MATHEMA: A Learner-controlled Adaptive Educational Hypermedia System

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***Abstract*-This paper describes the innovative, adaptive and intelligent techniques, supported by the Web-based adaptive educational hypermedia system called MATHEMA. The supported techniques by the AEHS MATHEMA are the following: curriculum sequencing, adaptive presentation, adaptive and meta-adaptive navigation support, interactive problem solving support, and adaptive group formation. These techniques answer to some open research issues such as, which is the appropriate learning style model for ad hoc domain application? How to combine individual contexts with collaborative contexts? What are effective and acceptable adaptations at the interaction, tool or content level we can implement in an adaptive educational hypermedia system used for both individual and collaborative learning? How do we incorporate problem-solving activity into adaptive educational hypermedia system? The educational purpose of the AEHS MATHEMA is to support senior high school students or novices of higher education, through an interactive and constructivist educational material, in learning Physics individually and/or collaboratively. In general, the AEHS MATHEMA is an effective learner-controlled system that dynamically generates courses according to learners' learning goal, knowledge level on each learning goal and main concept, learning style, Web experience, preference for visual and/or verbal feedback, and preference for the kind of navigation. Summative evaluation of the AEHS MATHEMA indicated that almost all its functions are useful, usable, and user-friendly.**

Keywords- Experiential Learning; Learning Styles; Socio-Constructivism; Adaptive and Intelligent Techniques; Usability

I. INTRODUCTION

The purpose of this paper is to present the innovative adaptive and intelligent techniques supported by the Web-based adaptive educational hypermedia system MATHEMA.

More specifically, in this paper we mainly focus upon the issues regarding the educational framework, that includes the didactic design, domain model, student model, etc, and the selection of the most appropriate adaptive and intelligent techniques, as well as we answer some open research issues concerning the design of the Adaptive Educational Hypermedia Systems (AEHS). The AEHS MATHEMA combines individual and collaborative contexts [117] and its design covers the following open research issues [15, 43]:

- The design of an educational framework based upon the theories of constructivist and social constructivist that will direct the educational decisions and the design of the domain model. Moreover, it will determine the goals and functionality of adaptation, the feedback, the assessment, the participation of the learner in collaborative problem solving activities, and it will specify the combination of the adaptation techniques appropriate for its functions.
- The selection of a learning style model appropriate for the domain of application, among all those that have been proposed by various psychologists, as well as the design of adaptation based on this model.
- Issues concerning the effective design of the learner's participation in the educational process, and sharing of control between the system and the learner, in a transparent way, will respond to the needs and the current state of the learner.
- The selection of appropriate adaptive navigation techniques will assist the learner's navigation according to his/her Web experience and knowledge level of current learning goal.
- The design of a meta-adaptive navigation technique will assist the learner in the selection of the most appropriate navigation technique matching in his/her profile.
- The design of an interactive problem solving technique through activities with the use of modern didactic approaches combined with both individual and collaborative learning.
- The learner assist the selecting of the most appropriate collaborator from a list of candidate collaborators created by the system, taking into account the learner's learning style, and the learning style and knowledge level on the current learning goal of candidate collaborators.

Moreover, the design of the AEHS MATHEMA aims at the development of an effective learner-controlled (learner-centered) system in such a way to have high functionality, usability, and usefulness of its functions.

AEHS can be considered as the solution to the problems of traditional online educational hypermedia systems. These problems are due to the static content, the "lost in hypermedia" syndrome and the "one-size-fits-all" approach. AEHSs combine ideas from Hypermedia and Intelligent Tutoring Systems (ITS) to produce applications whose content is adapted to each student's learning goal, knowledge level, background, interests, preferences, stereotypes, cognitive preferences, and learning style [16]. The purpose of such adaptive educational offerings is to maximize learner satisfaction, learning speed (efficiency) and educational effectiveness [90].

AEHSs have been found to be useful in engaging the learner more in the educational experience. Furthermore, these systems, increase the functionality of conventional hypermedia combining free browsing with personalization and can support all the continuum of the learning model, from a pure system-controlled to a fully learner-controlled [16].

In Web-based AEH systems, several adaptive and intelligent techniques have been applied to introduce adaptation such as: curriculum sequencing, adaptive presentation, adaptive navigation support, interactive problem solving support, intelligent analysis of learner solutions, example-based problem solving support, and adaptive collaboration support or adaptive group formation and/or peer help.

Table Ⅰ presents the main AEHSs and their implemented techniques. None of these systems supports all of the above-mentioned techniques. In general, these systems use combinations of the above-mentioned techniques in order to enrich adaptive functionality and enhance the support offered to learners. On the one hand, the majority of these systems support adaptive navigation (twenty-six out of thirty-one), which is one of the most popular techniques in current adaptive hypermedia systems, adaptive presentation (twenty) and curriculum sequencing (twelve). On the other hand, a few of these systems use the techniques of intelligent analysis of student solutions (one out of thirty-one), interactive problem solving support (two), example-based problem solving support (one), and adaptive collaboration support or adaptive group formation and/or peer help (four).

TABLE Ⅰ ADAPTIVE EDUCATIONAL HYPERMEDIA SYSTEMS AND THEIR IMPLEMENTED TECHNIQUES

Adaptive Educational Hypermedia System	**Curriculum Sequencing**	**Adaptive Presentation**	**Adaptive Navigation Support**	**Interactive Problem Solving Support**	**Intelligent Analysis of Student Solutions**	**Example-based Problem Solving Support**	**Adaptive Collaboration Support or Adaptive Group Formation & Peer Help**
ACE [104]	■		■				
ActiveMath [74]	■	■	■	■			
AES-CS [111]		■	■				
AHA! [29]		■	■				
ALE [103]			■				
ALICE [52]			■				
Anatom-Tutor [5]		■					
AST [102]	■		■				
CAMELEON [59]		■	■				
CA-OLE [97]		■					■
CS383 [19]		■					
ELM-ART [11]	■		■		■	■	
Flexi-OLM [65]		■	■				
Hypadapter [47]		■	■				
ILASH [4]		■	■				
INSPIRE [85]	■	■	■				
InterBook [12]	■		■				
ISIS-Tutor [10]	■		■	■			
iWeaver [115]		■	■				
KBS Hyperbook [79]	■		■				
Knowledge-Sea II [32]		■	■				
LSAS [3]		■	■				
LS-PLAN [62]	■	■	■				
MANIC [108]	■	■					
MetaDoc [7]		■	■				
MOT 2.0 [27]		■	■				■
ProSys [84]			■				
PUSH [48]		■					
TANGOW [18]	■		■				■
TANGOW-WOTAN [69]	■		■				■
WHURLE [76]		■	■				

It is really a challenge, therefore, for the designers to incorporate as much as possible techniques into their system when designing truly AEHSs. The most of the systems in the Table Ⅰ have implemented the techniques adaptive presentation and navigation that they are considered as main techniques for an adaptive hypermedia system. The combination of interactive problem solving support and adaptive group formation techniques is very important for modern educational systems, but nothing of the AEHS in the Table Ⅰ has been implemented so far. We consider this a very important combination so we adopted it in our system.

Students are diverse in terms of their experience, expectation, abilities and interests, and they vary in the learning styles. Learning styles are preferences for information types (concrete vs. abstract), presentation styles (visual vs. verbal, written) and learning actions such as hands-on versus planning and reflecting about a concept [82].

Students with different learning styles respond differently to various didactic approaches and the didactic strategies should match the learning styles of students [55]. The learning style models that have been used in AEHSs mainly are the Honey & Mumford's model (e.g., INSPIRE, SMILE, AHA), Felder & Silverman's model (e.g., CS383, Flexi-OLM, CAMELEON, ALE), Felder & Soloman's model (e.g., ILASH, TANGOW/WOTAN), Dunn & Dunn's model (e.g., iWeaver), and Witkin's dependence/ independence (e.g., AES-CS).

After an extended literature review of the AEHSs in the Table Ⅰ, we concluded that a learning style model has been adopted by all recent AEHSs, and it also has been immediately connected with the learning theories and didactic approaches that they are based upon. Consequently, the learning style model is a factor of decisive importance when designing modern educational systems as well as the chosen dimensions of students' learning style for group formation should fit with the domain of application. For example, if the domain of application consists of abstract concepts and content (like Physics) then, it would be best to use the abstract and concrete dimensions of students' learning style for forming groups [83].

Different didactic strategies, learning theories, and domain of applications have been used in AEHSs providing the central concept of the interactions that take place between the learner and the system and/or the basis for designing the different modules of the particular systems, such as the didactic model, the domain model, the learner model, and the adaptive mechanism.

After an extended literature review of the AEHSs presented in the Table 1, we can conclude that the kind of adaptive and intelligent techniques that the AEHSs support mainly depends on the learning theories and didactic strategies they use. On the one hand, there are systems supporting learning with didactic strategies such as learning by theory presentations (lectures), text reading, etc. On the other hand, there are systems supporting more learner-centred didactic approaches such as learning by explorations, problem-solving, guided discovery, etc. For example, MANIC uses curriculum sequencing and adaptive presentation techniques adopting didactic strategies based upon the preferences of students for graphical versus textual while ELM-ART uses curriculum sequencing, adaptive navigation support, intelligent analysis of student solutions and example-based problem solving support techniques adopting didactic strategies such as example-based problem solving, learning by examples, etc. We consider that the learning theories and didactic strategies are factors of decisive importance for the selection of the adaptive and intelligent techniques that they would be used in the development of an AEHS.

The AEHSs that have been developed so far use combinations of adaptive and intelligent techniques in order to increase their functionality. Some techniques may be used for all domain of applications (e.g., curriculum sequencing, adaptive presentation and navigation), while other may be used for specific domain of applications (e.g., interactive problem solving support, example-based interactive problem solving support, and intelligent analysis of student solutions). For example, in the first case belongs to the ALICE that supports only the adaptive navigation technique to offer prerequisite-based learning in the domain of Java. In the second case belongs to the ActiveMath that supports curriculum sequencing, adaptive presentation, adaptive navigation, and interactive problem solving techniques to offer active and exploratory learning in the domain of mathematics.

Consequently, we can say that the domain of application in an AEHS may play the most important role in the selection of its adaptive and intelligent techniques.One major goal of learner-centeredness is to provide active and collaborative learning environments [58]. Modern adaptive and intelligent techniques are needed to support didactic approaches such as problem solving, exploratory, and others that should use the learner-centered design (LCD) principles [101]. LCD requires theories that describe what we mean by "gaining expertise" to help develop learner-centered design principles.

Constructivist and *social constructivist* learning theories help us see how to help learners to bridge the gulf of expertise [101]. Constructivist learning theory states that understanding and learning involves active, constructive, generative processes (e.g., assimilation, augmentation, and self-reorganization). Learning is not a passive information transfer process from expert to novice, but rather an active process that employs a "learning by doing" approach where the learner must manipulate the material they are learning [101]. Social constructivist learning theory states that learning is enculturation. That is, learning does not occur in a vacuum, but must occur within some representation of the work context so that learners develop an understanding of that work context and culture. Learners must build their knowledge by participating in the professional work culture to develop an understanding of the common practices, languages, tools, and values of a professional culture [101].

Learning needs to be an active process, where learners ask questions, collect and organize information, and assess their work, all by using tools and engaging in activities from the given work domain. By doing so, learners can begin to develop an understanding of the work culture, i.e., the practices and language of the work domain [91].

Learners, then, need tools that help them with this active engagement in a work domain. Since learners lack an understanding of the work domain, they need additional support (or *scaffolding*) in their tools to help them engage in the new work activities [91]. Certainly learners cannot use the same tools that domain experts use (i.e., learner-centered tools) because of the difference in their levels of expertise. Thus, a learner-centered designer must design tools modeled on expert tools, but structured in ways that allow learners to participate in activities similar to those of domain experts to mediate the learner's development [6]. In addition, an effective learner-centered design except the effective combination of learning theories must also be based on usability principles [116].

Reference [107] proposes some principles about the learner-centered interface design, as well as the issue of integration of usability and learning. The proposed principles are the followings:

- match between designer and learner models;
- navigational fidelity;
- appropriate levels of learner control;

- prevention of peripheral cognitive errors;
- understandable and meaningful symbolic representations;
- support personally significant approaches to learning;
- strategies for cognitive error recognition, diagnosis, and recovery; and
- match with the curriculum.

The design of AEHS MATHEMA is based upon the above principles and it supports curriculum sequencing, adaptive presentation and navigation, interactive problem solving support and adaptive group formation techniques. The innovative techniques making it to distinguish from other AEHSs are the followings:

- the meta-adaptation technique that assists the learner in selecting of the most appropriate navigation technique, among the four techniques that it offers (direct guidance, link annotation, link hiding, and link sorting), that matches in his/her profile by taking into account his/her Web experience and knowledge level of the current learning goal;
- the interactive problem solving technique through activities using modern didactic approaches and combining both individual and collaborative learning. It is important for the Physics learning;
- the adaptive group formation technique that assists the learner in selecting the most appropriate collaborator from a list of candidate collaborators the system creates by taking into account the learner's learning style, the learning style and knowledge level on the current learning goal of candidate collaborators, the system establishes principles for the selection of the most appropriate learning style model, as well as teaching strategies for the adaptive presentation of the educational material according to the domain of application. Moreover, the system uses an "Advisor" advising the learner in his/her navigation.

The rest of the paper are organized as follows. In Section Ⅱ we describe the educational framework of the AEHS MATHEMA. In Section Ⅲ we describe the design of user interface and modules of the system. In Section Ⅳ we present the adaptive mechanism (adaptive and intelligent techniques). In Section Ⅴ we present the summative evaluation of the AEHS MATHEMA, and in Section Ⅵ we summarize the most significant points of our work and we refer to our future plans.

II. EDUCATIONAL FRAMEWORK

In this section, we refer to the design of an educational framework based upon the theories of constructivist and social constructivist that it will direct the educational decisions and the design of the didactic model, domain model, student model, the feedback, and the assessment of learner's knowledge level, as well as we present examples from the educational material.

