A Model for an Adaptive e-Learning Environment

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***Abstract*— Today, Learning Management Systems are able to support online training with different levels of granularity and formalization. The focus is, in our perspective, on automation of some aspects of the design process, execution and assessment, to interpret and manage the reticular nature of knowledge. The present contribution proposes a multidimensional design model, that describes the specifications needed for an educational environment, able to: increase productivity and operability, create conditions for a cooperative dialogue, develop participatory research activities of knowledge, observations and discoveries (ecological learning environment), and customize the learning design in a complex and holistic vision of the learning / teaching process. In particular, it examines the conditions that makes a learning environment "adaptive", and how those conditions are realized in an e-learning system. Finally, some system implementations will be analyzed to verify how they support : a) coaching / tutoring solutions with the finality to adapt the learning path; b) the teacher/author in advanced monitoring and planning activities, and dynamically re-define course activities; c) the student, in a dynamic, collaborative and synergistic construction of "significant knowledge" in a multi-learner environment.**

***Index Terms*— Instructional System Design, Interactive Design, Intelligent Tutoring Systems, Knowledge Management**

I. A MULTIDIMENSIONAL DESIGN MODEL

The didactical design of an e-course *(Instructional Design*, ID) [1] is the definition of a scenario of activities through which didactical strategies are defined (*design cycle*).

The Subject Matter Expert designs and plans an e-course applying a personal approach: he examines learning in the relationship between the learning process and its product, people and environment, knowledge and competence. He projects in phases and dynamic structures, with information and algorithms of actions, etc.

In our research we propose an holistic ID model, defined PENTHA Model (acronym of *Personalization*, *Environment*, *Network*, *Tutoring*, *Hypermedia*, *Activity*), based on five conceptual **dimensions**: Knowledge-, Cognitive-, Didactical-, Semiotic- and Social dimension (Figure 1). It proposes rules, conditions and typologies of an adaptable e-learning process.

Manuscript received July, 10, 2009 and accepted for the WCECS 2009 (International Conference on Education and Information Technology session) on July, 15, 2009.

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[1] A milestone in this sector is Gagne's Theory of 1965, that introduced the idea of task analysis to instructional design. Through task analysis, an instructional task could be broken down into sequential steps - hierarchical relationship of tasks and subtasks.

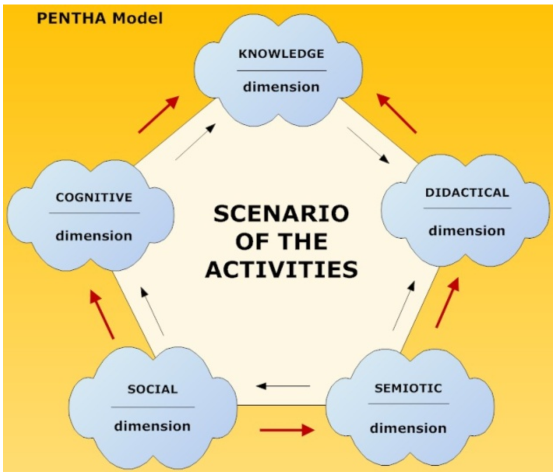

Figure 1: PENTHA Model Dimensions

The *Knowledge dimension* is a three level structure of abstraction: 1) "Learning Object" (LO), elementary didactical module, which can be used, re-used or referenced during the course session; 2) "Ontology", graphical structure which formally describes an educational domain through the specification of a vocabulary of concepts and the identification of relations between them; 3) "Metadata", structured data which describes the characteristics of a resource.

The *Cognitive dimension* involves: 1) The "cognitive state" of the student, dedicated to represent the students knowledge, at any given time; 2) The "learning preferences" (such as: difficulties, language, context, typical learning time, interactivity type and level, learning resource type, semantic density, etc.); 3) The "evolution rules" of the cognitive state and learning preferences, obtained: a) confronting the test results at the end of the assessment activities and previous test results; b) observing the used didactical materials, the acquired knowledge and skills, in order to determine the degree of receptivity (retention) of the learner to various types of issues/subjects.

The *Educational dimension* consist in a set of "selection rules", responsible for selecting the appropriate didactical nodes, and a set of "sequence rules", to apply a proper order of the content in question. The design rules must be able to access the learner's profile, which contains didactical preferences or prerequisites for the learner. In doing so, an individual content selection and learning process can be defined. Selection rules define the relations which were jointly responsible to identify the subsequent nodes. The result is a learner specific content graph, referred as *individual content graph*. In the learning process, the learner navigates through the individual content graph by mainly following its relations. The individual content graph serves as input for a set of sequence rules. The resulting sequence is the *learning path*, explicitly explained in the Syllabus, the personalized navigation structure of sections and sub-sections, activity types/modes, interactions of tutoring [2], etc..

