INSPIRE: An INtelligent System for Personalized Instruction in a Remote Environment

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Abstract. In this paper we present the architecture of an Adaptive Educational Hypermedia System, named INSPIRE. This particular system, throughout its interaction with the learner, dynamically generates lessons that gradually lead to the accomplishment of the learning goals selected by the learner. The generated lessons are adapted to the learner's knowledge level, learning style and follow his/her progress. The adaptive behavior of the system, the functionality of its various modules and the opportunities offered for learner's intervention are presented.

1. Introduction

Adaptive Educational Hypermedia Systems (AEHS) [2][3] extending the benefits derived from the instructional use of the Web, incorporate the idea of offering learners personalised support and/or instruction in a distance learning setting. The adaptive characteristics of an Educational Hypermedia System usually aim to both *usability* and *learning*. Thus, the educational implications are very important and should be considered through the design and development stages of the system. Although many questions are still open in the area of Instructional Design about *instruction* / *learning* and how it is efficiently provided / attained [17], it is important to consider adaptation within the framework of current learning theories and models, and thoroughly plan the sharing of the task of adaptation between the learner and the system.

We have developed an AEHS, named INSPIRE. Based on the learning goal that the learner selects, INSPIRE generates lessons that correspond to specific learning outcomes accommodating learner's knowledge level and learning style. Thus, aiming to individualize instruction, the system generates lesson plans tailored to the needs, preferences and knowledge level of each individual learner by making use of information about the learner gathered through their interaction. Furthermore, aiming to engage learners in the learning process, the system provides them with the option to intervene, expressing their perspective about their own characteristics or about the lesson contents and accordingly formulate their interaction with the system.

2 INSPIRE's adaptive functionality

The proposed system aims to facilitate distance learners during their study, adopting a pedagogical framework inspired by theories of the area of Instructional Design and Adult Learning. In the beginning of the interaction, the domain knowledge presented to the learner is restricted and gradually it is enriched, following the internal structure of the domain (*curriculum sequencing technique*), while a navigation route is proposed based on his/her progress (*adaptive navigation technique*).

The main instructional outcomes of the generated lessons on learners' level of performance are to understand and to remember the most important instances and generalities associated with the learning goal they study (*Remember*), to be able to apply them to specific cases (*Use*) and finally to be able to generate new generalities (*Find*) [12]. The presentation of the educational material provided for each different level of performance, i.e. Remember, Use and Find, is mainly determined by the learning style of the learner (*adaptive presentation technique*). Thus, learners' preferences, that usually guide systems' adaptation [2], are determined based on their learning style. Following the theory of learning styles [9][4][11], how much individuals learn, i.e. the effectiveness of instructional manipulations, is mainly influenced by the educational experiences geared toward their particular style of learning. This approach to learning emphasizes the fact that individuals perceive and process information in very different ways. In this paper we propose a framework for the system's adaptive behavior exploiting the learning style information. The learning style model that we adopted in the current implementation of the system is that of [8] where Honey and Mumford, based on Kolb's theory of experiential learning [9], suggested four types of learners: *Activists*, *Pragmatists*, *Reflectors*, *Theorists*.

The proposed system also supports end-learner modifiability offering opportunities to the learners to intervene in different stages of the lesson generation process, as well as on the construction of their learner model. Thus, learners have the option to activate or deactivate the lesson generation process of the system. In case they choose to activate it, they have the option to guide system's instructional decisions by updating accordingly their characteristics on their model, i.e. their knowledge level on the different concepts of the learning goal and their learning style. The externalization of the model to the learners is implemented in a manner that allows it to be understandable, transferable and usable [7].