A. Learning Theory and Learning Styles

Kolb's Experiential Learning Theory (ELT) [55] is a holistic theory of learning and proposes a constructivist theory of learning whereby social knowledge that created and recreated in the personal knowledge of the learner through the combination of grasping and transforming experience. The ELT model portrays two dialectically related modes of grasping experience: *Concrete Experience* (we perceive information by using concrete/ actual experiences such as feelings / touching / seeing / hearing) and *Abstract Conceptualization* (we perceive information best by using abstract thoughts or visual images / concepts, learning from thinking), and two dialectically related modes of transforming experience: *Reflective Observation* (we process information best by watching, thinking and reflecting), and *Active Experimentation* (we process information best by experimenting or doing something in real situations). These approaches to learning are associated with the four phases of the Kolb's learning cycle (Fig. 1).

Reference [55] argues that most people prefer to learn in one of four ways or styles, each of which represents one quadrant of the experiential learning cycle. Reference [55] labels these four ways or styles of learning: *Diverging*, *Assimilating*, *Converging*, and *Accommodating.* Reference [55] suggests that students develop a preference for learning in a particular way. The preferred style reflects a tendency rather than an absolute and students may adopt different learning styles in different situations, but they tend to favor some learning behaviors in preference to others. Kolb developed a self-completion questionnaire, the *Learning Style Inventory* (LSI) [54], so that the learners can identify their preferred learning style.

Learners with Diverging learning style are oriented toward feelings and people, and they have the ability to view concrete experiences from a number of perspectives. They prefer to learn through questions, simulations, visualizations, and perform better in situations that call for generation of ideas. Learners with Assimilating learning style are oriented toward rational, logical thinking and analysis, have the abilities to formulate theories and prefer abstract concepts. Learners with Converging learning style are oriented toward action and practicality, and they have strength on the practical applications of ideas and problem solving. Learners with accommodating learning style are oriented toward exploration and risk taking, and they have strength on doing things. People with an accommodative orientation tend to solve problems in an intuitive trial and error manner.

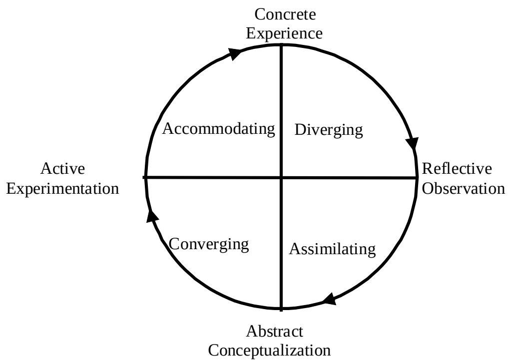


Fig. 1 Kolb's learning cycle

Learners learn from their individual interactions with educational resources, but they can also acquire knowledge during the accomplishment of activities in collaboration with others. Thus, the ELT provides a framework for understanding and managing the way teams learn from their experience. Since research into learning styles suggests that individuals learn differently, it is logical that some learners would prefer to learn individually, while others would prefer to learn from interaction in groups. People with different learning styles generate different perspectives in effective strategies for dynamic group interactivity [53, 54]. In addition, some of the learning style's dimensions have more effect on the collaborative work than others [83].

B. Didactic Model

Experiments of [38] indicated that learners have difficulties in the selection of the most important or the most profitable information in educational settings. According to [93], an important evolution towards new educational approaches is adaptive educational systems. He emphasizes characteristics like adaptation to individual needs, interests, and learning styles. Further on, he recommends a continuous monitoring and improvement of didactic methods and a strict separation of didactic methods and content. Also, [75] suggests the following didactic design principles: (a) relying on real-world problems; (b) activation of prior knowledge; (c) new knowledge must be demonstrated to the learner; (d) learners shall apply the new knowledge, and (e) the new knowledge must be integrated into the "learner's world".

As domain of application of the AEHS MATHEMA initially selected the physics, in the current version the AEHS MATHEMA has developed educational material for the electromagnetism. One important individual need of the learners in physics learning is to understand the subject matter and to avoid misconception and learning difficulties.

The Learners have particular difficulty in comprehending Physics concepts which have very few real-life referents and which incorporate invisible factors, forces operating at a distance, and complex abstractions [23]. Even advanced learners have difficulty in grasping non-intuitive, abstract concepts such as those found in electromagnetism [35]. It is possible, therefore, for the learners to have misconceptions and learning difficulties when studying electromagnetism. Indicatively, we present two *common misconceptions* in electromagnetism (section: *charged particle motion perpendicular to the direction of a uniform magnetic field*) that have been documented by [2, 66]:

- the learners consider that the magnetic poles exert forces on electric charges in the plane of the charge and magnet, regardless of whether the charge was moving or not, and that,
- a constant magnetic field changes the speed (magnitude of velocity) of a charged particle which moves in it.

Also, [2] mention that the learners have difficulty in determining the direction of the *Lorentz* force.

Research has established that learners' misconceptions in science are very tenacious and that conventional instruction is notably ineffective in promoting conceptual change [31]. One of the common strategies to foster conceptual change is to confront learners with discrepant events that contradict their misconceptions. This is intended to invoke *cognitive conflict* [87] that induces learners to reflect as they try to resolve the conflict. The discrepant events may be demonstrations or phenomena, which require learners to explain or make predictions.

Computer simulations can also be used to provide such discrepant events. This has additional advantage that learners can explore the simulation by changing the parameters and variables and visualizing immediately the consequences of their manipulations. Learners can interpret the underlying scientific conceptions of the program and compare them with their own conceptions. How to engage younger learners in complex Physics thinking is a challenge, but simulations provide one intriguing way to engage learners in the study of abstract, complex physical phenomena [30]. Computer simulations have been shown to be effective in conceptual change [72]. The cognitive conflicts arising from the simulations, lead the learners to discover possible misconceptions and reconstruct their own cognitive models [42].

While teaching in the frame of the constructivism, it is necessary to take learners' misconceptions and learning difficulties into consideration by using different teaching strategies and activities in order to support learners to reconstruct their own cognitive models, and designing learning environments where they can construct their ideas by themselves and co-construct their ideas by collaboration with their peers.

The reference [30] suggests that Physics is best taught through experiments, labs, demonstrations and visualizations, which help the learners to understand physical phenomena conceptually.

According to [25], Physics being an experimental science, observation, measuring and theoretical speculations are processes that cannot be separated from the physical knowledge construction, even in the classroom. According to [98], educators should consider stimulating the basic purposes of schooling curiosity, exploration, problem solving, and communication.

In the case of AEHSs, the use of multiple teaching strategies increases the possibilities to respond effectively the system in the aspect of needs and the demands of heterogeneous learners. To get the learners more effective, they should use multiple didactic approaches based upon the learning styles of learners [4].

For the didactic design of the AEHS MATHEMA regarding the specification and the selection of the most appropriate learning theory, didactic strategies, learning style for the selected domain of application, and educational material, we took into consideration the following:

- one major goal of learner-centeredness is to provide active and collaborative learning environments [58];
- students with different learning styles respond differently to various didactic approaches and the didactic strategies should match the learning styles of students [55];
- Students will be able to achieve learning goals more efficiently when pedagogical procedures are adapted to their individual differences [33].
- Since research into learning styles suggests that individuals learn differently, it is logical then that some learners would prefer to learn individually, while others would prefer to learn from interaction in groups. People with different learning styles generate different perspectives in effective strategies for dynamic group interactivity [54].
- the learning style model is a factor of decisive importance when designing modern educational systems (conclusion in Section I).

- an effective learner-centered design must be based on the effective combination of learning theories and usability principles [116].
- A learning style model has been adopted by all recent AEHSs, and it also has been immediately connected with the learning theories and didactic approaches that they are based upon (conclusion in Section I)
- The learning theories and didactic strategies are factors of decisive importance for the selection of the adaptive and intelligent techniques that they would be used in the development of an AEHS (conclusion in Section I).
- Modern adaptive and intelligent techniques are needed to support didactic approaches such as problem solving, exploratory, and others that should use the learner-centered design (LCD) principles [101].
- Some of the learning style's dimensions (i.e., concrete-abstract) have more effect on the collaborative work than others [83].
- The domain of application in an AEHS may play the most important role in the selection of adaptive and intelligent techniques (conclusion in section I) as well as the chosen dimensions of students' learning style for group formation should fit with the domain of application [83].
- The learning theories and didactic strategies are factors of decisive importance for the selection of the adaptive and intelligent techniques that they would be used in the development of an AEHS (conclusion in Section I).
- The proposals of [75, 30, 25, 98, 72, 4] are mentioned above.
- The proposals of [100] for the production of high quality educational software in Physics, which are the following:
- We should implement simulations of phenomena and process that are very difficult or dangerous to implement in a school environment as well as the creation and study of alternative worlds.
- We should create multiple representations for a physical phenomenon.
- We should specify the content in the basis of the learners' cognitive needs and utilize the errors of learners.
- The increased interactivity between the learner and computer and the promotion of learner's autonomy, may help the comprehension, creation, and construction of scientific knowledge.
- The design principles of constructivist type educational software [8]. These principles include:
    - the use of authentic learning tasks so that the learning is seen as meaningful by the students;
    - the use of discovery learning methods that enable the students to construct their own understanding, rather than instruction by a computer;
    - an emphasis on learning how to learn and how to solve problems rather than learning facts;
    - support collaborative learning and problem-solving.

All of the above-mentioned advocate selection of the most appropriate learning theory including both constructivist and social constructivist principles. This theory is Kolb's Experiential Learning Theory for the following reasons:

- it is a holistic theory of learning that is based on the constructivist and social constructivist theories. As holistic theory may cover every kind of educational material;
- it can cover all proposals of [75, 30, 25, 98, 72, 4, 100, 8];
- it can match the appropriate didactic strategies in learners' learning style by exploited the researches of [109, 44];
- having selected as domain of application the Physics, the learning style model of Kolb [54] can recognize the concrete-abstract dimension of learning style for group formation;
- it supports a learning style model that satisfy all the criteria of the most appropriate learning style model suggested by [95], as follows:
    - empirical justification: it is supported by [109] and [44] researches;
    - assessment instrument: Kolb has developed the Learning Style Inventory (LSI) Questionnaire to recognize the learners' learning style;
    - description of didactic strategies: After extended researches, [109, 44] have proposed the most appropriate didactic approaches for each learning style;
    - appropriation of the context: As to the appropriation of the context, we conducted an experimental study based upon the Kolb's ELT and the researches of [109, 44]. The results indicated that the participants significantly improved their knowledge level by studying through the AEHS MATHEMA [83];
    - cost: It has a low cost.
- It can support didactic approaches for conceptual change such as simulations, explorations, guided discovery, etc;
- It can support an educationally and technologically feasible adaptive framework.

The most effective learners should use multiple strategies to ensure that they monitor their comprehension. Thus, we need adequate didactic strategies in order to promote meaningful learning. Taking into consideration all the above as well as the proposals of [109] and [44] about the most appropriate didactic approaches matched to each learning style of learners, we selected the following didactic approaches: *questions using analogies and/or video simulations, presentation of theory and examples, exercise solving, and problem solving activity.*

Moreover, in the development of the educational material we took care of the content quality of the courses to improve learners' achievement.

III. DESIGN OF USER INTERFACE AND MODULES

A. User Interface

In Fig. 2, we can see the user interface of the AEHS MATHEMA. In each page, there are three different areas, the Tool-Bar Area, the Navigation Area and the Content Area.

The Tool-Bar Area includes all the appropriate tools for interaction with the system (Student model, Group formation, Help, Symbols, Physics quantities, and Notes).

The Navigation Area includes the links to current main concept content, and links to other main concepts in a hypertext form. A structural navigation form of links [81] has been adopted to outline the structure of the main concepts and the structure of the main concept contents in order to support learner-controlled navigation, as it is adopted by INSPIRE.

Learner's orientation and navigation is supported by changing the appearance of the links and icons in the Navigation Area in order to:

- propose a navigation route according to learner's progress;
- inform learners of their knowledge level on the different main concepts of the current learning goal;
- denote the current educational material page and the pages already visited. The links to content of a main concept are different for different didactic approaches, and consequently, different for students with different learning style. Links to pages of a main concept are colored magenta. An animated arrow in front of the link denotes the current page (see Fig. 2). Moreover, there are links to concepts from previous learning goals related to the current main concept. Furthermore, in front of the link to a main concept there is additional information about the current knowledge level of the student, i.e., his/her knowledge level on a main concept. In particular, the filling of a *clepsydra* (sandglass) is adopted as a visual metaphor to denote the students' progress.

A history-based mechanism has also been developed to support students' orientation in the domain space; thus, a check mark (✓) appears in front of the link to a content page, after its visit (see Fig. 2).