The *Semiotic dimension* is realized in the specific construction of texts and their hypertext organization, the introduction of multimedia elements in the creation of "communicative situations", and the relationship between production-reception-signification [9]. It opens to a "pragmatic-semantic text interpretation" [3].

The *Social dimension* is a combination of the above mentioned four dimensions for the use of collaborative tools and the definition/introduction of cooperative activities (external arrows of the PENTHA model – Figure 1). It presupposes the relevance of collaborative strategies in relation to the learning objectives of the course, and the availability of adequate network services for the group communication, within which to structure the virtual space. It is possible to create communities of practice (*shared knowledge*), a dynamic, synergistic and collaborative construction of significant knowledge [7].

Learning Activities are the focus of this complex system. Sharing them in sequences (dedicated searches, research and analysis) aims to encourage the construction of learning processes based on reflection, expressive creativity and design.

It stimulates advanced **cognitive abilities and skills,** like:

- The activation of *declarative knowledge*, which describes "how things are", in a format that may be manipulated, decomposed and analyzed by its reasoners. Declarative knowledge tends to be flexible and broadly applicable
- The activation of *procedural knowledge*, is related to the procedure how to carry out an action. Procedural knowledge tends to be more fluent and automatic
- The activation of the *propositional thought*, which translates the experience into knowledge semantics
- The construction of *mental images*, which can recognize and identify the information retained
- The activation of the *narrative thought,* that interprets own experience, comparing it with the experience of others [1].

It aims to activate the dynamics of collaborative learning, based on the realization of artifacts and projects, and a personalized educational approach (*peer-learning*, *peer-tutoring* and *situated learning*).

The paradigm shift from teacher-centered to learner-centered learning needs a didactical screenplay (scenario): macro project (about operation modes), micro project (about e-content and e-tivity [4] types), and scripts of activity sequences.

The proposed concept is based on an **approach** that :

- values a sequence of instruction that is as holistic as possible, to foster meaning-making and motivation
- allows learners to make many scope and sequence decisions on their own during the learning process
- facilitates rapid prototyping in the instructional development process
- integrates viable approaches to scope and sequence into a coherent design theory.

Planning sequences of teaching and learning [5] allows to distinguish three principal **strategies :**

- *Theory-driven*, to learn, develop or test a theory (facts and concepts)
- *Method-driven*, to apply or develop a methodology (rules and procedures)
- *Problem-driven*, to solve a practical problem or simulation *(problem solving)*

We assume, in fact, that students build their own knowledge (*constructivist approach* [6]) on the basis of what they already know, realizing what they are doing and for what objective (*problem posing).* Activating a combination of *bottom-up* processes, driven largely by rationale, questions and ideas of the students, and a process (*from above*), structured in a sequence of conceptual development levels related between them [6].

Furthermore, we identify seven **tutoring modes** that may be adopted by the teacher/tutors in their relationship with the students [7] **:**

- *Modeling*, in which the teacher demonstrates how to perform a task
- *Coaching*, where the teacher actively supports the students, while teaching, motivating, analyzing their performances, provide feedback, reflection over the assignment to stimulate, discuss about the models adopted
- *Scaffolding*, which favors the modeling of the learning path taken, a reflection on the actions developed by the student stimulated by the teacher
- *Fading*, a method for adjusting and adapting the path to the achievements of the student until proof of his capability in full autonomy
- *Narrating*, which encourages students to verbalize their experiences
- *Reflecting*, which pushes the student to compare their own problems with an expert /tutor; and encourages him to perform pull actions [8]
- *Exploring,* which pushes the students to solve problems with new or alternative solutions

This is accomplished through the use of educational tools; for manipulation and viewing (i.e. knowledge maps) to facilitate testing of complex phenomena and support of teaching/learning sequences. These actions are intended towards knowledge management, which implies how to react to specific situations in real time.

This just enhances the didactical enactive aspect [9] of learning, the formal- and informal, active (*learning by doing*, *learning by thinking*) and dynamic learning.

[2] see below "tutoring modes"

[3] according to theories where a text consists of two elements : the first is a text-sense representation and the second is a text-correlate representation. It defines the "operations" which are to be carried out in the course of the interpretation, the "sequence" of these operations, and the "well-formedness" of the results of these operations. See *Semiotic Textology* of J. Petofi [9]

[4] "E-tivity" is a framework to create an online *active learning* and i*nteractive*. This is a model which was proposed and developed by G. Salmon, Open University, UK.