3 The Architecture of INSPIRE

INSPIRE's architecture has been designed so as to facilitate knowledge communication between the learner and the system and to support its adaptive functionality. INSPIRE is comprised of five different modules (see Fig. 1): *(i)* the *Interaction Monitoring Module* that monitors and handles learner's responses during his/her interaction with the system,*(ii)* the *Learner's Diagnostic Module* that processes data recorded about the learner and decides on how to classify the learner's knowledge, *(iii)* the *Lesson Generation Module* that generates the lesson contents according to learner's knowledge goals, knowledge level,*(iv)* the *Presentation Module* whose function is to generate the educational material pages sent to the learner and (*v*) the *Data Storage*, which holds the *Domain knowledge* and the *Learner's Model*.

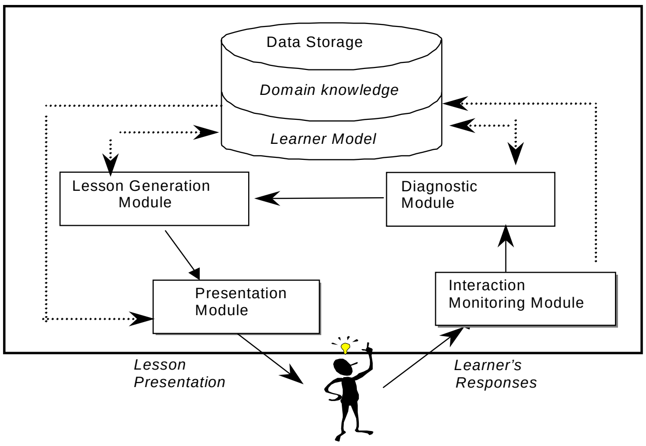

Fig. 1. INSPIRE's components and the interactions with the learner

3.1 Representing Knowledge about the Domain and the Learner: *Data Storage*

The domain knowledge of the system is structured in three hierarchical levels of knowledge abstraction: *learning goals*, *concepts* and *educational material* [14]. Every learning goal is associated with a subset of concepts. Assigning qualitative characterisations provides interrelation among the different concepts of a learning goal, i.e. *outcome concepts*, *prerequisite concepts* and *related concepts*. Note that the prerequisites and related concepts are linked to specific outcome concepts. The outcome concepts of a learning goal are further organized in a layered structure, i.e. the outcome concepts belonging to a specific layer are those that should be presented before the ones of the next layer.

The educational material related to each outcome concept consists of *knowledge modules,* developed according to three different levels of performance proposed in [12], *Remember*, *Use* and *Find*. Each different level of performance is associated with a different combination of multiple types of educational material aiming to increase learning efficiency as follows: (*i*) the *Remember* level of performance includes information necessary to present the concept, i.e. expository and inquisitory theory presentations and/or examples plus images and/or questions and self-estimation tests, assessment tests, (*ii*) the *Use* level of performance includes information necessary to apply the concept to specific cases, i.e. hints from the theory and/or examples and/or exercises and/or activities based on computer simulations, self-estimation tests, assessment tests, and (*iii*) the *Find* level of performance aims to the ability of the learner to find a new concept, principle, procedure, and thus the educational material provided includes activities on simulations, exploration activities, case studies. The representation of the knowledge modules in the database is based on the ARIADNE recommendation for educational metadata [1]. Metadata specify the attributes that fully and adequately describe the knowledge modules of the educational material.

The learner model

The learner model is the system's representation of the learner. It supports learner's communication with the system and reflects some of his/her features. It describes the learner (general information, learning style) and his/her "current state" (knowledge level on the different concepts and learning goals, performance on assessment tests, number, type and order of resources s/he has accessed etc.).

The knowledge level of the learner on a certain concept is assigned one of the characterizations {I, RS, AS, S} = {Insufficient, Rather Sufficient, Almost Sufficient, Sufficient}. This assignment is made based on learners' answers to assessment questions of different types. The diagnostic module uses the approach described in [15] for multicriterial decision-making in order to assess learner's knowledge level on each particular concept of a learning goal.