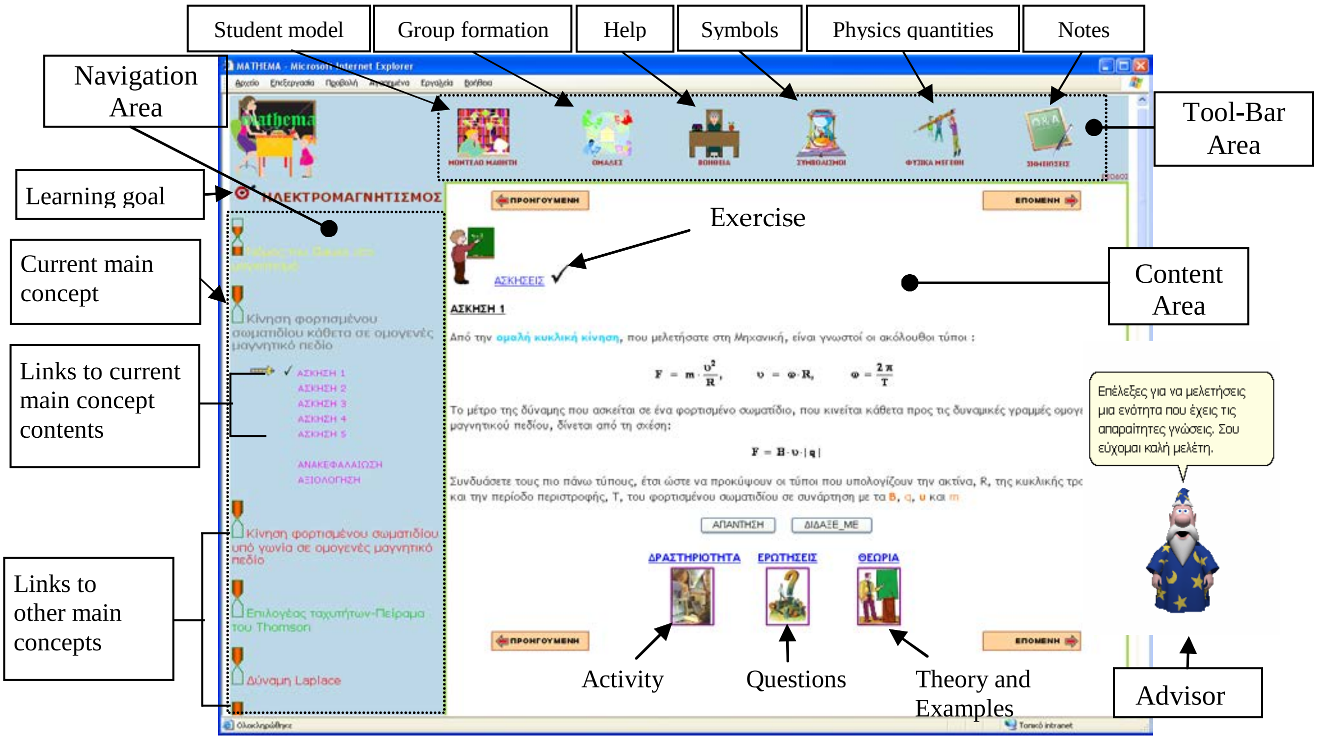


Fig. 2 User interface of the AEHS MATHEMA

Our system, apart from the traditional navigation techniques, it makes use of an "Advisor" (see Fig. 2) that assists the student, after each of his/her link choice, reminding to him/her the meaning of color of his/her chosen link. For example, if the color of his/her chosen link is red, then the "Advisor" reminds the student that he/she is not ready to study the chosen main concept and it also recommends to the student that it would be best for him/her to choose any other link with a green color. The "Advisor" also informs the student, when he/she makes use of the link hiding technique, that the system has presented additional links in the Navigation Area, after his/her successful assessment of the prerequisite main concepts.

Furthermore, the student has the ability through his/her Student Model on the Tool-Bar Area to activate/deactivate the "Advisor", if he/she does not wish suggestions from it, after each of his/her link choice.

The Content Area contains the educational material.

B. Domain Model

The structural element of an AEHS is the representation of knowledge through the domain model. The domain model is structured in such a way to support the system to select the educational material according to the needs and the current state of each learner. The domain model of the AEHS MATHEMA is the base of adaptation design. In the design process, we took into consideration the representation of knowledge as well as the quality of educational material that have significantly influence on the quality of educational efficacy. The system is designed to include a set of learning goals. Each learning goal relates to a set of main concepts appropriate for its comprehension.

The domain model of the AEHS MATHEMA adopts the hierarchical representation of knowledge as it has been implemented by ELM-ART and INSPIRE systems, as follows: At the first level, the *learning goals* are defined, at the second level, the *main concepts* are defined, and at the third level, the *pages with the corresponding educational material* are defined. The concepts of a learning goal are declared with their own qualitative features, in the same way of that of INSPIRE's domain model, as follows: *main concepts, prerequisite concepts, and relative concepts*, moreover, in the AEHS MATHEMA the *degree of difficulty* of each main concept is declared. Table Ⅱ shows a part of the domain model of the AEHS MATHEMA concerning the learning goal of electromagnetism.

TABLE Ⅱ A PART OF THE DOMAIN MODEL OF THE AEHS MATHEMA

	Main Concept	Degree of Difficulty	Prerequisite(s)
1	Electric Field Intensity	1	-
2	Electric Flow	2	1
3	Gauss's Law of Electricity	3	1,2
4	Electric Potential and Electric Potential Difference	1	1,2
5	Charged Particle Motion in Uniform Electric Field	2	1,4

In the Table Ⅱ, we can see a few main concepts with their degree of difficulty and prerequisite(s). The low degree of difficulty concepts are represented with Number 1, the medium degree of difficulty concepts are represented with Number 2, and the high degree of difficulty concepts are represented with Number 3. For example, the main concept of electric field intensity has a low degree of difficulty and no prerequisite. The main concept of Gauss's law of electricity has a high degree of difficulty and prerequisite main concepts, both the electric field intensity and electric flow.

For each didactic approach, the domain model offers one to six pages with educational material (in the current version of the AEHS MATHEMA). Thus, for example, we can have six pages to solve the exercises so that they shall have different degree of difficulty and support of the three lower levels (knowledge, comprehension, and application) of Bloom's taxonomy. The system maintains the following information in the domain model:

- learning goals,
- main concepts for each learning goal,
- prerequisites,
- degree of difficulty for each main concept, and
- pages with educational material.

C. Student Model

The kind of student model that supports the AEHS MATHEMA is the *overlay model*. This model provides information about the knowledge level, learning style and other characteristics of students as well as it allow the student to interact with it and to update. Moreover, it includes items from the interaction of the student with the system regarding his/her progress in relation with the didactic design and offered opportunities. The system monitors the student interactions with it and his/her assessment, as long as he/she studies through the AEHS MATHEMA, and it reads just the links to educational material and/or the educational material. The characteristics of the system maintenance of the student model are as following:

- first name and surname,
- gender,
- username,
- password,
- learning style,
- current learning goal,
- current didactic approach,
- current page,
- current navigation technique,
- knowledge level of each learning goal,
- knowledge level of each main concept (quantitative and qualitative description),
- number of main conceptions that he/she has been success in the assessment tests,
- navigation history,
- meta-adaptation state,
- initial Web experience and knowledge level (prior knowledge) to the current learning goal,
- presentation way of the feedback messages,
- preference about the navigation assistance offered by the "Advisor",
- activation/deactivation of the curriculum sequencing technique,
- phases of the guided dialogues that the learner participates during the interactive problem solving.

The initialization of the student model is done in the same way as the AST, Hypadapter, and INSPIRES systems. That is, when the learner logs in the system for the first time, he/she:

- selects the initial learning goal;
- declares his/her preference for one among three presentation ways of feedback messages;
- declares his/her level of Web experience and his/her knowledge level on the selected learning goal;
- declares if he/she wishes to have assistance from the "Advisor" concerning his/her navigation;
- completes the Kolb's LSI questionnaire in order to obtain the recognition of his/her learning style.

The student model is transparent for the learner (open learner model) and controllable by him/her. That is, the learner has the access ability to his/her individual model with the aim to see or change some of his/her characteristics.

Especially, the learner is given the following accessibilities:

- choice of his/her learning goal;
- utilization of the system's assistance concerning his/her navigation;
- information about his/her characteristics that he/she can change with the aim to control the adaptation of the system regarding the curriculum sequencing, adaptive presentation and navigation, and the adaptive group formation techniques;

- updating of his/her learning style;
- updating of his/her navigation technique;
- updating the presentation way of the feedback messages;
- activation/deactivation of the curriculum sequencing technique;
- activation/deactivation of the navigation assistance offered by the "Advisor";
- changing his/her knowledge level for each main concept.

From the characteristics of the system maintenance for each learner, seven of them only are presented to him/her through the Student Model. In Fig. 3, we can see a snapshot of the Student Model of the AEHS MATHEMA. As you can see, the seven characteristics are the following: learning style, current navigation technique, activation/deactivation of the curriculum sequencing technique, presentation way of the feedback messages, preference about the navigation assistance offered by the "Advisor", knowledge level of each main concept (qualitative description), and phases of the guided dialogues that the learner participates during the interactive problem solving.

D. Feedback

The system helps learners to meet their goals by giving them the appropriate feedback. Cognitive psychologists consider feedback as one of the vital sources of information necessary for the correction of incorrect responses to help the learners to reconstruct their cognitive models and support them in meta-cognition processes [56].

Contemporary learning theories emphasize the importance of feedback. Reference [114] relates feedback to different points in the learning experience and sees it as a tool for scaffolding learners toward more self-regulation. The construction of self-regulation refers to the degree to which learners can regulate aspects of their thinking, motivation and behavior during learning [89], and involves the development of specific strategies that help learners evaluate their learning, check their understanding and correct errors when appropriate [113].

According to [113], teachers can improve students' ability to transfer what they have learned at school by helping students learn how to monitor their learning and how to seek and use feedback about their progress. In addition, she supports that the feedback should guide and tutor learners as well as stimulate and cultivate processes like self-explanation, self-regulation, self-evaluation, which require experience and reflection. Reflection is defined as a cognitive activity for monitoring, evaluating, and modifying one's thinking and process [63].

According to [70], the effective feedback aims at:

- assisting learners in identifying their false beliefs, coming aware of their misconceptions and inadequacies, and reconstructing their knowledge;
- assisting learners determine performance expectations, identify what they have already learned and what they are able to do, and judge their personal learning progress;
- supporting learners towards the achievement of the underlying learning goals;
- providing two types of feedback, the verification and elaboration.

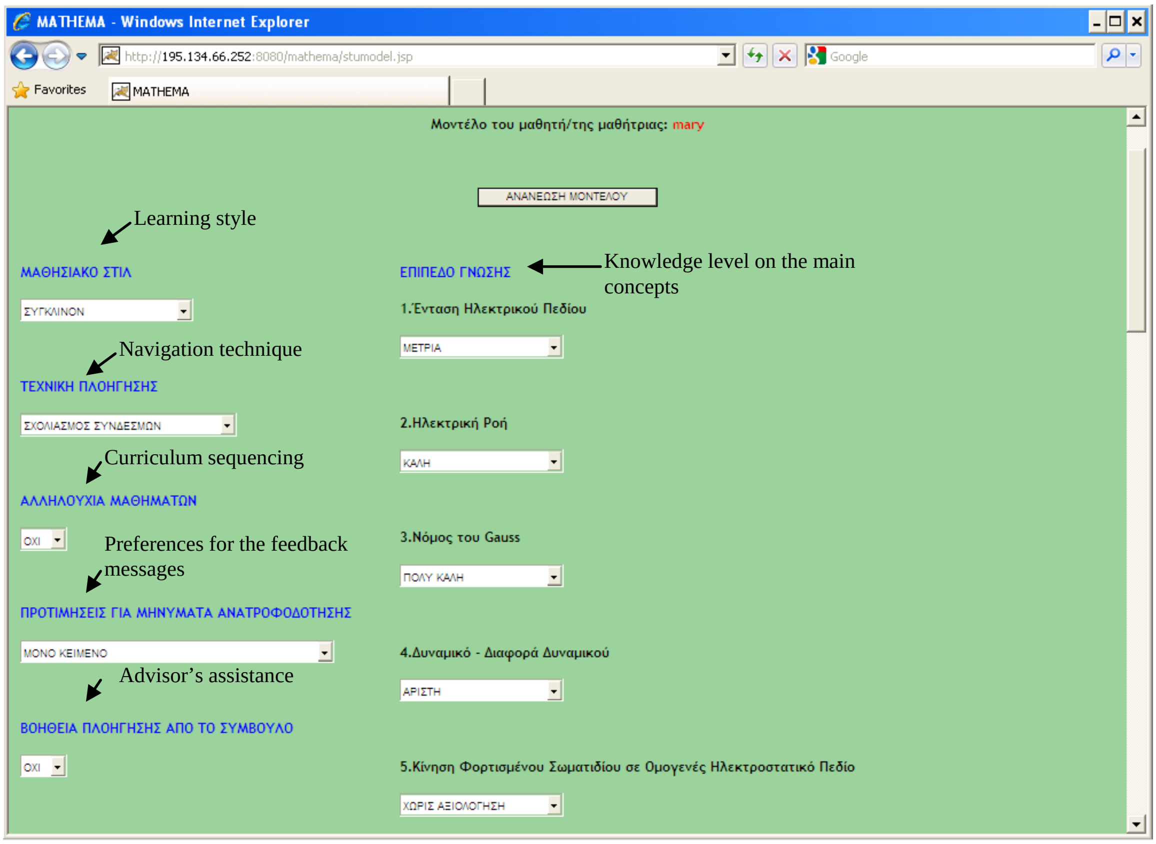
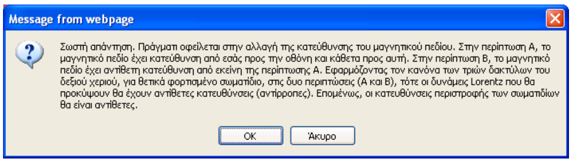


Fig. 3 A snapshot of the Student Model of the AEHS MATHEMA

The feedback method we use is the combination of *response-contingent* with *answer-until-correct* methods. This method uses both verification and elaboration to provide the learner with additional knowledge related to the question he/she has been asked also explains why the correct answer is correct or why the wrong answer is wrong. In the case the student chooses a wrong answer, the system does not give to him/her the correct answer, but it gives to him/her appropriate additional information to guide him/her towards the correct answer.

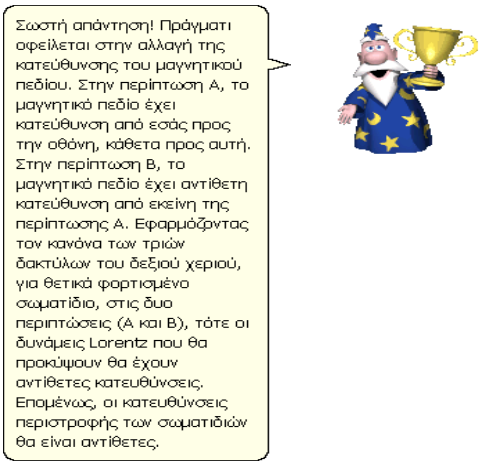
Feedback in the AEHS MATHEMA is supported as follows:

(a) through text, speaking, or with a combination of text and speaking (Fig. 4).