[5] Compare *Teaching Learning Sequences* (TLS), and the Reigeluth's *Elaboration Theory*.

[6] The concept of constructivism emphasizes the student as being the "active learner", playing a central role in mediating and controlling learn

[7] Compare Jonassen's *Constructivist Learning Environments* (CLE) and the *Cognitive apprenticeship* concept [11: ch.2]

[8] "push" action: tutor drives the learner towards the right way if he is away; "pull" action: the learner asks tutoring, when he needs it; tutor acts on explicit request

[9] "Enactive Knowledge" is information gained through perception- action interaction in the environment (*Bateson theory*)

II. Specification for Adaptive and Intelligent E-Learning Platform

In this theoretical framework, an LMS that supports complex **learning scenarios** leads today to the definition of Learning Design specification and integrated multi-learner learning environments, which:

- enables a socio-constructivist approach, the design/ re-design of the didactical projects, creates enactive, autopoietic, collaborative learning and personalized tutoring
- has the availability and control of multiple resources (network of dispositifs) for the training and management of reticular nature of knowledge, and the type of user interactions like user/Learning Objects (LO), user/user, user/HumanTutor (HT), user/eTutor, HTutor/eTutor, Author/ eTutor
- enables content management at a high level of abstraction through ontology's maintained in accordance with common standards for knowledge representation
- provides quantitative results of assessment, tests, etc.
- enables intelligent tutoring actions, with an extended faculty and granularity for learning path data recording and monitoring, and the management of multiple actors with different roles
- provides a logical and obvious graphical interface, to avoid cognitive disorientation during use of the application
- allows logical-graphics simulations (for exercises, brainstorming and developing ideas)

In conclusion (**Tab. 1**), to define a customized learning path, it is necessary:

1) Five essential **functions** to be supported by the LMS platform **:**

- Analysis of personal characteristics of students (how they perform storytelling, organizing, retrieving and applying knowledge content to solve new problems), their needs and expectations (***profiling*** *action*)
- Analysis of their behaviors during the execution of the study, the ability to monitor the student during collaborative activities and recognize the completion of tasks from students participating in group assignments (***behavior recording*** *action*)
- Structuring, visualization, storytelling and re-draft of didactical sequences (***presenting*** *action*)
- Semantics analysis of produced flowcharts and concept maps (***planning*** *action*)
- Analysis of activities, associated to social- and knowledge networks (***scanning*** *action*)

2) Four classes of **technologies**: *communication* systems - synchronous (videoconferencing etc.) and asynchronous (forum, blog, del.icio.us, etc..); systems for *sharing resource* - synchronous (screen sharing, electronic whiteboard etc.) and asynchronous (access to shared databases, shared documents etc.); tools for *knowledge mapping and simulation* (conceptual maps, flowcharting, etc.); systems to support *group activities* (collaborative writing, collaborative document synthesis etc.).

3) An **intelligent tutoring function** to support the teacher/tutor in his actions, guide students to complete their courses on the base of their performance, progress and styles of learning [8], towards the realization of "self-directed" and personalized learning processes.

4) An **e-portfolios functionality** to involve students engaged in self-reflection and critical thinking, as they collect and evaluate artifacts, use technology and make connections to student learning outcomes. It contains the student curriculum, acquired competences, personal grade book, personal repository of documents, graphic or multimedia driven elements, selected websites, or other personal items [3].

Tab. 1 – PENTHA Model Components

keywords	**focus**
Personalization **E**nvironment **N**etwork of relationships **T**utoring **H**ypermedia **A**ctivity sequence	Tutoring and learning path adaptation on "intelligent" environment
pedagogical approach	**methodology**
socio-constructivism	Teaching-Learning Sequences
dimensions	**basic strategies**
– Kd - Knowledge – Cd - Cognitive – Dd - Didactical – S1d - Semiotic – S2d - Social	– theory-driven – method-driven – problem-driven
cognitive abilities	**action skills**
– declarative knowledge – procedural knowledge – propositional thought – mental images – narrative thought	– knowledge semantic – knowledge mapping – knowledge algorithm – knowledge simulation – storytelling – critical thinking
learning dynamics	**tutoring modes**
– active learning – cognitive apprenticeship – self-directed learning – social discussion – coop/collaborative learning – communities of practice	– Modeling – Coaching – Scaffolding – Fading – Narrating – Reflecting – Exploring
Support LMS functions	**LMS technologies**
– profiling action – behavior recording action – presenting action – planning action – scanning action	– synchronous /asynchronous social networks – cognitive tutoring – education workflow engine – e-portfolios

Subsequently, we present the results of a research about software products and specific tools, functions and concepts corresponding (even partially) to the above defined characteristics. Four products were selected and described in more details.

