$g_i : A \rightarrow [g_{i*}, g_i^*] \subset \mathfrak{R} / a \rightarrow g(a) \in \mathfrak{R},$$

where $[g_{i*}, g_i^*]$ is the criterion evaluation scale, with g_{i*} the worst level of the i th criterion, g_i^* the best level of the i th criterion, $g_i(a)$ the evaluation or performance of action a on the i th criterion and $\underline{g}(a)$ the vector of performances of action a on the n criteria. F

There are several methods for multi-criteria preference modelling that can be applied according to the nature of the decision problem. In this phase we will use one of the most traditional approaches, that leads to a functional representation g that can be formed directly from the criteria g_1, \dots, g_n that constitute A . Thus, the comprehensive preference model is characterized by a unique synthesizing criterion $g: g(a)=V[g_1(a), \dots, g_n(a)]$, where V is an aggregation function. The function will be in the form:

$$V(a) = \sum p_i g_i(a)$$

where $g_i(a)$ are the evaluations of each learning object a regarding the suitability for each category of learners. The weights p_i consist the preference model, and show the importance of each parameter (criterion) in the decision of selecting a course. The final value of V is the total utility of each learning object for the learner under study. The following normalizing constraint holds, in order for the final utility V to be provided in terms of the climax ["Not suitable at all", "Not very suitable", "Moderately suitable", "Very suitable", "Perfectly suitable"]:

$$\sum_{i=1}^4 p_i = 1$$

This approach is based on two fundamental concessions: firstly, it does not allow any situation of incomparability between two actions, and secondly it addresses the evaluation (assessment) problem in a synthesizing, exhaustive and definite fashion (which is not always the case in decision problems) [37]. Both hold for the decision problem under study.

Summarizing, we can see here that the learner wants to select an e-learning course from the ones offered in the agent-based system. The LBroker agent is responsible of receiving all offers, evaluating them and presenting the learner with a ranking of the recommended courses. The specific modelling method is presented in greater detail in [38].

7. Application to the NEMO project

The NEMO "Non-Excluding Models for Web-based Education" IST project [39] aims in designing and developing a web-based platform for empowering the education and training procedures of learning communities with special needs, in an adaptive and personalized way. NEMO intends to engage the technology element in such a way that it will provide the substantial basis of a new level of educational services, focusing on individuals' special needs that can be viewed under a global and more formal perspective. The NEMO user groups belong to three wider user communities with special educational and vocational needs: people with hearing impairments, elderly people, and people with cognitive disabilities. The main objective of NEMO thus, is delivering a platform that will provide the desired level of educational services to these three learning communities.

The goals of the educational methodology of the project are accomplished by the provision to the users of a series of three "sessions": the Self-Knowledge, the Self-Direction and the Self-Efficacy sessions. Each session type can be viewed as a separate e-learning course. Whose content and navigation steps may have a common basic goal and structure, but also can be implemented in several different variants. In order to demonstrate the functionality of the described matching processes into a more applied context, we study their application in user characteristics and content attributes matching for appropriate sessions discovery and recommendation in the NEMO project. To be more specific, we identify the special educational needs of one of the three special user communities of NEMO and the special content attributes that affect the learning procedures for this community, and we examine the application of the described agent-based course discovery and recommendation procedures. First we introduce the learning community whose special educational needs and preferences we aim to model: people with mental retardation.

7.1 User Modelling

Designers of web-based learning environments have less appreciation of cognitive disabilities than sensory or mobility impairments. Designers tend to think of mental disabilities as a broad and general intellectual impairment, and they tend to ignore the specific deficits resulting from mental disabilities. More importantly, it appears that the mapping between those specific deficits and equally specific design solutions is not taken into consideration. This is why efficient profiling of the user characteristic is needed [40].