Currently, the learning style of the learner is initialised through the submission of the questionnaire developed by Honey & Mumford [8] or directly by the learner, who has the option to select his/her dominant learning style based on information provided by the system about the general characteristics of the different categories. In the first case, the learner, the first time s/he logs in the system submits the questionnaire and automatically according to the procedure defined in [8], his/her dominant learning style is determined and stored in his/her learner profile.

3.2 Monitoring the Learner: Interaction Monitoring Module

The function of the interaction-monitoring module is to log the requests made by the learner, as part of his/her HTTP request, and update the learner's model with the newly acquired information. Since the interaction-monitoring module is the only part of INSPIRE that receives direct input from the learner, it is responsible for collecting data concerning the learner's observable behavior and for notifying the other modules about any actions performed by him/her. Such actions are, the inspection or modification of his/her model, the selection of a learning goal and the activation/deactivation of the lesson generation process.

3.3 Planning the Lesson’s Contents: *Lesson Generation Module*

The Lesson Generation Module realizes the lesson generation process, which plans the content and the delivery of each lesson. The outcome concepts of a learning goal are presented gradually according to the priority of the layer they belong to. The lesson generation process determines which layer of the outcome concepts (See in Sect. 3.1 the structure of the domain knowledge) should be proposed to the learner. This decision is mainly guided by his/her knowledge level on the outcome concepts of the previous layers.

Every outcome concept on the selected layer is accompanied by its prerequisites and related ones. In the proposed approach we use different strategies for planning the content of a lesson on each particular layer. This process, takes into account the relative importance of each concept on the learning goal as well as the knowledge level of the learner on those concepts. For example:

- If the knowledge level of the learner has been evaluated as {Insufficient} on a number of outcome concepts. Then, s/he has to study the educational material of the *Remember* level on these outcome concepts and their entire prerequisite ones.
- If the knowledge level of the learner has been evaluated as {Rather Sufficient} on a number of outcome concepts and {Sufficient} on several prerequisite concepts. Then, s/he has to study the educational material of the *Use* level on these outcome concepts and the rest of the prerequisite ones of the outcome.

The relative importance of the concepts included in a lesson determines the extent of their presentation. Thus, the generated lesson includes: *(i)* complete presentation of the outcome concepts (according to the three levels of performance), *(ii)* links to brief presentations of the prerequisite concepts focusing on their relation to the outcome and *(iii)* links to the definition of the related concepts in a glossary. The educational material associated to each of the concepts is predefined while its presentation to the learner is tailored to his/her learning style. Also, the results of the lesson generation process, on the contents and delivery of the generated lessons reflect on the navigational route proposed by the system (See Section 3.3. Adaptive Navigation).

3.4 Presenting the Lesson: *Presentation Module*

This module is responsible for the presentation of the lesson to the learner. The Lesson Generation Module has already determined the lesson contents based on the knowledge level of the learner, but the presentation module will decide on the appearance of the knowledge modules based on the learning style of the learner.

Adaptive Presentation

Learners with different learning style view different presentations of the educational material. The main objective is to support learners, following their preferred way of studying. To this end we exploit the information of their learning style in order to guide decisions on the instructional approach proposed to each individual learner.

According to the proposed framework, the multiple representations of the outcome concepts (expository and inquisitory presentations, examples, exercises, activities based on computer simulations, exploration of resources and group works) constitute different instructional primitives [10] which are combined to formulate alternative instructional strategies for the presentation of the educational material. The selection of the appropriate instructional strategy for each learning style category reflects some tendencies of the category in approaching information and is in accordance to related work proposed in the literature [6] [16]. Furthermore, empirical investigations on the learning preferences of learners have been realised during the first stages of the formative evaluation [13] of the system aiming to provide direct information from learners about their attitudes towards the instructional material while studying.