III. Use cases: OLAT and LAMS - *Learning Management Systems*

A. Among the *open source* LMS's, **OLAT** ("Online Learning and Teaching") **[10]** was selected as the most complete in terms of functions needs for the *learning path adaptation approach.* Among others, it has a network of dispositifs for supporting synchronous and asynchronous

[10] project of MELS Centre of University of Zurich (CH) [13]

learning, advanced integrated tools (like Wiki, Chat, Forum etc.) and the possibility to include external modules (like *Collaborative Web 2.0 functionalities*).

It allows several modes of collaborative learning. Students can work as class member, joining groups or individually; can subscribe to/create project- or working-/learning groups, where they can create folders as personal file repository, which are shareable by other group members in the specific Group. Communicate with colleagues, tutors/teachers via the integrated "Chat" facility. Furthermore, the *Personal Homepage* can be personalized (configured) according to the learners needs.

The Author can decide to define a forum within a section/subsection of a course, associated to a "Learning Group", enabling activities among others like collaborative discussion of files, documents and handouts etc, at course based group level.

OLAT allows Teachers/Authors to create, re-design (modify) and manage courses dynamically. A particularity of OLAT is the "course structure" having following characteristics:

- is *structured*, tree based, without limitations driven by access and visibility parameters (based on XML).
- is "*ecologic"*, allowing "thinking by relations" approaches, creating connections and dependencies between Learning Objects, in an integrated and interdisciplinary mode
- is *graphically intuitive*, to ensure awareness (and motivation) to the Learning Entity and Teacher/Tutors. In particular, the integrated Course Editor, allowing to create courses, exercises and assessments in a simple and intuitive way without requiring advanced programming or computer skills.
- is *flexible*, in terms of space and time management, personal learning pace and "granularity" in affronting the subjects in the "learning path" .

OLAT has an extensive and advanced test facility with an integrated hint support. Tests and questionnaires will be stored in a standardized, IMS QTI format. This format enables the use of tests as course elements in different OLAT courses or in other LMS, that support the mentioned IMS format. In tests or questionnaires authors may include multimedia files. Scoring is registered in the "My achievement" section, that can be used to influence the "learning path" flow. Using this capability, the author can, on a basic level, adapt the "learning approach". This scoring parameter capability is heavily used in ongoing OLAT extensions toward an advanced tutoring and adaptation functionality.

This platform support logging/tracking at course module level with the ability to define the logging granularity. Human tutors can use available utilities to analyze/summarize the learners behavior.

In summary, OLAT provides a socio-constructivist learning approach, and offers conditions for flexi-learning, works towards a dynamic and collaborative construction of knowledge. It allows to design teaching as a screenplay in a holistic way, with the introduction of some basic tutoring actions. Furthermore, allows presenting, profiling and scanning actions (without automatic, global hint facility).

Does however, not support a "core level" content management function through ontology's and logic-simulation graphics.

B. **LAMS** ("Learning Activity Management Systems") [11] is proposed as a system, primarily dedicated to learning sequences and collaborative activities. It allows to create sequences of activities, in a graphical environment using "drag and drop", which facilitates the creation, exchange, re-use and adaptation of these sequences.

LAMS is integrating RAMS ("Research Activity Management System) an evolution, based on "human group eResearch" workflow. LAMS / RAMS are defines as *Education Workflow Engine*, to obtain optimum functions of planning. Both implementations have a reduced function of recording behavior; it is only possible to trace and report the runtime path of a student and his position, modules completed in the learning path, and highlights any collaborative work in progress. More sophisticated tutoring, logging and tracking functionalities are normally executed by the "hosting" LMS platform using an intelligent tutoring system.

LAMS is used as learning sequences aggregator for other LMS platforms to carry out specific "collaborative sequence" course activities. The depth of LAMS integration varies depending on the LMS; the most advanced implementations are those of Moodle, and .LRN, where LAMS sequences are considered "pseudo native" LMS platform components. The more common (simpler) integration mode is to enable access to the external LAMS environment through the "external link" approach. Upcoming integrations (like for the OLAT LMS) is a tight integration solution based on wrapper technology, including the possibility of bidirectional data transfer. This will allow test-, assessment data from the LAMS sequence, to be integrated in the achievement structure of the native LMS platform (example common Grade book etc.).