As resulting from research during the last 25 years [41], the main deficiencies in cognitive domain are focused in three aspects of information processing in individuals with mental retardation. At the very early stages of information processing, individuals with mental retardation do not process some basic aspects of visual stimuli such as depth cues or movement cues in the same way as individuals with average intelligence do. The second aspect of information processing that is deficient in individuals with mental retardation is encoding, which refers to the initial aspects of making information meaningful. The third aspect is based on many studies, which suggest that individuals with mental retardation take longer to encode information and are less accurate in encoding information. The most firmly established finding in the study of individuals with mental retardation is that they have deficiencies in the use of cognitive strategies. This does not mean, however, that individuals with particular disabilities do not possess a quantity of cognitive strategies; they rather apply them in inappropriate or ineffective ways, having less control over certain aspects of their thinking [41].

In the context of the NEMO project, we systematically analysed the educational needs and characteristics of this learner's group, and defined a number of elements of the learner model, along with respective values that they can acquire. Our analysis was based on the described IMS LIP specification, and either provided the value spaces (vocabularies) of the LIP elements that were specially designed to cover the needs of the user community we study, or it introduced the necessary extensions to the LIP structure and elements in order to model specific parameters related with these learners. In Table 3, an example learner profile is presented. This profile is formalized, reusable and can be directly translated into a form understandable by all learning environments based on the LIP specification (as an XML model). The rationale for the choice to include the new, proposed LIP elements in the accessibility segment is based on the particularity of the user group, and is described in detail in [42].

7.2 Content Modeling

The second important aspect in assembling the basis of the matching mechanism is the identification of the content characteristics that can play an important role in the education and training processes of learners with special needs (as depicted from their learner profile) and their formal specification. The goal is to identify the existing elements of the LOM specification that are important for describing the NEMO educational content; then, to extent elements, taxonomies or vocabularies in order to include those attributes of the content that are judged necessary for the learning community. Such characteristics can be grouped in the categories of LOM, but for the target community mostly fall under the General, Technical and Educational categories [43].

Let us present an example description of an e-learning course of the NEMO project. The e-learning courses of NEMO are the sessions of the Web-based Educational Methodology implemented (for the remainder of this section we will refer to NEMO e-learning courses and sessions interchangeably). One session aiming to a learner belonging into the community described in the previous section, can be made available in several formats, in order to cover

the needs of the different types of learners in the specific community. These formats have different technical and educational properties, which are described in a metadata model based on LOM, as it is presented in Table 4.

7.3 Matching

Let us present now the way the broker agents are going to engage the methodologies described, in order to match learner characteristics with content attributes and provide the learners with the NEMO sessions matching most to their special educational needs. First we are going to apply the matching mechanism only by engaging a rule-based process, and then we will also enrich it with multi-attribute selection process based on the MCDM method already described.

Let us demonstrate how the recommendation procedure works in the context of the agent-based system. A content author creates different e-learning courses concerning the same subject. The author wishes those courses to address different learner needs, depending on the cognitive style of the learner. When a course is created, the content author also provides an evaluation of its suitability for each different category of the Honey & Mumford model. The author creates thus five different courses, with different evaluations upon the criteria (as depicted in Table 5).

NAME	EXPLANATION	VALUE
Identification		
Identification.Name	The detailed name of the individual or organization.	Barry Weldon
Identification.address	Unformatted string address.	1 Marathonos Ave., Greece.
Accessibility		
Accessibility.language.typeName	The type of the language.	Gr
Accessibility.language.proficiency.profmode.Read	Read Proficiency.	Poor
Accessibility.language.proficiency.profmode.Write	Write Proficiency	Poor
Accessibility.preference.ext_preference.InteractionDevices.typeName	The type of InputTech preference.	SingleKey
Accessibility.disability.ext_disability.mental.TypeName	The type of disability being defined.	Language disorder
Accessibility.preference.ext_preference.Honey-Mumford.Activist	Cognitive Preference according to the Honey & Mumford model for the Activist category.	90
Accessibility.preference.ext_preference.Honey-Mumford.Reflector	Cognitive Preference according to the Honey & Mumford model for the Reflector category.	55
Accessibility.preference.ext_preference.Honey-Mumford.Theorist	Cognitive Preference according to the Honey & Mumford model for the Theorist category.	25
Accessibility.preference.ext_preference.Honey-Mumford.Pragmatist	Cognitive Preference according to the Honey & Mumford model for the Pragmatist category.	85