Thus, all learners are provided with the same knowledge modules. However, the method and order of the presentation of the different representations that they include, is adapted, implementing multiple instructional strategies that focus on different perspectives of the concept. This way, we attempt to maximise the benefit gained from style awareness [9][8]. Learners are motivated to pass through all the provided educational material exploiting their own capabilities and developing new ones. Consequently, for Reflectors who tend to collect and analyse data before taking action, *example-oriented* (see Fig.2), proposing him/her to start reading the example, continue with a brief theory presentation and then try to solve an exercise. Accordingly, for the presentation of material to Activists, who are more motivated by experimentation and attracted by challenge, the instructional strategy adopted is *activity-oriented* (see Fig.3), proposing him/her to start experiment with an activity designed for a computer simulation and providing him/her with the necessary information (examples and theory).

Fig. 2. INSPIRE's main screen presenting the initial page of an outcome concept. The screen is divided into three areas: (A) Navigation Area (B) Content Area, and (C) Toolbar. In the Content Area, different knowledge units comprising a page of educational material as viewed by Reflectors: (3) An application example (1) Link to hints from the theory (2) An exercise (3)Link to an activity on a computer simulation.

Concerning the implementation of the adopted instructional strategy, if it is example-oriented then the knowledge module "example" will be embedded at the beginning of the page while the rest of the modules will appear next as links; if the instructional strategy is activity-oriented then the knowledge module "activity" will be embedded at the beginning of the page while the rest of the modules will appear next as links;

In INSPIRE, the use of multiple representations in different instructional strategies formulating their presentation alleviates the problem of rewriting the same content tailored to each learning style category. The different knowledge modules are presented as different areas in the educational material pages. These areas are associated with a condition referring to the learning style of the learner and they are, either embedded in the page, or appear as links, or they do not appear at all. This way, the same knowledge modules can provide multiple alternative representations of the same concept through the adaptive presentation technique.