IV. USES CASES: CTAT AND SMART TUTOR - *INTELLIGENT TUTORING SYSTEMS*

A. **CTAT** ("Cognitive Tutor Authoring Tool*"*) [12] is one of the few examples of authoring tools that can create dedicated tutor disciplines. Born with the intent to promote the understanding of problem-solving knowledge. It uses:

- *Behavior Recorder* technology, that allows (through logging/tracking) to monitor how the student is performing, and detect the difficulties that he encounters;
- *Authoring facility*, that support the creation of dedicated eTutors for a vast variety of "subject matter" oriented, problem solving activities based on several, selectable models;
- *Rule Engine*, which through agents, executes "subject matter" dedicated rules for logical exception decisions.

To allow the eTutor to perform these operations, it is necessary that the author of the course provides the necessary rules and logical links for the specific "subject matter" or domain.

Its technical peculiarity is to represent the performance of the student as learning paths. Specifically:

[11] project of Macquarie University (2005) [4], [14]

[12] project of Pittsburgh Advanced Cognitive Tutor Center, Carnegie Mellon University [5], [15]

- guide the student towards the achievement of test objectives, based on the structure of problem solving (*reification action*)
- divides the problems in secondary target and active actions of scaffolding and reasoning
- monitors the status of each student's knowledge on a moment-by-moment base and tailors course material for each student, based on continuous assessments
- understands the subject matter because it represents material the same way a student would, and it can use this representation to solve problems in a way that imitates the student performance.
- provides immediate feedback on errors and associates suggestions (through *hints*).
- provides suggestions for further study, recognizing the difficulties of learners, using simple message "submission" describing objectives, timing, problems in the course, what is expected from the course sections (Syllabus type approach), etc.
- presents a system of “push and pull” tutoring (like sophisticated solutions for the development of meaningful relationships).

CTAT applies an algorithm called "model tracing" to monitor a student involved in solving a problem: it compares the students' actions against those defined appropriate according to a specific model.

B. **SmartTutor** [13] is a web-based self-learning support implementation, based on Artificial Intelligence. It offers three different modes of learning:

- *Walk Through Mode* - learners are provided with a pre-defined learning path. Learning sessions are arranged in a specific order; learners will go through them one by one to build up their knowledge in that learning domain.
- *Custom Mode* - learners are provided with a higher flexibility of learning. They can define their target learning sessions. SmartTutor will suggest a customized learning path based on the learning session selected and the corresponding prerequisites. Therefore, learners will not miss out any fundamental session for the target learning session selected.
- *Review Mode* - which supports the students in its exams preparation, “identifying” the sessions in which the learners have not performed well and provides reviews, suggestions of "action", tests, to help overcoming the encountered difficulties.

Smart Tutor guide students to complete their courses on the base of their performance and their learning profile. The progress of individual learning and performance are monitored and analyzed to provide personalized learning recommendations. This allows to provide a more timely and accurate feedback related to the performance and learning path of the learner. In particular:

- empowers individual learners with different needs and learning styles to learn at their own pace and mode with personalized guidance during the learning process
- respond to learners' questions and insights much faster and share the feedback with other learners
- provides instructors with an interface to promote collaborative learning through the use of just-in-time learning resources and online threaded discussions
- allows instructors to monitor the learners' progress and adapt suitable learning materials/topics accordingly
- streamlines the process of content management and course development, allowing instructors to spend more time on pedagogical design of the courses
- assists course administration through simple management of all interactions with learners and instructors.

[13] project of R&D SOULearning. Centre della Hong Kong University [12,5], [16]

V. Conclusion

The concept of personalization is fundamental for the innovation process in e-Learning. In this essay we suggest an instructional design model (PENTHA Model) which recognizes five conceptual dimensions, and describes didactical strategies, tutoring modes and learning dynamics for learning path adaptation on intelligent LMS platforms. We summarized what functions must be present and supported by the LMS platform to realize/optimize the Learning Design for an “Adaptation approach”.

The functions offered by the today available LMS’s or similar software products partially satisfy the requirements.

Some of the issues may still remain open for further research. To achieve an LMS based “Adaptive Learning Environment” the characteristics mentioned in this essay should be present in an adequate form to support Authors to develop *rule driven*, subject oriented, adaptable course content, in taking the concepts of CTAT and SmartTutor as base reference point.

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