Table 3: An example user profile using the LIP data model

Element	Sub-element	Data type	Values
General	Title	LangString	“gr” “SK Session Alt.3”
	Language	CharacterString	“gr”
	Description	LangString	“gr”, “This is a web SK session for people with mental disorder”
	Structure	Vocabulary (state)	Collection
	Aggregation	Vocabulary (enumerated)	2
Technical	Format	CharacterString	HTML page
	Size	CharacterString	8kb
	Location	CharacterString	\ Cap_Read
Educational	Interactivity Type	Vocabulary (state)	Active
	Learning Resource Type	Vocabulary (state)	Questionnaire
	Interactivity Level	Vocabulary (enumerated)	Medium
	Semantic Density	Vocabulary (enumerated)	High
	Context	Vocabulary (state)	Training
	Difficulty	Vocabulary (enumerated)	Medium
	Language	CharacterString	“gr”
	AuditoryLoudness	Vocabulary (enumerated)	Medium
	Color Brightness (also known as Presentation Properties)	Vocabulary (enumerated)	medium
	Color Complexity	Vocabulary (enumerated)	1-2
	Importance	Vocabulary (enumerated)	1
	DetailOfSound	Vocabulary (enumerated)	High
	DetailOfText	Vocabulary (enumerated)	2 sentences
	DetailOfSentence	Vocabulary (enumerated)	4-5
	SuitabilityForTheorists	Vocabulary (enumerated)	1- Not suitable at all
	SuitabilityForActivists	Vocabulary (enumerated)	5- Perfectly suitable
	SuitabilityForReflectors	Vocabulary (enumerated)	3- Moderately suitable
SuitabilityForPragmatists	Vocabulary (enumerated)	1- Not suitable at all	

Table 4: An example e-learning NEMO session description based on LOM

	Course1	Course2	Course3	Course4	Course5
Activist	3	2	5	3	5
Reflector	1	3	1	2	2
Theorist	4	5	2	1	1
Pragmatist	3	2	1	5	2

Table 5: The content author provides an description of each course on a scale from ‘1- Not Suitable At All’ to ‘5-Perfectly Suitable’, regarding each one of the cognitive categories.

7.3.1 Engaging the rules-based approach

First, we will study the application of the rule-based approach for matching of user characteristics and content attributes, in the context of the agent framework. The knowledge base of the Learner Broker includes rules similar to the following ones:

IF User.Language.typeName='gr' THEN Session.General.Language='gr' ;
IF User.Language.Profmode.Read='Poor' THEN Session.Educational.SemanticDensity='High' ;
IF User.Accessibility.Honey_Mumford.Activist>80 THEN Session.Educational.SuitabilityForActivist>='Very Suitable' ;

A usual session discovery and recommendation scenario will then be:

1. The learner expresses a request for following a NEMO session to the LAssistant. The LAssistant properly forwards the request to the LBroker.
2. The LBroker publishes the request for the session to all CPBroker agents.
3. The LBroker receives a number of offers from the CPBroker Agents, in a form of LOM descriptions of the e-learning sessions.
4. The LBroker engages the rules and evaluates the proposed offers against the learner profile.
5. If any offered sessions satisfy the constraints posed by the rules, they are forwarded to the LAssistant in order to be presented to the learner.

This procedure creates an unsorted list of recommended sessions that are proposed to the learner. We wish to moreover aid the decision of selection by providing extra information about the suitability of each session. In order to do so, we engage the MCDM model discussed in section 6.2.

7.3.2 Engaging the multi-criteria decision making approach

For comprehension reasons, we simplify the complexity of the modelling procedure and demonstrate it on four criteria: the categories of the Honey & Mumford model. In the case of this NEMO user group, the model is selected thus only to demonstrate the mechanism and to maintain consistency with the example presented in Section 4. This modelling can be appropriately substituted by other learning styles models that exist in the literature [1], depending on the judgement of the educational experts. These criteria take their values from a 5-scaled climax of qualitative descriptions [“Not suitable at all”, “Not very suitable”, “Moderately suitable”, “Very suitable”, “Perfectly suitable”] showing the suitability of each e-learning course for each category. Introducing the multi-criteria methodology presented in the previous section the Broker will select an e-learning course according to these steps:

1. The LAssistant provides the LBroker the multi-attribute cognitive model of the user, according to the results of the Honey and Mumford model (Table 6).
2. When the LBroker receives the five offers for learning objects, it calculates the total utility (that is suitability) of each one, using the methodology described in the previous section.
3. The LBroker ranks the available courses so that an evaluation of the offers can be presented to the user (Table 7).