(a) text

(b) speaking



(c) text and speaking

Fig. 4 Three ways of feedback messages presentation

(b) through guided dialogues. Fig. 5 shows an example of a guided dialogue.

Your calculated value is incorrect. Perhaps it is due either to the wrong use of the formula that calculates the radius R or to the wrong use of standard metrics (SI) units or to the wrong calculation of the absolute value of the charge q or to the wrong calculations. The mathematical formula that calculates the radius R of the particle circular motion is:

$$R = \frac{m \cdot v}{B \cdot |q|}$$

Repeat your calculations and select one of the answers below:

- Zero
- Infinite
- Indeterminable
- Else

Choice: Indeterminable

Generally, the value of a fraction is infinite if the numerator is not zero or infinite and the denominator is zero. So, the value of the radius R is infinite if the numerator is not zero or infinite, and the denominator is zero. However, since the value of linear velocity v is zero, the numerator is zero. Also, B and q are not zero, so the denominator is not zero. Consequently, the value of the radius R is not infinite but it is zero.

Do you insist that the value of the radius R is infinite?

- Yes
- No

Choice: Yes

During your study of simulation you might have concluded that the radius R of the circular motion of the particle is infinite if the particle moves rectilinearly. In this case, the particle remains motionless. This means that the radius R of the circular motion is zero.

Fig. 5 An example of guided dialogue

E. *Assessment of Learner's Knowledge level*

The assessment of learner's knowledge level:

- is a constituent part of an AEHS. In general, the adaptive systems offer educational material adapted to abilities and needs of learners;
- is used for curriculum sequencing, adaptive presentation, adaptive navigation, and adaptive group formation and/or peer help;
- intents to determine the knowledge level of an individual learner about a concept;
- is done with the measurement of knowledge level of learner to one or more assessment tests including questions or exercises, referring to a concept or set of concepts, which have different degree of difficulty. An important issue in this case is the specification of the degree of difficulty of the questions or exercises. Also, another important issue is the optimal design of the test so that to respond in learning outcomes.

In the AEHS MATHEMA, the learners' knowledge level on the main concepts of each learning goal that they study is evaluated by using the assessment tests that the students submit to the system. The AEHS MATHEMA uses a conventional test, including at most twenty multiple-choice questions, to assess the learner's knowledge level for each main concept. For each question is given a weight (percentage to total score) equivalent to the question's degree of difficulty (four levels). The weights are decided by an expert physician to take into account the degree of difficulty of each question or exercise, and learning outcomes. The total score results from the sum of all the weights of learner's correct answers, and it estimates the *quantitative assessment* of learner's knowledge level for a main concept.

The *qualitative assessment* of learner's knowledge level results from a fuzzy logic estimation. The qualitative assessment of learner for a main concept takes values in the set: {No Assessment, Inadequate, Almost Adequate, Adequate, and Advanced}. The filling of a *clepsydra* (sandglass) is adopted as a visual metaphor to denote the students' progress (see Table III).

TABLE III VISUAL METAPHOR OF LEARNER'S KNOWLEDGE LEVEL

No Assessment	Inadequate	Almost Adequate	Adequate	Advanced
				

The minimum knowledge level for a student to succeed in the assessment tests is a variable of the system. The system administrator (e.g. the teacher) has the ability to change the minimum knowledge level through parameterization offered by the system.

For example, if the system administrator determines that the "Almost Adequate" is the minimum knowledge level that the student has to succeed for a main concept, then the assessment of the student will be successful if his/her knowledge level will be characterized at least as "Almost Adequate".

The assessment of learners' knowledge level is used by the system for adaptive navigation support and group formation.

F. Educational Material

In the following, we give a general description of the educational material about the didactic approaches we have mentioned:

1) Questions Using Analogies and/or Video Simulations:

We make use of analogies in order to connect the learner's prior knowledge with the new knowledge to help students familiarize with concepts that are abstract and outside their previous experience. In order to be effective, analogies must be familiar to students, and their features/functions must be congruent with those of the target. Since adult perspectives are not identical with those of adolescents, it is not surprising that, even though students are familiar with the physical phenomena or event that might be used as the analogy, they are not always familiar with those features that provide the similarity to the target.

Once a suitable analogy is found, considerable time must be spent by students in discussion of similarities between the analogy and the target. It is also important for students to understand how the analogy and target differ to avoid confusion or misconceptions. The analogies not only help students construct their own knowledge but they also assist the system in basing instruction on students' prior knowledge and existing misconceptions.

Thus, the AEHS MATHEMA, in order to motivate students to learn by provoking their interest, uses an analogy which is familiar to students (e.g., the motion of the moon around of the earth) and the target is from electromagnetism (e.g., charged particle motion in the uniform magnetic field) and then, we ask them to find out similarities and differences.

We make use of various video simulations in order to help learners be able to find out relations between physical quantities (or dimensions), by comparing the simulations (similarities and differences) and to answer questions. The system helps learners meet their goals by giving them the appropriate feedback.

In this case, the learners follow the following steps:

STEP 1: they make predictions of the kind of motion (e.g., a charged particle which is moving in the magnetic field),

STEP 2: through video simulations they observe the real motion and then compare their prediction with the observed motion, and

STEP 3: they answer questions, and receive feedback from the system for reflection and self-correction.

2) Presentation of Theory and Examples:

The system provides the learners with the appropriate theoretical background with the main concept of Physics that they have chosen to study. It also provides the learners with various examples of solved exercises. Undoubtedly, examples are crucially important for educational goals. Reference [1] identified didactic principles and processing strategies. For example, a successful principle might be the provision of examples with different superficial features or the provision of completion problems within which certain information of examples must be added.

Moreover, the system presents the examples of solved exercises to the learners step by step, by making use of flash animations.

3) Exercise Solving:

The system provides the learners with various exercises, related to the current main concept and some answer of their solution, covering the knowledge, comprehension, and application levels of Bloom's taxonomy. The system guides the learners to find out the correct answer (solution) among the given answers (solutions) of an exercise by giving them the appropriate feedback.

In this didactic approach, the learners follow the following steps:

STEP 1: The learners are given exercises and they are asked through multiple-choice options to select the correct answer.

STEP 2: In the case that they have selected a wrong answer, the system gives the appropriate feedback to them in order to help them to reflect.

STEP 3: The learners select another option and the system repeats the Steps 2 and 3 until the learners to select the correct answer.

The following exercise solving example is intended to help learners overcome their misconception that they usually have on this main concept, which is: a constant magnetic field changes the speed (magnitude of velocity) of a charged particle that moves in it [2].

An exercise-solving example: we have a charged particle moving at constant speed rectilinearly. Then, it is moving in a plane perpendicular to a magnetic field executing a semi-circular orbit with the magnetic force, and it is moving rectilinearly again (see Fig. 6).

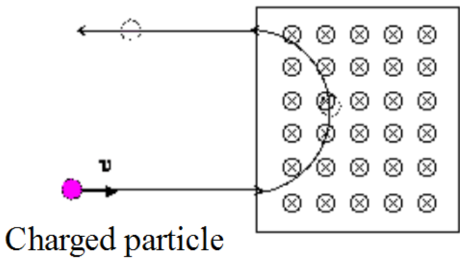


Fig. 6 A charged particle moving

Questions:

a) The particle is:
- positive charged;
- negative charged.

b) In which of positions below the magnitude of velocity is the biggest?
- before the charged particle comes into the magnetic field;
- when the charged particle is moving in the magnetic field;
- when the charged particle comes out of the magnetic field;
- everywhere the magnitude of velocity of the charged particle is the same.

Table Ⅳ presents the feedback that the learner receives after his/her selection.

4) Problem Solving Activity

It is described below in the Interactive Problem Solving Support technique of what the AEHS MATHEMA offers.

IV. ADAPTIVE MECHANISM

In this section, we refer to adaptive and intelligent techniques that our system supports. In order to meet our goals, we implemented the following adaptive and intelligent techniques in our system: curriculum sequencing, adaptive presentation, adaptive and meta-adaptive navigation support, interactive problem solving support, and adaptive group formation in the effort of developing a fully learner-controlled, usable, functional, and user-friendly system. The adaptation mechanism is based upon the didactic model, domain model, and student model in order to take decisions about the above techniques.

The specific characteristics of learners that the adaptation mechanism use for adaptation are the following: learning goal, knowledge level for each main concept, knowledge level on each learning goal, Web experience, learning style, abstract or concrete dimension of learning style, preference for visual and/or verbal feedback, and preference for the kind of navigation.

A. Curriculum Sequencing

Personalized curriculum sequencing is an important research issue for web-based learning systems because no fixed learning paths will be appropriate for all learners. Therefore, many researchers focused on developing Web systems with personalized learning mechanisms to assist on-line web-based learning and adaptively provide learning paths in order to promote the learning performance of individual learners.

TABLE Ⅳ FEEDBACK GIVEN BY THE SYSTEM ACCORDING TO LEARNER'S SELECTION

Options	**System's feedback**
Positive charged	Correct answer! Indeed, if we make use of the right hand rule, for a positive charged particle, we will have this kind of motion.
Negative charged	You should make use of the right hand rule. Keep in your mind that the exerted force on a positive charged particle is in the opposite direction with those of a negative charged particle.
Before the charged particle comes into the magnetic field	Initially, the charged particle is rectilinearly moving with a constant velocity. When it enters the magnetic field then the Lorentz force is exerted on it and forces it in moving on a circular orbit. As you know from the mechanics in circular motion the magnitude of the particle velocity remains constant while its direction is changed. Consequently, the magnitude of particle velocity before and in the magnetic field is the same.
When the charged particle is moving in the magnetic field	
When the charged particle comes out of the magnetic field	Initially, the charged particle is rectilinearly moving with a constant velocity. When it enters the magnetic field then the Lorentz force is exerted on it and forces it in moving on a circular orbit. As you know from the mechanics, in circular motion the magnitude of the particle velocity remains constant while its direction is changed. When the charged particle comes out of the magnetic field, no force is exerted on it, so it will continue at the same velocity (the same magnitude and direction) it was previously going.
Everywhere the magnitude of the velocity of the charged particle is the same	Correct answer! Indeed, the magnitude of velocity of the charged particle is the same everywhere. Initially, the charged particle is rectilinearly moving with a constant velocity. When it enters the magnetic field then the Lorentz force is exerted on it and forces it in moving on a circular orbit. As you know from the mechanics, in circular motion the magnitude of the particle velocity remains constant while its direction is changed. When the charged particle comes out of the magnetic field no force is exerted on it, so it will continue at the same velocity (the same magnitude and direction) it was previously going.

However, most personalized Web systems usually neglect to consider if learner ability and the difficulty level of the recommended courseware match while performing personalized learning services. Moreover, the problem of concept continuity of learning paths also needs to be considered while implementing personalized curriculum sequencing because smooth learning paths enhance the linked strength between learning concepts. Generally, inappropriate courseware leads to learner cognitive overload or disorientation during learning processes, thus reducing learning performance [22].

The concepts of each learning goal in the AEHS MATHEMA are progressively presented following the internal structure of the concepts. The concepts of the learning goal are organized in a *layered structure* following a simple-to-complex sequence [94], according to which at the first layer the simplest and more fundamental concepts are included, providing an overview of the learning goal, and then, subsequent layers of concepts add complexity or detail to a part or aspect of the learning goal [85].

Curriculum sequencing is used in combination with the link annotation technique (see below). This combination is used in the case that the learner, at the first time who logged in the system, has declared that he/she has little or no Web experience and medium knowledge level of the current learning goal. In this case, the main concepts of the learning goal are presented in three layers. In the first level, the main concepts with low degree of difficulty are presented. In the second level, the main concepts with medium degree of difficulty are presented, and in the third level, the main concepts with high degree of difficulty are presented. In order to have the student study the main concepts of the next level must study the main concepts of the current level.

B. Adaptive Presentation

The most effective learners should use multiple strategies to ensure that they monitor their comprehension. The goal is for the student to develop self-awareness of his/her comprehension [4]. Thus, we need adequate didactic strategies in order to promote meaningful learning. If the learners are able to determine their own pathway in selecting the available information, in the manner that best suits to their own learning style, then the whole learning process may be more efficient [9].

According to [55], learners learn better when the subject matter is presented in a style consistent with their preferred learning style. The cycle may be entered at any point, but the stages should be followed in sequence. The learning cycle thus provides feedback, which is the basis for new action and evaluation of the consequences of that action. Learners should go through the cycle several times, so it may best be thought of as a spiral of cycles. It would be the best for them to start with the corresponding stage that fits better to their learning style.

According to [55], the conditions under which learners learn better are the following:

Assimilating: when presented with sound logical theories to consider;

Converging: when provided with practical applications of concepts and theories;

Accommodating: when allowed to gain 'hands on' experience;

Diverging: when allowed to observe and gather a wide range of information.

As we mentioned in previous section, we selected the following didactic approaches as the most appropriate for the domain of application (electromagnetism): questions using analogies and/or video simulations, presentation of theory and examples, exercise solving, and problem solving activity.

Taking all the above into consideration, we conducted a research on the subject of electromagnetism. Didactic strategies and educational material were adapted by the AEHS MATHEMA to the students according to their learning styles, as follows:

Diverging: (a) Questions using analogies and/or video simulations, (b) Presentation of theory and Examples, (c) Exercise Solving; (d) Problem Solving Activity;

Assimilating: (a) Presentation of theory and Examples, (b) Exercise Solving, (c) Problem Solving Activity, (d) Questions using analogies and/or video simulations;

Converging: (a) Exercise Solving, (b) Problem Solving Activity, (c) Questions using analogies and/or video simulations, (d) Presentation of theory and Examples;

Accommodating: (a) Problem Solving Activity, (b) Questions using analogies and/or video simulations, (c) Presentation of theory and Examples, (d) Exercise Solving.

The results of this research indicated that the participants improved their performances a lot [83]. Didactic strategy applied for each learning style is the sequence of didactic approaches. The educational material is the same for all learners.