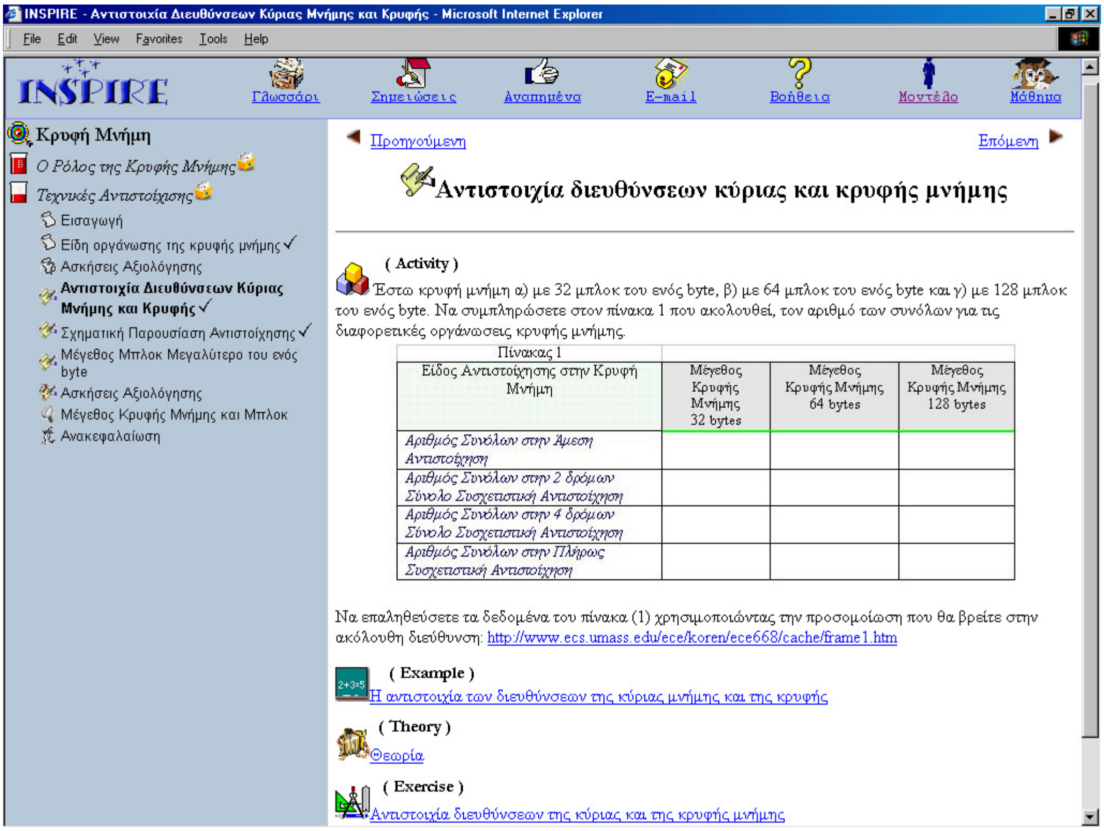

Fig. 3. Different knowledge modules comprising a page of educational material as viewed by Activists: (1) An activity on a computer simulation (2) Links to application examples (3) Link to hints from the theory (4) Link to an exercise.

Adaptive Navigation Support

The system supports learner's navigation and orientation in the lesson contents, by annotating the links that appear in the Navigation Area. Additional information is provided to the learner through the use of icons next to the names of concepts and the educational material, that distinguish the outcome from the prerequisite concepts as well as the educational material provided for each level of performance (see Fig.4 - Navigation Area). Especially on the outcome concepts, the filling of a measuring cup is used as a metaphor denoting learner's progress.

Furthermore, two state icons accompany the prerequisite concepts and the educational material of the outcomes reflecting the instructional decisions of the lesson generation process on the educational material that the learner should study next. Thus, coloured icons accompany the links that lead to the material that the system proposes the learner to study next, while black and white icons appear next to the rest of the links (see Fig.4 - Navigation Area).