This approach can be applied complementary to the rule based approach, in order to increase the feasibility and effectiveness of the session discovery and recommendation. Working in parallel, the rule-based shell can be applied to filter the initial number of offers seeming to satisfy the selection problem constraints, and in a next level the multi-attribute model can be applied in order to rank the proposed alternatives and either recommend the learner the most suitable, or provide the learner with a utility indication of the suitability of each proposed session.

	Activist	Reflector	Theorist	Pragmatist
LSQ values	90%	55%	25%	85%
Normalized	0,35	0,22	0,10	0,33

Table 6: The cognitive styles preference model, as derived from the Honey and Mumford Learning Styles Questionnaire (values are properly normalized, according to Equation 2).

	Course1	Course2	Course3	Course4	Course5
Utility	2,67	2,51	2,51	3,25	2,96

Table 7: The total utilities of the available learning objects (a score upon the '1-Not Suitable At All' to '5-Perfectly Suitable' climax).

8. Conclusions

In this paper we presented a generic agent-based framework for e-learning courses discovery and recommendation to learners, according to their needs and preferences. The learner characteristics were formally modelled and specified using the IMS Learner Information Package specification, and the content attributes that affect the selection were also modelled and specified using the IEEE Learning Object Metadata specification. Then, two matching mechanisms were presented in order for the broker agents to recommend the e-learning courses most suitable to the learner's needs and preferences: a rule-based expert shell, and a multi-criteria evaluation model. In order to study the feasibility and effectiveness of the approach, the learner and content modelling procedures were applied in the case of the a user group of the NEMO IST Project, who belong to the special learning community of people with mental retardation. A combined application of the two matching mechanisms was then introduced, for the broker agents searching and recommending the NEMO e-learning courses to the learners of the community.

The advantages of such an enhanced approach derive from the capability of the broker agents to identify, examine and recommend those e-learning courses that most fit the learner profile, according to the properties of the learning content. The use of the learning technologies standards for creation and storing of information concerning the learner and the learning content, promotes reusability of this information and interoperability with other systems. As disadvantages, we can identify the need for all participating agents to be able to understand and communicate the information needed for these procedures to be carried out; but this is a cost that has to be paid in order for enhancing the agent intelligence and also supporting the decision selection of the learner.

At this point, interface or implementation issues were not discussed, as they fell beyond the purpose of this paper. Other issues are yet to be considered, as the application of more complex rule-based reasoning mechanisms and multi-criteria decision making methodologies.

9. Acknowledgements

The work presented in this paper is partially funded by the European Commission Information Society Technologies (IST) Programme through the IST-2000-25308 NEMO “Non-Excluding Models for web-based Education” Project.