Fig. 7 shows how our system applies the didactic strategy for a learner with converging learning style named Giorgos. It presents an exercise to be solved by Giorgos and at the bottom of the educational material page, it also presents the appropriate three linked icons to educational material related to other didactic approaches. Reference [55] suggests the learners follow all stages successively. However, Giorgos is free to choose the next educational material to study if it is necessary.

C. Adaptive Navigation Support

Not all learners can manage the high level of control offered by hypermedia systems. Some learners may lost or become disorientated in such systems [81], and a number of studies indicate that learners' prior knowledge is an essential factor that influences the degree of disorientation that learners experience in hypermedia systems. In particular, novice hypermedia users met more disorientation problems [37, 60]. Reference [60] also found that students with high prior knowledge of the content were better able to navigate easily, remember where they had been, and decide how to get to where they wanted to go. These students reported more feelings positive about using the system than did the low prior knowledge students and seemed to suffer much less from frustration while performing their tasks.

Another study by [73] examined the effects of prior knowledge on hypermedia navigation and showed that subjects who lacked sufficient prior knowledge of the topic covered, demonstrated more disorientation problems than subjects with high prior knowledge. Non-knowledgeable learners tended to open more additional notes, which suggested that they could not remember where they had been and that they had difficulties in finding the information that they required.

Research into individual differences suggests that prior knowledge has significant effects on student learning in hypermedia systems with experts and novices showing different preferences to the use of hypermedia learning systems and requiring different levels of navigation support.

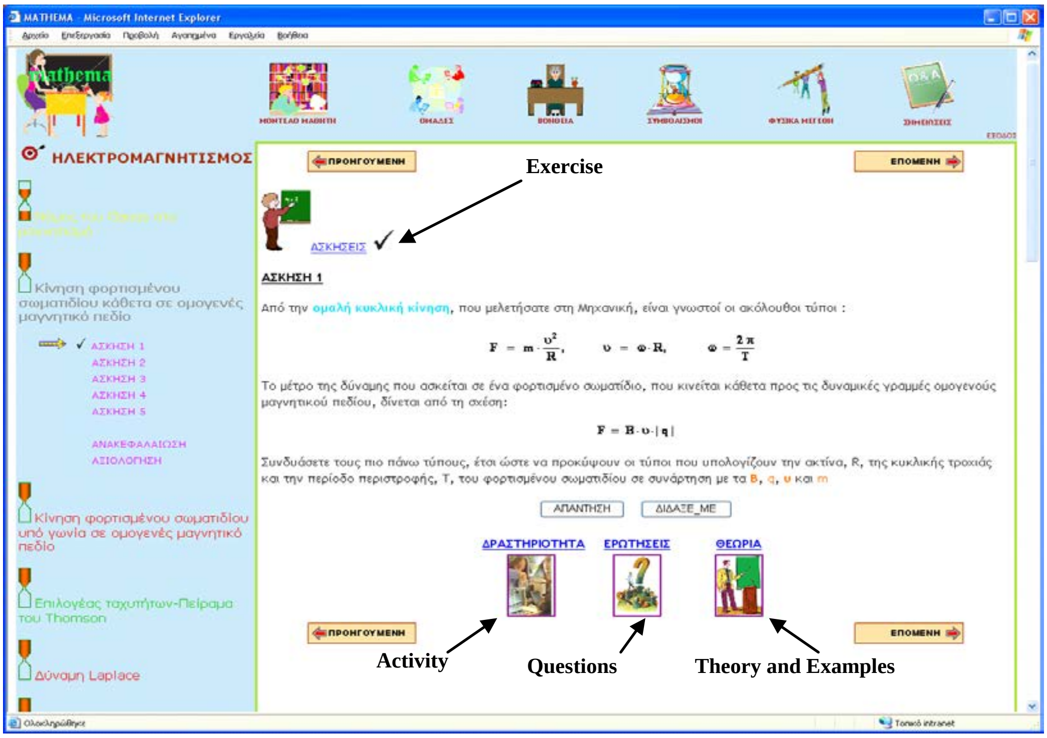


Fig. 7 A page of the system where the educational material has adapted to Giorgos who has “Converging” learning style

Reference [61] investigated the differences between novices and experts in searching for information on the Web. They found that experts performed significantly faster and better on searches for sites using a search engine than novices did. Other studies also found similar results, including [34, 46]. In general, these studies suggest that users with more system experience have more efficient navigation strategies than users with less experience. Reference [106] argued that the contrast between experts and novices lies in the differences in the organization of their conceptual structures. Experts possess a mental representation (i.e., a hierarchical structure) of the concepts in the domain. Conversely, a novice’s structure is more chaotic and disorganized.

According to [80], nonlinear learning environments (e.g., hypertexts) cause *extraneous cognitive load*. Thus, reducing the amount of selection and sequencing efforts of students should significantly reduce cognitive load.

The AEHSs manipulate link anchors with pages (and link destinations) to guide learners towards interesting, relevant information. The manipulation of links presented within pages is typically done in one or more of the following ways: direct guidance, link annotation, link hiding, link disabling, link removal, link sorting, link generation, map adaptation, and social navigation [16].

The adaptive navigation techniques that are most popular in Web-based AEHSs are direct guidance, link annotation, link hiding and link sorting or ordering. In the Table Ⅴ, we present the advantages and disadvantages of the most popular adaptive navigation techniques, as these referred by [13, 14, 15, 21, 29].

TABLE Ⅴ ADVANTAGES AND DISADVANTAGES OF THE MOST POPULAR ADAPTIVE NAVIGATION TECHNIQUES IN WEB-BASED AEHSS

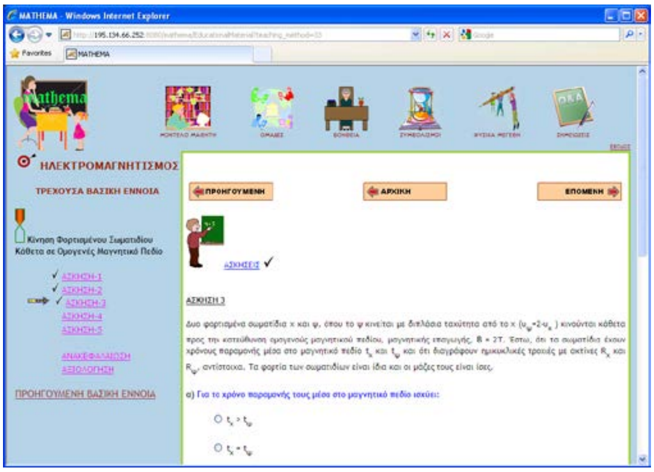
Technique	Advantages	Disadvantages
Direct Guidance	Assists learners to find the "next best" page for them to visit according to their goals, knowledge level, and/or other parameters presented in the learner model.	A problem with direct guidance is that it does not provide support for the learners who do not wish to follow the system’s guidance.
Link Sorting	The main purpose of this technique is to assist the learner by ordering all the links of a particular page according to the learner model and some learner-valuable criteria: the closer to the top, the more relevant the link is.	Disrupts consistency in pages, and can cause navigation problems for the learner beginner.
Link Annotation	The idea of this technique is to augment the links with some of annotations (usually with icons or bullets in front or behind of the links or by colored the links), which can inform the learner more about the current state of the pages (e.g. ready or not ready to be learned by the learner).	Provides less direct guidance. Students with low prior knowledge may feel difficult to select the links.
Link Hiding	Hiding protects learners from the complexity of the whole hyperspace and reduces their cognitive overload by hiding from the learner all the links to pages that he/she is "not expected to learn." Thus, the system restricts the navigation space by hiding, removing, or disabling links to irrelevant pages. Links leading to inappropriate or non-relevant information are hidden, removed or disabled. A page can be considered irrelevant for several reasons: for example, if it is not related to the user’s current learning goal or if it presents materials which the user is not yet prepared to understand.	Makes learners feel confused because of the pages with a varying link structure. Learners become very unhappy when previously available links become invisible or disabled as well as when links with new educational material become suddenly visible.

The adaptation and meta-adaptation of navigation in our system are based upon the learner's Web experience and knowledge level on the current learning goal.

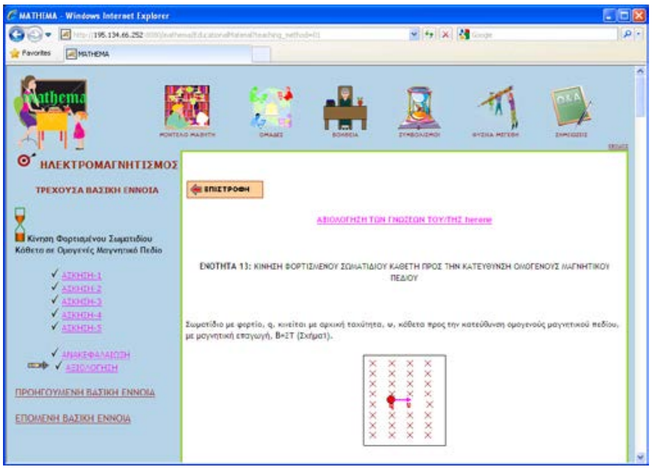
In adaptive navigation support, the AEHS MATHEMA offers the following navigation techniques: *direct guidance*, *link annotation*, *link hiding*, and *link sorting*.

In short, we will describe these navigation techniques:

Direct guidance: The system suggests the next main concept to be studied by the learner take into account his/her current learning goal, knowledge level on the current main concept, and learning style. In the Navigation Area, the appropriate current main concept, and links to "previous main concept" and "next main concept" are presented.



(a)



(b)

Fig. 8 Direct guidance navigation technique

In order for the learner to study the next main concept, he/she should be successfully assessed in the test of the current main concept. The link to the next main concept is appeared on the Navigation Area when the learner succeeds in the assessment test. In the Fig. 8a we can see the current main concept that is the charged particle motion perpendicular to the direction of uniform magnetic field, the educational material of the didactic approach of exercise solving, and the link "Previous main concept". In the case that the learner succeeds in the assessment test on the current main concept, then the adaptive mechanism will appear the new link "Next main concept" (see Fig. 8b). In Fig. 8a the educational material has suggested to Herene who has converging style. The clepsydra before the link to current main concept shows that the Herene has no assesses for the current main concept yet.

In Fig. 8b Herene has studied all the educational material for the current main concept and at this moment has submitted the assessment test in which successfully assessed (Adequate knowledge).

Since the Herene succeeded in the assessment test, the adaptive mechanism appears the link "Next main concept" on the Navigation Area. In addition, the clepsydra now shows the knowledge level of the Herene on the current main concept.

Link annotation: this method provides information about each main concept by coloring its link. The coloring provides information about the current state of student, which mean that: (a) he/she is ready or not to be taught the particular main concept; (b) he/she has been taught the main concept, and he/she has been successfully assessed or not in tests on the particular main concept. Moreover, the coloring provides information about the degree of difficulty of main concepts. In this way, the system encourages the learners to follow a non sequential navigation and it also assists the learners who usually follow the system's guides, to succeed a better knowledge level. For the coloring of links, the adaptive mechanism takes into account the learner's knowledge level on the prerequisite(s) main concepts, the degree of difficulty of the particular main concept as well as the learner's knowledge level on the particular main concept.

The system colors the visible links to the main concepts as follows:

a) Link to the current main concept is colored gray and it is boldfaced.

b) Links to the main concepts that the learner is not ready to study are colored red, because the necessary prerequisite main concepts were not met.

c) Links to the main concepts that the learner has already studied and has succeeded in the assessment tests are colored yellow.

d) The links to the main concepts that the learner is ready to study are colored as follows:

- Light green refers to that a main concept has low degree of difficulty.
- Green refers to that a main concept has medium degree of difficulty.
- Dark green refers to that a main concept has high degree of difficulty.

e) The links to the main concepts that the learner has already studied but he/she has successfully assessed in the assessment tests are colored orange.

Some of the colors, we mentioned above, are used as light-traffic metaphor. For example, red means stop and green means go on.

The changing of the link color is automatically done by the adaptive mechanism after each assessment of the learner's knowledge level for the correspondent main concept. After each learner's assessment, the system revises the links' color. A red link to a main concept turns green when the learner has been successfully assessed for all the prerequisite main concepts. A green link to a main concept turns yellow when the learner has been successfully assessed for the correspondent main concept.

Apart from the links to main concepts, there are links to pages with educational material for each main concept. Links to pages with educational material of the current main concept are colored magenta. These links are different for different didactic approaches, and consequently different for learners with different learning style.

Except the coloring of links, we make use of an "Advisor", as we mentioned above, to navigate the learner. An example of the navigation assistance provided by the "Advisor" is the following: You have chosen a main concept the link's color of which is red. This means that you have not studied the prerequisite main concepts yet so that you are not ready to study this main concept. It would be best for you to choose any other main concept to study the link's color of which to be green. I wish you a good study and all the best!

The Fig. 9 shows a snapshot of a page using annotation technique where we can see the different colors of links.

Link hiding: Link hiding protects the learner from the complexity of hyperspace and reduces the cognitive overload. Through this technique the adaptive mechanism limits up the navigation space by hiding inappropriate links. Links to main concepts that the learner is not ready to learn (because the learner has not studied the prerequisite main concepts yet) are hidden.

The adaptive mechanism initially appears on the Navigation Area only the links of main concepts that the learner is ready to study because either they do not have prerequisite main concept(s) or the learner has not successfully assessed on all prerequisite main concepts (see Fig. 10a).

Fig. 10a presents two only links on the Navigation Area at the first time that the student Zafeira logged in the system. The adaptive mechanism presented to her only two links to main concepts on the Navigation area, the links to the electric field intensity and magnetic field intensity, because they have no prerequisite main concepts.

When the Zafeira will study and would successfully be assessed on all the prerequisite main concepts of a particular main concept, then and only then, the adaptive mechanism will appear this main concept on the Navigation Area.

In Fig. 10b, three links to main concepts are appeared in the Navigation Area, the two initial links of Fig. 10a and moreover the link to electric flow. The third link is appeared by the adaptive mechanism because the Zafeira studied the educational material of the main concept of electric field intensity and successfully assessed in tests. The main concept of electric field intensity is a prerequisite main concept of electric flow.