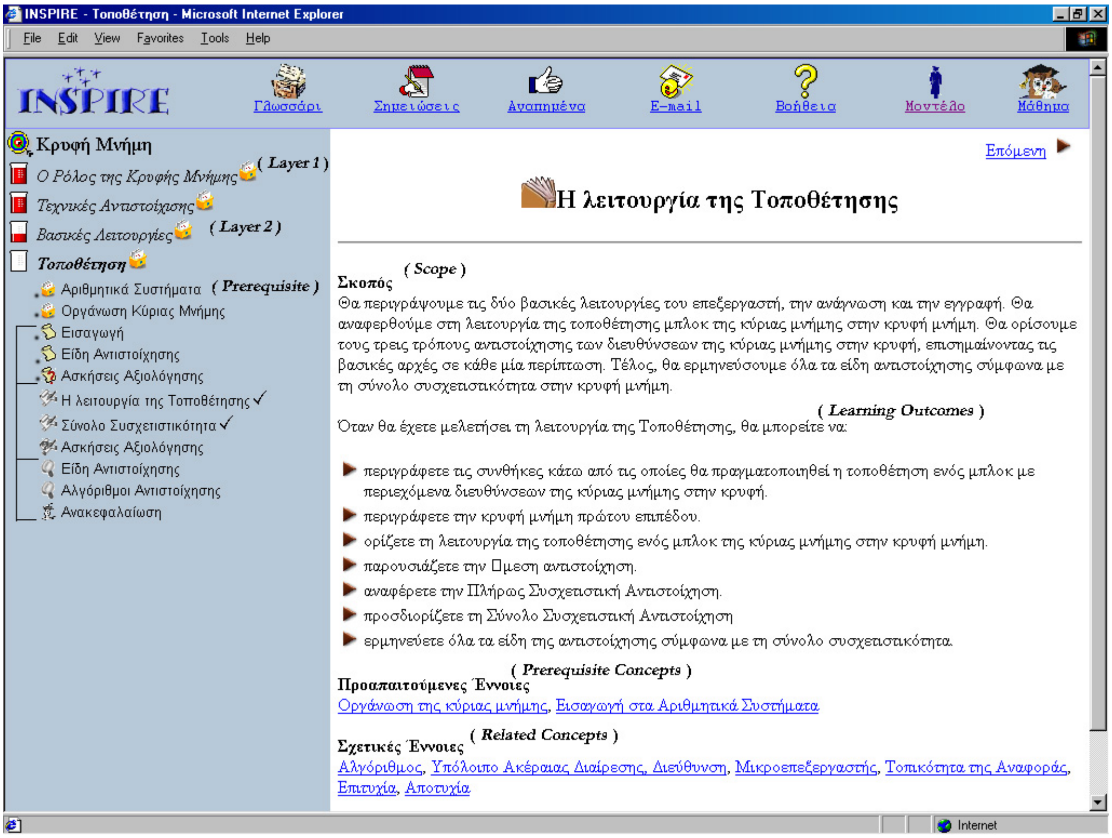

Fig. 4. INSPIRE's main screen presenting the initial page of an outcome concept.

4 Implementation Issues

INSPIRE is currently used to support an introductory course on Computer Architecture. In particular, educational material referring to the learning goal "Which is the role of cache memory and its basic operations" has been developed based on the chapter *Computer Memory* of the university module "Computer Architecture" [5] developed in the Computer Science department, University of Athens. The current implementation of the system is using an IIS web server running on Windows NT, which processes the requests made by the learners. The learner model and the educational metadata describing the educational material [1] are stored in a SQL Server database that communicates with the web server through use of the ActiveX Data Objects (ADO) technology. The education material itself is stored in the file system pages. We are making use of the Active Server Pages (ASP) technology developed by Microsoft, which allows the dynamic generation of HTML page, in order to implement the adaptive presentation technique.

5 Conclusions and Further Research

INSPIRE is an adaptive system that monitors learner's activity and dynamically adapts the generated lessons to accommodate diversity in learners' knowledge state and learning style. An experiment focusing on the evaluation of the instructional design of the system has been conducted with students of the department of Informatics of the University of Athens, attending the course on Computer Architecture and with participants of a seminar on the usability of educational software. The initial reactions towards the system have been encouraging while students' comments inspired several improvements on system's interface.

The system is both adaptive and adaptable, as it allows the learner to control the interaction and provides guidance or help. The learner model of the system provides a complete description of the current state of the learner and it is open to the learner to make changes and in this way allows him/her to intervene in the lesson generation process, supporting "end-learner modifiability". Further processing of the information stored in the learner model can be exploited by: (*i*) the system for the learner diagnosis process, (*ii*) the learner in order to be informed on system's decisions and intervene accordingly, as it will be described below, and (*iii*) the tutor for the evaluation of the provided material and for monitoring learners' progress and study attitude. From the various statistics stored in the learner model the tutor can have a quantitative estimation of the learners preferences on the educational material, in the sense of the time they spent on it, their performance, their requests to the system for help on specific pages etc. Furthermore, the tutor can examine the system's learner profile in order to get information about each learner's attitude while studying, and their progress.

The knowledge level and the learning style of the learner are used for the appropriate selection of the lesson contents and the presentation of the educational material. In the current implementation of the system, the learning style of each individual learner is recognized through the submission of the appropriate questionnaire or by the learner. Further research is on progress concerning the estimation of the way each learner uses the educational material in order to identify inconsistencies in the association of the learning style of the learner (already known) with the different types of educational material. For example, it is expected that the Activist will spent most of his/her time on activities and exercises, while the Reflector on theory presentations and examples. The way a learner uses the educational material in conjunction with his/her progress is valuable information denoting how successful is the selection of particular type of educational material for the particular learner. Furthermore, this information can also be used for the dynamic adaptation of the instructional strategy adopted for presentation of the educational material during learner's interaction with the system.

Acknowledgement

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