References

- [1] Sampson, D., and Karagiannidis, C., Accommodating Learning Styles in Adaptation Logics for Personalised Learning Systems, in *Proc. ED-MEDIA 2002*, Denver, Colorado, USA, 2002.
- [2] Aroyo, L. and Kommers, P., Intelligent Agents for Educational Computer-Aided Systems, *Journal of Interactive Learning Research* vol. 10, 1999, 3-4.
- [3] Sycara K, Multi-agent Infrastructure, *Agent Discovery, Middle Agents for Web Services and Interoperation*, in Luck M. et al. (Eds.) *ACAI 2001*, LNAI 2086, Springer-Verlag, 2001.
- [4] IEEE, Learning Technologies Standards Committee (<http://ltsc.ieee.org/>).
- [5] ARIADNE, (<http://www.ariadne-eu.org/>)
- [6] IMS Global Learning Consortium, Inc. (<http://www.imsproject.org>).
- [7] ADL Advanced Distributed Learning Network (<http://www.adlnet.org/>).
- [8] CEN/ISSS Information Society Standardization System, Learning Technologies Workshop (<http://www.cenorm.be/iss/Workshop/lt/>).
- [9] Johnson, W.L., Rickel, J.W. and Lester, J.C., Animated Pedagogical Agents: Face-to-Face Interaction in Interactive Learning Environments, *International Journal of Artificial Intelligence in Education* vol. 11, 2000, 47-78.
- [10] Mengelle, T. and Frasson, C., A Multi-Agent Architecture for an ITS with Multiple Strategies, in *Computer Aided Learning and Instruction in Science and Engineering* (A. Sanchez, I. Castro, eds.), LNCS 1108, Springer-Verlag, 1996.
- [11] Florea, A., An agent-based collaboration learning system, in *Proc. of ICCE99, 7th International Conference on Computers in Education*, Chiba, Japonia, 4-7 November 1999.
- [12] Olguin, C.J.M., Delgado, A.L.N. and Ricarte, I.L.M., An Agent Infrastructure to set Collaborative Environments. *Educational Technology & Society* vol. 3(3), 2000.
- [13] Boticario, J.G. and Gaudioso, E., A multiagent architecture for a web-based adaptive system, in *Adaptive User Interfaces, Papers from the 2000 AAAI Spring Symposium* (S. Rogers and W. Iba, eds.), AAAI Press, Stanford, CA, USA, 2000.
- [14] J. Greer, G. McCalla, J. Vassileva, R. Deters, S. Bull, L. Kettel, Lessons learned in deploying a multi-agent learning support system: the I-Help experience, *Proceedings of AIED'2001*, San Antonio, 410-421, 2001.
- [15] J. Vassileva, G. McCalla, J. Greer, Multi-Agent Multi-User Modelling in I-Help”, in E. Andre and A. Paiva (eds.), Special Issue on User Modelling and Intelligent Agents, *User Modelling and User Adapted Interaction*, 2002.

- [16] Vassileva J., Greer J., McCalla G., Deters R., Zapata D., Mudgal C., Grant S., A Multi-Agent Approach to the Design of Peer-Help Environments, in *Proceedings of AIED'99*, 1999, 38-45.
- [17] Andrade, A., Jaques, P., Vicari R., Bordini, R., Jung, J., A Computational Model of Distance Learning Based on Vygotsky's Socio-Cultural Approach, *MABLE Workshop (Multi-Agent Based Learning Environments). X International Conference on Artificial Intelligence on Education*, San Antonio, Texas, 19-23 May 2001.
- [18] C. Webber, L. Bergia, S. Pesty, N. Balacheff, Baghera project: a multi-agent architecture for human learning, *Proceedings of the Workshop Multi-Agent Architectures for Distributed Learning Environments, AIED2001*, San Antonio, Texas, USA, 2001.
- [19] Demazeau Y., From Interactions to Collective Behaviour in Agent-Based Systems, in *Proc. of 1st European Conference on Cognitive Sciences*, Saint-Malo, France, 1995.
- [20] FIPA – Foundation for Intelligent Physical Agents, <http://www.fipa.org>.
- [21] Maes, P., Darrell, T., Blumberg, B. and Pentland, A., The ALIVE System: Wireless, Full-Body Interaction with Autonomous Agents, in Special issue on Multimedia and Multisensory Virtual Worlds, *ACM-Springer Multimedia Systems*, 1996.
- [22] Capuano, N., Marsella, M. and Salerno, S. , ABITS: An Agent Based Intelligent Tutoring System for Distance Learning. *CRMPA working paper*, 2000. (<http://virtcampus.cl-ki.uni-osnabrueck.de/its-2000/paper/capuano/ws2-paper-3.htm>)
- [23] Cheikes, B.A., GIA: An Agent-Based Architecture for Intelligent Tutoring Systems, in *Proc. CIKM Workshop on Intelligent Information Agents*. Baltimore, Maryland, USA, 1995.
- [24] Solomos K., Avouris N., Learning From Multiple Collaborating Intelligent Tutors: An Agent-Based Approach, *Journal of Interactive Learning Research*, Special Issue on Intelligent Agents for Educational Computer-Aided Systems, Vol. 10 (3/4), 1999.
- [25] Chen, W. and Mizoguchi, R., Communication Content Ontology for Learner Model Agent in Multi-Agent Architecture, in *Proc. of AIED99 Workshop on Ontologies for Intelligent educational Systems*, 1999.
- [26] Triantis A.G., Kameas A.D., Nikiforidis G., On the Implementation of a Multi-Agent System for Computer Based Medical Education, *Proc. of Information and Communication Technologies in Education, 2nd Panhellenic Conference with International Participation*, Patras, Greece, 2000.
- [27] D. Sampson and Ch. Karagiannidis, Re-using Adaptation Logics for Personalised Learning Applications, *IEEE 10th International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (IEEE WET-ICE-2001)*, MIT, USA, 20-21 June 2001.
- [28] IMS Learner Information Package Information Model Specification, Final Specification, Version 1.0, IMS Global Learning Consortium, 2001.
- [29] eXtensible Markup Language (XML), <http://www.w3c.org>.
- [30] Honey, P. and Mumford, A., *The Manual of Learning Styles* (3rd Ed., Maidenhead, Peter Honey 1992).
- [31] Grigoriadou, M., Papanikolaou, K., Kornilakis, H. and Magoulas, G., INSPIRE: An Intelligent System for Personalized Instruction in a Remote Environment, in *Proc. of 8th International Conference on User Modeling*, Sonthofen, Germany, 2001.
- [32] IMS Learning Resource Meta-data Information Model Specification, Final Specification, Version 1.2.2, IMS Global Learning Consortium, 2002.
- [33] IEEE Draft Standard for Learning Object Metadata, IEEE P1484.12.1/d6.4, 2002.