The main concept of electric flow appears in the second position for the reason that the adaptive mechanism follows the hierarchy of the concepts, as been declared in the domain model. It is important to point out that the "Advisor" will inform the learner that the adaptive mechanism appeared a new link on the Navigation Area and explains the reason why it is done.

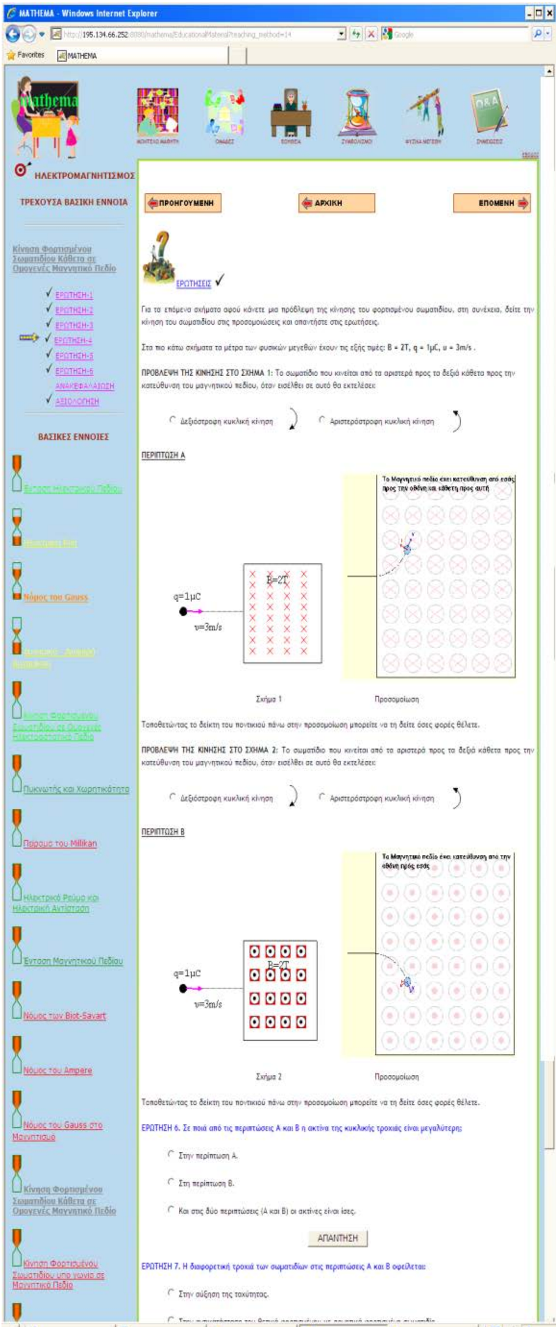
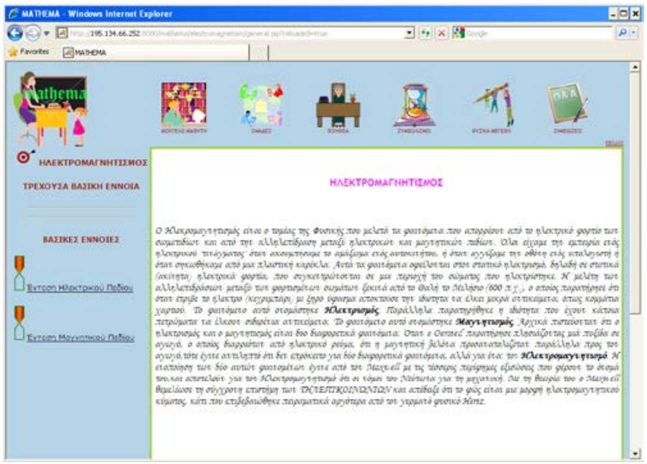
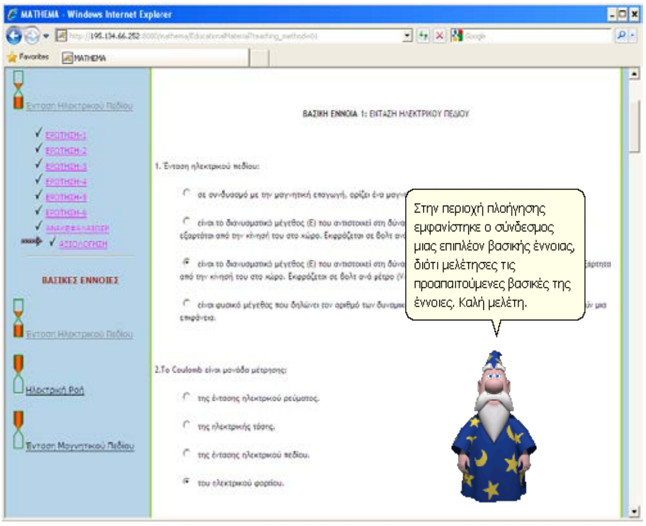


Fig. 9 Link annotation navigation technique



(a)



(b)

Fig. 10 Link hiding navigation technique

Link sorting: The idea of link sorting technique is to sort all the links of a particular page according to the user model and to some user-valuable criteria in order to emphasize some main concepts in contrast with others: the more close to the top, the more relevant the link is.

The adaptive mechanism sorts the main concepts according to their degree of difficulty. The main concepts, which have low degree of difficulty, list at the top of the Navigation Area. The main concepts, which have medium degree of difficulty, list at the middle of the Navigation Area. The main concepts, which have high degree of difficulty, list at the bottom of the Navigation Area.

D. Meta-adaptive Navigation Support

Several studies indicated that not all students perform in the same way to each adaptive navigation technique. A study of ELM-ART has demonstrated that casual learners stay longer within a system when adaptive navigation support is provided.

It also provided evidence that direct guidance works best for learners with little prior knowledge while adaptive annotation is most helpful for learners with some reasonable subject knowledge.

A study of InterBook has shown that adaptive annotation encourages non-sequential navigation and helps learners who follow the system's guidance to achieve a better level of knowledge.

Also, this study has shown that the adaptive navigation support techniques link annotation, link sorting, and link hiding can improve learner performance in hypermedia by significantly reducing navigation difficulty.

However, experiments showed that adaptive annotation is not a silver bullet and may not work in some contexts [13]. Reference [105] provided good evidence that learners with higher prior knowledge seem to prefer non-restrictive adaptive methods, while learners with low prior knowledge can profit from the guidance or methods more restrictive adaptive. Depending on the context, an adaptive navigation support technique may or may not work properly. According to [15], most relevant techniques for learners with little or no knowledge of the subject are the restrictive techniques such as direct guidance or hiding that guides them by adaptively limiting their navigation choice. In contrast, most relevant techniques for the learners with some reasonable knowledge level of the subject are "rich" linking techniques such as adaptive annotation and multiple link generation.

All the information above, advocates in the need of *meta-adaptation*. So far, several meta-adaptation methods have been proposed. According to [15], a meta-adaptive system should have a number of different adaptation techniques at its disposal. It should also be aware of the limits of applicability of every technique and that be able to select adaptively the most appropriate adaptation technique that fits best the given learner and the given context. It is also natural to expect that meta-adaptive systems will be able to extend constantly their own knowledge about the applicability of different techniques by observing the success of these techniques in different context and learning from these observations.

Reference [86] proposes the self-regulated adaptivity. According to [86], self-regulation refers to an adaptive system's capacity to observe its own adaptive behavior, assess its efficacy in attaining design goals expressed in computable form, and modify its adaptive behavior in an attempt to reach these goals. On the basis of self-regulated adaptivity, [86] proposes five strategies for annotation of links in meta-adaptive hypermedia systems as follows: Strategy A: No annotation; Strategy B: Annotation using different link colors; Strategy C: Annotation using bullets of different colors; Strategy D: Annotation using custom icons, and Strategy E: Link hiding.

Reference [64] proposes meta-adaptive systems based on meta-adaptable agents in which the capability of agents to adapt themselves to the environment (via mechanisms producing intelligent behaviors) is itself adapted according to the changes of the environment. In order to describe how such a system works, they presented a friendly meta-adaptable model called *troglodytes*. In this model, they have some troglodytes trying to survive by recollecting bananas, hunting dinosaurs cooperatively, escaping from lions, and reproducing themselves to spread all around their world. As [64] refer to their article, they introduce only some common concepts and notation to describe meta-adaptable environments. However, there is no evidence on which domain of education such a system can offer.

All the above-mentioned meta-adaptation proposals suggest a system-controlled meta-adaptation technique where the system decides which is the most appropriate navigation technique for each student and context and acts accordingly. Our proposition is a learner-controlled meta-adaptation (meta-adaptability) technique where the system assists the student to take decision for the navigation technique that fits better to him/her by presenting to him/her the advantages and disadvantages of the navigation techniques that it supports as well as additional information about them, when the student fulfils the requirements for meta-adaptation. Self-regulated learning is an active constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior [88].

According to [113], self-regulation involves the development of specific strategies that help learners evaluate their learning, check their understanding and correct errors when appropriate. Learning requires students to pay attention, to observe, to memorize, to understand, to set goals and to assume responsibility for their own learning. These cognitive activities are not possible without the active involvement and engagement of the learner. AEH systems must help students to become active and goal oriented by building on their natural desire to explore, to understand new things, to master them and to take some control over their own learning. Taking control over one's learning means allowing students to make some decisions about what to learn and how.

The purpose of meta-adaptation is to assist the learner to take decision for the navigation technique that fits best to him/her. That is, through the meta-adaptation we intended to help the learners be more self-regulated learners.

In our system, the purpose of meta-adaptation is to assist the student to take decision for the navigation technique that fits best to him/her in accordance with the system's suggestion. Taking into account the propositions for meta-adaptation of [15, 86, 64] as well as our proposition, we designed and implemented the learner-controlled meta-adaptation in the AEHS MATHEMA and we describe it below.

Initially, the system considers that the student has no prior knowledge on the learning goal that he/she selects to study. Thus, it considers the student as novice. At the first time when a student logs in the system, he/she is called to declare his/her Web experience and knowledge level on the current learning goal, as follows:

How many Web experience and knowledge level for the current learning goal do you have?

- Little or no Web experience and little or no knowledge level on the current learning goal.
- Little or no Web experience and medium knowledge level on the current learning goal.
- Highly Web experienced and little or no knowledge level on the current learning goal.
- Highly Web experienced and medium knowledge level on the current learning goal.

After the learner's declaration, the system adapts the appropriate navigation technique to him/her according to his/her Web experience and knowledge level of the current learning goal, as the Table Ⅵ shows.

TABLE Ⅵ ADAPTIVE NAVIGATION TECHNIQUE ACCORDING TO LEARNER'S WEB EXPERIENCE AND KNOWLEDGE LEVEL OF THE CURRENT LEARNING GOAL

Level of Web Experience and Knowledge Level on the Current Learning Goal	Navigation Technique Suggested by the System
Little or no Web experience and little or no knowledge on the current learning goal	Direct guidance
Little or no Web experience and medium knowledge on the current learning goal	Link annotation in combination with curriculum sequencing
Highly Web experienced and little or no knowledge on the current learning goal	Link hiding
Highly Web experienced and medium knowledge on the current learning goal	Link annotation

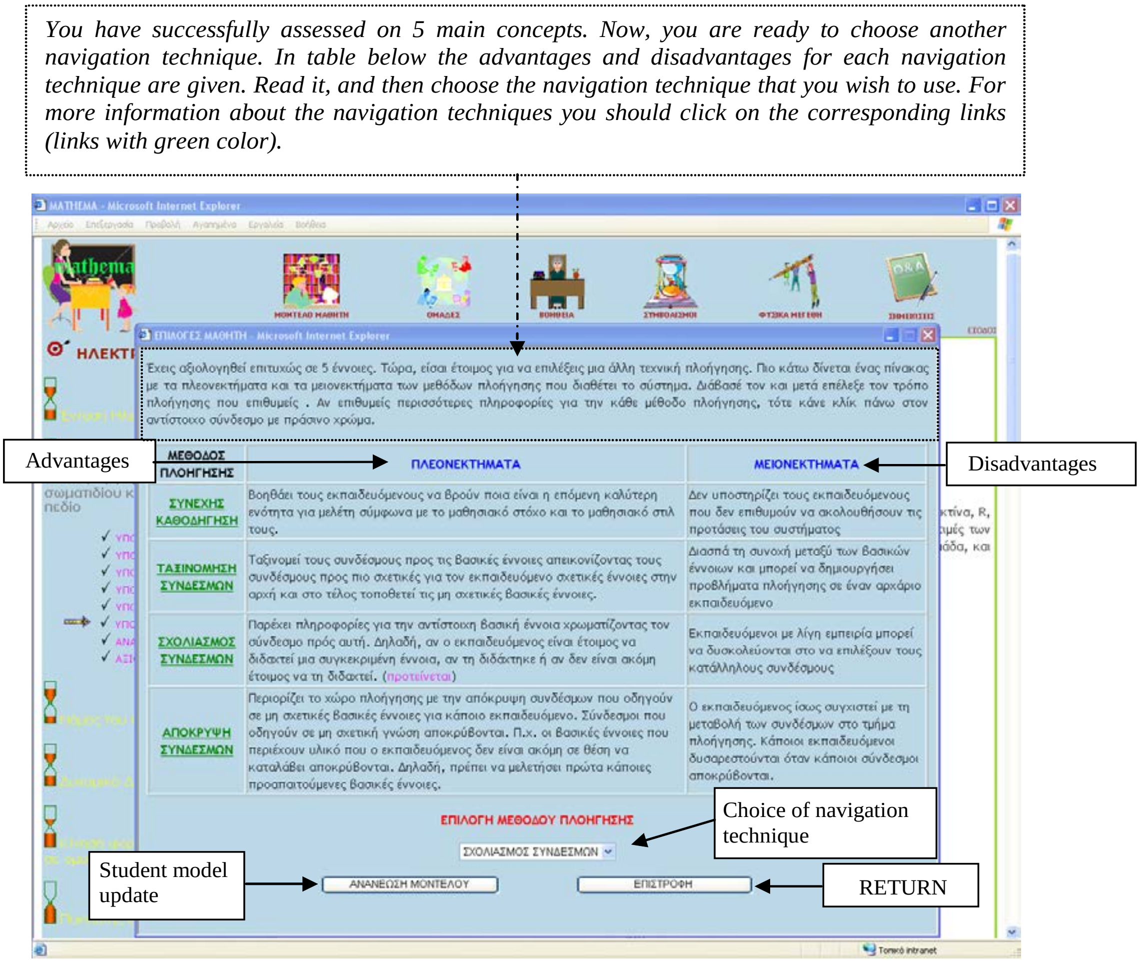


Fig. 11 The meta-adaptive mechanism informs the learner about the advantages and disadvantages of the navigation techniques supported by the system

The student is informed by the system about the navigation technique that is adapted to him/her and explains the reasons why the automatically selected by the system navigation technique was adapted to him/her. However, the system recommends the student to change the automatically selected navigation technique, when he/she has fulfilled the requirements for changing it (successful assessments on ***n*** main concepts). The assessment tests are used as criteria for the estimation of the prior knowledge of the student. The system also informs the student that the automatically selected navigation technique and the recommendation are intended to protect him/her from navigation problems. The meta-adaptation mechanism, after successful assessments of the student knowledge level on ***n*** main concepts, appears information with the advantages and disadvantages of navigation techniques on the screen and the student is asked, if he/she wishes, to change the navigation technique (see Fig. 11).