- [34] D. Sampson, V. Papaioannou, P. Karadimitriou, EM2: An environment for editing and management of educational metadata, to appear in *Educational Technology & Society Journal of International Forum of Educational Technology & Society and IEEE Computer Society Learning Technology Task Force*, ISSN 1436-4522, Special Issue on Innovations in Learning Technologies.
- [35] J. P. Bigus, J. Bigus, *Constructing Intelligent Agents with Java* (John Wiley & Sons, 1998).
- [36] Russel S. J., Norvig P., *Artificial Intelligence: A Modern Approach* (Prentice Hall Series in AI, 1994).
- [37] Roy, B. (1996). *Multicriteria Methodology for Decision Aiding*. Kluwer Academic Publishers.
- [38] NEMO “Non-Excluding Models for Web-Based Education”, European Commission Information Technology Programme, IST-2000-25308.
- [39] N. Manouselis, D. Sampson, Dynamic Educational e-Content Selection Using Multiple Criteria in Web-based Personalized Learning Environments, in *Proc. ED-MEDIA 2002*, Denver, Colorado, USA, 2002.
- [40] Ellen Francik, *Telecommunications problems and Design Strategies for People with Cognitive Disabilities*. Rehabilitation Engineering Research Center on Universal Telecommunications Access, 1999.
- [41] Gay, G.R., Supporting students with Learning Disabilities: an Introduction to Web-based Process Oriented Instruction”, *Technology and Persons with Disabilities Proceedings of the 15h Annual International Conference, "Technology and Persons with Disabilities"*, Los Angeles, March 20-25 2000.
- [42] N. Manouselis, K. Panagiotou, R. Psichidou, D. Sampson, Issues in Designing Web-based Environments for Learning Communities with Special Educational Needs, to appear in *Proc. of the IEEE International Conference on Advanced Learning Technologies (ICALT'02)*, Kazan, Russia, September 9-12, 2002.
- [43] N. Manouselis, R. Psichidou, K. Panagiotou, D. Sampson, Content Attributes that Affect Learning in Communities with Special Educational Needs, to appear in *Proc. of the International Conference on Computers in Education (ICCE'02)*, Auckland, New Zealand, 3-6 December 2002.