The system also informs the student that, if he/she does not wish to follow its automatically selected navigation technique and recommendation, then he/she is able to change the navigation technique whenever he/she wishes through his/her Student Model on the Tool-Bar Area.

E. Interactive Problem Solving Support

Different kinds of tasks are typically involved in collaborative learning activities. One of them, eventually the most eminent, is problem solving. Much of the current work in cognitive psychology has shown that students learn better when engaged in solving problems [71]. Physics instructors generally believe that the problem solving leads to the understanding of physics and that is a reliable way to demonstrate the understanding for purposes of evaluation [67].

The interactive problem solving technique provides the learner with intelligent help on every step of problem solving from giving a hint to executing the next step for the learner [16].

Representative AEHSs supporting this technique are the systems ISIS-Tutor, ELM-ART, and ActiveMath. After an extended literature review of these systems, we concluded that these support the learners in the following:

- problem solving, recognition and correction of errors and misconceptions;
- development of critical thinking;
- reflection.

Moreover, we concluded that these systems do not support the following:

- problem solving activities in constructivist and social constructivist environments that utilize modern didactic approaches;
- both individual and collaborative learning.

In the AEHS MATHEMA, we designed and implemented the interactive problem solving through an activity by making use of experimentation through simulations, explorations, guided discovery, and collaboration didactic approaches. The learning goal of explorations and guided discovery didactic approaches is to motivate the learners to self-direct their learning process to learn how to apply knowledge and generally to develop higher-order thinking. The purpose of exploration is the learners to find out and comprehend concepts/knowledge embedded in target domain. An exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, and innovation [68].

The main purpose of the guided discovery methodology is to lead learners to discover domain concepts with various learning facilities such as simulation, demonstration environments, and so on [51]. Reference [68] suggests that peer collaboration offers three cognitive benefits: *articulation*, *conflict* and *co-construction*. For the sake of their joint activity, learners need to articulate their opinions, predictions and interpretations.

Conflict sometimes arises in peer collaboration when learners disagree with each other in their interpretations or approaches to the task. When working on a task or solving a problem, learners co-construct shared knowledge and understanding by complementing and building on each other's ideas [110].

The interactive problem solving activity consists of six steps. These steps are intended to support the learner to succeed in the following learning outcomes:

- join with prior knowledge and new knowledge;
- combine known with unknown formulas in order to extract new formulas appropriate for the problem solving;
- recognize the restrictions in the values of parameters of the extracting new formulas through three phases (exploration, presentation, explanations);
- apply the extracting new formulas for specific values of parameters;
- predict the kind of motion of bodies or particles;
- solve quantitative problems and make qualitative observations through simulations;
- compare the calculated values or predictions with the corresponding values or the kind of motion that he/she has received from simulation to check for errors and explain the differences;
- discuss with his/her peers with the aim to exchange experience, opinions, and findings of their work;
- recognize his/her errors or misconceptions through a guided dialogue with the system;
- justify his/her answers and selections.

The general framework of the problem solving activity is as follows:

Step 1: Activation of prior knowledge and its connection with new knowledge (i.e., use of formulas from previous knowledge and the formulas of the subject matter that the learners are studying with the aim of extracting formulas for calculating certain Physics quantities or dimensions).

Step 2: Recognizing of restrictions on the values of parameters of the extracting formulas in Step 1 through a *guided dialog* with the system. The aim of the *guided dialog* is to help learners identify restrictions on the values of parameters of extracting formulas in Step 1. The guided dialog is carried through three phases. In the first phase, the students are given guided questions to explore the restrictions (exploration), in the second phase the system presents the restrictions and asks if they agree or disagree with them or some of them (presentation). In the case the student agree, the system proceeds with Step3 of the Activity, otherwise proceeds with third phase to explain the reason(s) why these are restrictions (explanation).

Step 3: Application of extracting formulas and prediction of the kind of motion.

Step 4: Working with the simulation, comparison of the results obtained from the simulation with the results of the Step 3, and explanation of the differences.

Step 5: Negotiation and Collaboration in pairs of learners in order to share their experience, opinions, findings, etc and to co-construct knowledge.

Step 6: Checking of results through a *guided dialog* with the system. The aim of the *guided dialog* is to detect either possible misconceptions or learning difficulties of learners in order to help them reflect and reconstruct their own cognitive model. In this Step, the *guided dialog* between the learner and the system could be done either individually or collaboratively.

The guided dialog in Step 6 is carried out in four phases as follows:

Phase 1: The learner is asked to write down on the check form of the system the final value of the physical quantity (or dimension) that he/she believes as correct value or the predicted kind of the motion and the corresponding value or the kind of motion that he/she received from the simulation. The system examines four cases. For the goal of this paper, we present only the case leading in Phase 2 of the dialog. This case is as follows: If the result is not correct and the simulation result is correct then the system proceeds to the Phase 2 of the dialog.

Phase 2: The system presents the correct mathematical formula to the learner and additional help about its application. The learner is asked to calculate the physical quantity (or dimension) again (as in Step 3 of the Activity) and to choose the correct one among the given answers. If the learner chooses the correct answer, then the system returns to the Phase 1 of the dialog so that the learner will check any other result. If the learner again chooses a wrong answer then the system proceeds to the Phase 3 of the dialog.

Phase 3: The system gives the learner an explanation, by using mathematical arguments, why the answer is not correct. Then the system asks the learner if he/she insists on his/her point of view, and if the learner chooses "Yes" then the system proceeds to the Phase 4 of the dialog if "No" then the system returns to the Phase 1 of the dialog so that the learner can check any other result.

Phase 4: The system gives the learner a different explanation why the answer is not correct by using arguments based on the experience that the learner obtained through the simulation. Then the system asks the learner whether he/she wishes to calculate the physical quantity (or dimension) again or to return to the Phase 1 of the dialog and to check any other result.

F. Adaptive Group Formation

As we mentioned above the learners collaborate in pairs in problem solving activities, so that they will share their experience, opinions, and findings in order to co-construct shared knowledge and understanding. Consequently, the group formation is necessary. Thus, the AEHS MATHEMA enforces the learner’s learning by involving an adaptive group formation technique. According to [16], the technologies for adaptive group formation and/or peer help attempt to use knowledge about collaborating peers (most often represented in their student models) to form a matching group for different kinds of collaborative tasks.

After an extended literature review, we present the main features of all the Computer Supported Collaborative Learning (CSCL) systems and AEHSs supporting adaptive group formation and/or peer help in the Table Ⅶ. The most of the CSCL and AEHS in the Table Ⅶ are based upon several learners’ characteristics to support adaptive group formation and/or peer help, and they implement it based upon a system-controlled and/or on educator-controlled design. That is, the system or the educator decides the group formation and the learners are informed of this without having the possibility to change it or to negotiate a collaboration agreement with their candidate collaborators.

TABLE Ⅶ ADAPTIVE GROUP FORMATION AND/OR PEER HELP IMPLEMENTATIONS IN CSCL AND AEHSS

System	CSCL or AEHS	Learner’s Characteristics for Group Formation and/or Peer Help	Assistance to the Learners in Selecting the Collaborator(S) and Negotiating A Collaboration Agreement
Ca-Ole [97]	AEHS	Level of Knowledge.	-
Copper [92]	CSCL	Linguistic Capabilities of Available Students, and A Collection of Collaborative Activity Templates	-
Christodoulopoulos and Papanikolaou’s System [24]	CSCL	Knowledge Level for The Current Lesson, Learning Styles	Teacher-Students Negotiations of the Final Group Synthesis
Ikeda and Mizoguchi’s System [49]	CSCL	Learning Goal and Social Role	-
Iminds [99]	CSCL	Previous Performance in Group Activities	-
Mot 2.0 [27]	AEHS	Knowledge Level, Social and Grouping Features (Tagging, Rating, Feedback, Subscriptions)	-
Muehlenbrock’s System [77]	CSCL	Agenda Information, Availability of Preferred Communication Channels, Activity, Location.	Assistance in Finding Peer Helpers
Omadogenesis [39]	CSCL	Gender, Ethic Background, Motivations, Attitudes, Interests, Etc	-
Pecasse [40]	Cscl	Learners’ Proficiency and Learners’ Ability As Assessors	-
Pegasus [57]	CSCL	Learning Style	Teacher-Students Negotiations of the Final Group Synthesis
Phelps [41]	CSCL	Willingness, Ability, Availability, and Knowledge Profile	Assistance in Finding Peer Helpers
Tangow [18]	AEHS	Users’ Personal Features, Preferences, Knowledge and Behavior While Interacting with the Course	-
Tangow/Wotan [69]	AEHS	Active/Reflective of Felder-Soloman Model	-
Team-maker [20]	CSCL	Gender, Skills, Students’ Schedules, and the Instructor’s Criteria for the Creating Groups	-

Exceptions are the CSCL tools of [24] and [57], where the system categorizes the learners into groups and then it allows them to communicate with the educator for negotiating for their final group synthesis. However, in these CSCL tools the learners are not offered the control and the assistance in selecting their collaborators and negotiating with them a collaboration agreement. In addition, two of the CSCL systems of the Table Ⅶ (Muehlenbrock's system and PHelpS) offer assistance to the learners in finding peer helpers by making use of the following learner characteristics: agenda information, availability of preferred communication channels, activity, location, willingness, ability, availability, and knowledge profile. However, these systems present the peer helpers in a list without taking into account the learning styles concerning their group effectiveness.

The AEHSs listed in the Table Ⅶ (CA-OLE, MOT 2.0, TANGOW, TANGOW/WOTAN) make use of the level of knowledge, social and grouping features (tagging, rating, feedback subscriptions), users' personal features, preferences, behavior while interacting with the course, and learning styles as characteristics for adaptive group formation.

The group formation is decided by the system and the learners are informed without having the possibility to change it or to negotiate a collaboration agreement with their possible candidate collaborators. Moreover, none of these systems uses learning style in combination with previous performance of learners in supporting adaptive group formation and/or peer help.

Taking into consideration of the following:

- the importance of learning style as one of the learners' characteristic that influences positively on the group productivity and effectiveness [36];
- the learner-centeredness as a main goal of active and collaborative learning environments [58], as well as the collaboration willingness as a significant factor influencing the group effectiveness [45];
- the results of our research [83] that the concrete-concrete students perform significantly better in problem solving activities than the abstract-concrete students and slightly better than the abstract-abstract students;
- The results of the [96] research that the active-active, reflective-reflective, and active-reflective student groups have no significant performance differences when they collaborate in problem solving activities.

We designed and implemented a learner-controlled adaptive group formation technique in the AEHS MATHEMA by using the abstract and concrete dimensions of learning styles and knowledge level on the current learning goal of learners as characteristics for adaptation.

For this purpose, our system creates a priority list of possible candidate mates for a certain learner, taking into account the abstract or concrete dimension of his/her learning style and his/her candidate collaborators' learning style and knowledge level on the current learning goal as well (see Fig. 12).

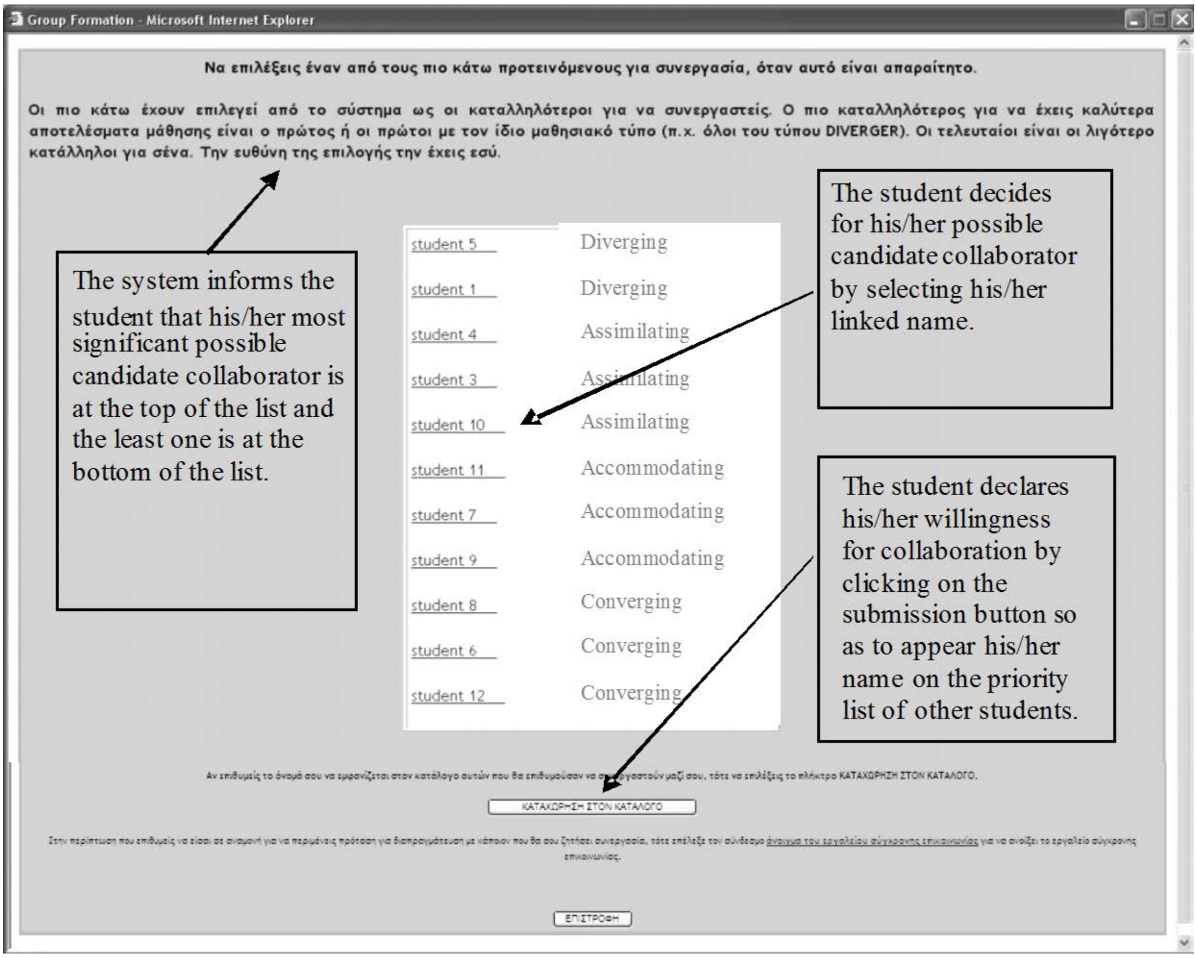


Fig. 12 Adaptive group formation in the AEHS MATHEMA

Also, the system informs the learner that his/her most significant possible candidate mate is at the top of the list and the least one is at the bottom of the list. After this, the learner chooses his/her mate and negotiates a collaboration agreement with him/her.

In Fig. 12, we can see eleven candidate collaborators for the student Giorgos. They are sorted according to their learning style and, if some of them belong to the same learning style, then they are sorted according to their knowledge level on the current learning goal. The first and second candidate collaborators have the same learning style that is the Diverging. In this case, the priority is defined by the knowledge level on the current learning goal. This means that the first candidate collaborator has greater knowledge level than the second candidate collaborator.

In collaboration, the learners through the chat tool offered by the AEHS MATHEMA can exchange their experience, opinions, and findings as well as they can interchange Web pages and files.

As it can be seen in Fig. 12, the learner has two options for collaboration.

V. EVALUATION OF THE AEHS MATHEMA

Evaluation of an educational system is important and it should be ensured the correct methods are used. In particular, it is very significant to evaluate the entire AEHS both from a technological perspective and from a learner-centered perspective [78]. The evaluation of learner and tutor feedback is essential in the production of high quality personalized services. There are a few evaluations available in the AH domain relative to the amount of research interest this domain is attracting. Majority of the research in this domain focuses on the technological design and performance of systems without justifying the designs through the lessons learned from evaluations [26].

In order to provide the best support for learners, a learner-centered evaluation approach for enhancing and validating the student model of AEHS was used for serving three goals: verifying the quality of our AEHS, detecting problems in the system functionality or interface, and supporting adaptivity decisions. The benefits of the learner-centered approach are savings time and cost, ensuring the completeness of system functionality, minimizing required repair efforts, and improving user satisfaction [78].

In the frame of the summative evaluation of the AEHS MATHEMA, we conducted a research in order to investigate the quality and usability of its functions, the effectiveness of the system, the functionality of adaptivity decisions, and to detect problems in the system functionality or interface taking into account the user-centered evaluation method of [112]. According to [112] the usability, perceived usefulness and appropriateness of adaptation are the three most commonly assessed variables.

During the design of the questionnaire for the system's evaluation, we also took into account the [50] guidelines for specifying and measuring usability.

A. Participants

The research was conducted in the Department of Informatics and Telecommunications, University of Athens, Greece in June 2010. 43 students participated in the research.

B. Educational Material and Questionnaires

1) Educational Material:

The main source of educational material was the AEHS MATHEMA.

2) Questionnaires:

The main goal of the questionnaire given to the students was the investigation and recording of their opinions about the AEHS MATHEMA. The questionnaire included both closed-ended and open-ended questions with the aim of evaluation of the following issues:

a) usefulness, usability, and suitability of the presentation of educational material;
b) usefulness, usability, and argumentation of the guided dialogues;
c) usefulness and effectiveness of the methods of recognition and correction of students' errors and misconceptions;
d) flexibility and efficiency of system's use;
e) usefulness and usability of the system guidance;
f) usefulness and usability of the learner assessment;
g) usefulness and usability of the adaptive presentation;
h) usefulness, usability, and effectiveness of the feedback;
i) simplicity of site navigation, usefulness and usability of the adaptive navigation techniques and meta-adaptive navigation technique;
j) usefulness and usability of the adaptive group formation technique;
k) visibility of the system status;
l) usability of learner control and freedom;
m) usability of the learner assessment;
n) usability of the interactivity with the system.

Moreover, the questionnaire included questions concerning the utilization of the AEHS MATHEMA by high schools teachers. For the students' answers to closed-ended questions, we used a five-point Likert Scale (strongly agree, agree, neutral, disagree, and strongly disagree). Furthermore, the students are allowed to justify their selection.

The goal of the open-ended questions was the encouragement of the students to express their opinion about the functions of the AEHS MATHEMA, and to detect and describe problems in the system functionality or interface as well as to give their solutions or ideas with the aim of improvement of the system.

C. Experimental Process

The evaluation of the AEHS MATHEMA was done by the students in the frame of the discipline "Informatics and Education". Individual work was given to the participants, graded with 60 percent of the total grade. At the beginning, we gave the student information about all the functions of the AEHS MATHEMA to do a demonstration of them on the system. The students studied the environment of the AEHS MATHEMA and completed the questionnaire. The evaluation lasted 30 days.

D. Method

Our evaluation approach was based upon that advocated and applied by [112].

E. Data Collection

The data collection is done by the evaluation questionnaire completed by the participants.

F. Data Analysis

The answers of the participants about the closed-ended questions of the Likert scale are grouped into three categories as: “Disagreement” (strongly disagree, disagree), “Neutral” and “Agreement” (strongly agree, agree). For the data analysis, the means of the Likert scale’s grading (-2 to 2), the standard deviations and the percentages of the participants who expressed their “Agreement” were used. For example, the indication 1.5 (0.1) – 90.7% in the Table Ⅷ means that, the mean of the participants grade (selection) is 1.5, the standard deviation is 0.1, and the percentages of the participants expressed their “Agreement” is 90.7. The answers of the participants to the open-ended questions as well as the justifications were set down and coded.

TABLE Ⅷ RESULTS OF THE SYSTEM’S EVALUATION

Adaptive Presentation	Usefulness	1.5(0.3) – 93.0%
	Usability	1.3(0.2) – 86.0%
Site Navigation	Simplicity	1.0(0.2) – 67.4%
Adaptive Navigation Techniques	Usefulness	1.7(0.1) – 100%
	Usability	1.5(0.1) – 90.7%
Meta-adaptive Navigation Technique	Usefulness	1.3(0.2) – 88.4%
	Usability	1.4(0.2) – 86.0%
Adaptive Group Formation Technique	Usefulness	1.2(0.2) – 83.7%
	Usability	0.4(0.2) – 58.1%
Methods of Recognition, Diagnosis and Recovery of Students’ Errors and Misconceptions (Problem Solving Support)	Usefulness	1.8(0.3) – 97.7%
	Effectiveness	1.9(0.3) – 100%
Learner Assessment	Usability	1.5(0.3) – 86%
Learner Control and Freedom	Usability	1.3(0.2) – 88.4%
Feedback Methods	usefulness	1.8(0.3) – 100%
	usability	1.6(0.3) – 93%
	effectiveness	1.7(0.3) – 97.7%
Guided Dialogues	usefulness	1.4(0.3) – 86.0%
	usability	1.5(0.3) – 90.7%
	argumentation	1.9(0.3) – 100%
Educational Material	suitability	1.7(0.3) – 100%
System Status	visibility	1.4(0.3) – 90.7%
System Guidance	usefulness	1.6(0.3) – 95.3%
	usability	0.7(0.2) – 58.1%
Flexibility and Efficiency of Use		1.6(0.3) – 95.3%
Learner Attention	facilitation	1.4(0.3) – 90.7%
Learner’s Deep Knowledge of the Subject	effectiveness	1.4(0.2) – 88.4%
Learner’s Reflection	effectiveness	1.7(0.3) – 97.7%
Learner’s Self-regulation	effectiveness	1.6(0.3) – 93.0%
Development of Learner’s Critical Thinking	effectiveness	1.5(0.2) – 93.0%
Learner’s Activation	effectiveness	1.5(0.2) – 97.7%
New Opportunities for the Teaching and Learning	effectiveness	1.3(0.2) –90.7%

G. Results and Conclusions

1) Results:

Table Ⅷ shows the results of the quantitative data analysis of the questionnaire.

2) Conclusions:

A great amount of the participants (83.7% to 100%) considers that almost all the functions of the system are useful. It is important to point out that the function of recognition and correction of student misconceptions is considered by the participants as useful enough (97.7%). The calculation of the knowledge level is considered by the participants as useful enough (86.0%), but they are very reluctant on deciding whether the MATHEMA may be used as assessment tool (51.2%).

Moreover, a great amount of the participants (81.4% to 93%) considers that almost all the functions of the system are usable and user-friendly, but a smaller amount of the participants considers that the function of collaboration assistance is usable and user-friendly (58.1%).

A great amount of the participants (90.7%) believes that the system supports the learners in comprehensive study of educational material.

The general sensation of the participants for the system is that it is satisfactorily effective concerning the services that it offers in the subject learning (95.3%), in the deep knowledge of subject (88.4%), in learner reflection (97.7%), in learner self-regulation (93%), and in development of critical thinking of learner (93.0%).

A great amount of the participants (greater than 95%) considers that the guided dialogues and feedback are effective and definite.

A great amount of the participants considers that the system facilitates the student attention (90.7%), and it creates new opportunities in teaching and learning (90.7%).

In general, the AEHS MATHEMA is distinguished for the high functionality, usefulness, and usability of its functions, as expressed by the participants through the closed-ended and open-ended questions. The comments and the proposals of the participants about the weaknesses of the system, in the matter of the collaboration assistance through the chat tool of the AEHS MATHEMA and the assessment tool were taken into consideration by the authors for the improvement of these functions.

Indicative comments of the participants about the AEHS MATHEMA, as they were written by the participants on the questionnaire, are as follows:

- "It is true that I did not believe that my foray with the AEHS MATHEMA to be so exciting. I thought that, I would be bored out of my mind at a moment, but it did not happen. The AEHS MATHEMA is an environment that offers enough functions with various ways to approach them and they are always personalized to your needs. It is what differentiates it from other systems that I have studied so far. I liked this environment, and particularly my pursuit with Physics, since it is one of my favorite subjects, and if I would be given me a chance to study again the AEHS MATHEMA, I would have done it without any thought."
- "I consider that the environment of the AEHS MATHEMA is an important, usable, and enjoyable tool that assists importantly the learner to study and comprehend a subject."
- "The activity have had a great interest, nevertheless a repetition without improvements would not have any sense at all."
- "The AEHS MATHEMA is a very user-friendly environment which presents the subject matter with a well organized and comprehensive way."
- "It is an innovative tool for the learning of main concepts of electromagnetism with alternative ways for different teaching methods and according to each learner's needs."
- "The AEHS MATHEMA is a pleasant environment and I think that it has a well organized and appropriate educational material for each goal."
- "It was important enough for me to take a journey in such an environment."

VI. DISCUSSION AND FUTURE WORK

This paper advances research in the area of AEHS. The issues that it designates are: (a) the meta-adaptation technique that assists the learner in selecting the most appropriate navigation technique among the four techniques that it offers (direct guidance, link annotation, link hiding, and link sorting), that matches in his/her profile by taking into account his/her Web experience and knowledge level of the current learning goal; (b) the interactive problem solving technique through activities by using modern didactic approaches and combining both individual and collaborative learning, which is important for the Physics learning; and (c) the adaptive group formation technique that assists the learner in selecting the most appropriate collaborator from a list of candidate collaborators that the system creates by taking into account the learner's learning style, and the learning style and knowledge level on the current learning goal of candidate collaborators. Moreover, the system establishes principles for the selection of the most appropriate learning style model, and teaching strategies for the adaptive presentation of the educational material according to the domain of application as well as the system uses an "Advisor" advising the learner in his/her navigation.

To sum up, in this paper, we describe the educational framework including, the design of didactic model, domain model, learner model, etc., as well as the adaptive mechanism (adaptive and intelligent techniques) of the AEHS MATHEMA. Our system is based upon Kolbs' Experiential Learning Theory and learning styles model. In order to support the learning facilities and to enrich the adaptive and intelligent functionality of the AEHS MATHEMA, we implemented the following techniques: curriculum sequencing, adaptive presentation, adaptive and meta-adaptive navigation support, interactive problem solving support, and adaptive group formation. The summative evaluation of the AEHS MATHEMA indicated that almost all its functions are useful, usable, and user-friendly.

In the future, in an effort to implement all the adaptive and intelligent techniques that should have a truly AEHS, it is really a challenge for us to incorporate intelligent analysis of student solution, and example-based problem solving support in the AEHS MATHEMA.

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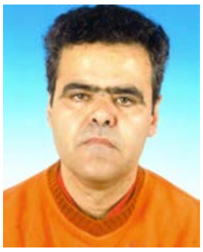

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