Interactive Problem Solving Support in the Adaptive Educational Hypermedia System MATHEMA

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Abstract—This paper describes the interactive problem solving support offered by our adaptive educational hypermedia system called MATHEMA. The general goal of the MATHEMA is the support of senior high school students or the beginners of higher education, through an interactive and constructivist environment, in learning physics (electromagnetism) individually and/or collaboratively, and to overcome their possible misconceptions and learning difficulties. Initially, a review of related work about the implemented AEHS/ITS and the didactic design principles of the MATHEMA are presented. Through the interactive problem solving, the system supports the students in solving electromagnetism problems, individually and/or collaboratively, by following an activity that is based on the experimentation with simulations, explorations, guided discovery, and collaboration didactic approaches. An experimental study with senior high school students showed that they improve their performances when following this activity. A questionnaire that we gave to the students to express their opinion about our system helped us to improve the quality of the courses.

Index Terms—Adaptive educational hypermedia, interactive problem solving, learning styles, misconceptions.

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1 INTRODUCTION

1.1 Adaptive Educational Hypermedia Systems: An Overview

ADAPTIVE Educational Hypermedia Systems (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. These systems build a model for each learner reflecting the individual learner's features, and apply this model for adaptation of the teaching methodology to the specific needs of each particular learner. AEHS 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. A number of research groups have independently realized that a hypermedia system coupled with an ITS can offer more functionality than a traditional static educational hypermedia [12]. Thus, these systems possess the ability to make intelligent decisions about the interactions that take place during learning and aim to support the learners without being directive. Furthermore, AEHS 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 [10].

In Web-based AEHS, several *adaptive and intelligent techniques* have been applied to introduce adaptation such as:

1. *Curriculum sequencing*: Helps the learner to follow an optimal path through the learning material.
2. *Adaptive presentation*: Adapt the content presented in each hypermedia node according to specific characteristics of learner.
3. *Adaptive navigation support*: Assist the learner in hyperspace orientation and navigation by changing the appearance of visible links.
4. *Interactive problem solving support*: Provides the learner with intelligent help on every step of problem solving from giving a hint to executing the next step for the learner.
5. *Intelligent analysis of student solutions*: Uses intelligent analyzers that not only tell the learner whether the solution is correct, but also tell him/her what exactly is wrong or incomplete.
6. E*xample-based problem solving support*: Helps the learners solve new problems not by articulating their errors, but by suggesting them relevant successful problem solving cases, chosen from their earlier experience.
7. *Adaptive collaboration support—adaptive group formation and peer help*: These techniques support the collaboration process just like the interactive problem solving support systems assist an individual learner in solving a problem or use knowledge about possible collaborating peers to form a matching group for different kinds of collaborative tasks.

In Table 1, we present the main AEHS/ITS and their implemented techniques. None of these systems supports all of the above-mentioned techniques. In general, these

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TABLE 1
Adaptive Educational Hypermedia Systems/Intelligent Tutoring Systems and Their Implemented Techniques

	Curriculum Sequencing	Adaptive Presentation	Adaptive Navigation Support	Interactive Problem Solving Support	Intelligent Analysis of Student Solutions	Example-based Problem Solving Support	Adaptive Collaboration Support/ Adaptive Group Fomation and Peer Help
ACE [70]	▨		▨				
ActiveMath [54]	▨	▨	▨	▨			
AES-CS [75]		▨	▨				
AHA ! [19]		▨	▨				
ALE [69]			▨				
ALICE [42]			▨				
Anatom-Tutor [5]		▨					
Arthur [31]	▨						
AST [68]	▨	adapt. testing	▨				
CAMELEON [46]		▨	▨				
CS383 [14]		▨					
DCG [77]	▨						
ELM-ART [10]	▨	partial	▨		▨	▨	
ELM-ART II [78]	▨	partial	▨		▨	▨	
Flexi-OLM [47]		▨	▨				
Hypadapter [36]		▨	▨				
ILASH [4]		▨	▨				
INSPIRE [59]	▨	▨	▨				
InterBook [11]	▨	partial	▨				
ISIS-Tutor [9]	▨		▨	▨			
iWeaver [80]		▨	▨				
KBS Hyperbook [57]	▨		▨				
Knowledge-Sea II [24]		▨	▨				
LSAS [3]		▨	▨				
MANIC [71]	▨	▨					
MetaDoc [8]		▨	▨				
MOT [17]		▨	▨				
ProSys [60]			▨				
PUSH [38]		▨					
SMILE [72]	▨						
TANGOW [13]	▨		▨				▨
TANGOW/WOTAN [61]	▨		▨				▨
VC Prolog Tutor [63]	▨				▨		
WHURLE [56]		▨	▨				

systems use combinations of them 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 (26 out of 34), which is one of the most popular techniques in current adaptive hypermedia systems, adaptive presentation (19), and curriculum sequencing (16). On the other hand, a few of these systems use the techniques of intelligent analysis of student solutions (3 out of 34), interactive problem solving support (2), example-based problem solving support (2), and adaptive collaboration support or adaptive group formation and peer help (2). In the future, it is a real challenge for the designers to incorporate all the seven techniques in AEHS.

1.2 Students' Learning Styles as a Source for Adaptation in AEHS/ITS

A primary principle of individualized learning is that no single didactic strategy is best for all students. As a consequence, students will be able to achieve learning goals more efficiently when pedagogical procedures are adapted to their individual differences [48]. Students are diverse in terms of their experience, expectation, abilities, and interests; and they vary in the learning styles as well. The learning style describes individual differences in learning. Students with different learning styles respond differently to various didactic approaches and the didactic strategies should match the learning styles of students [44].

Many researchers studied the learning styles and learning preferences of the learners to adapt didactic approaches to the way they prefer to learn. The benefits we obtain when designing a lesson taking into account the students' learning style are: 1) the improvement of the learner's response on the subject matter and 2) the improvement of their cognitive performance. Nevertheless, learning style is only one of the variables influencing learner achievement. Other factors, such as the quality and the content of the course, may be more important [23].

It has been referred that most of AEHS using learning styles do not use criteria for the selection of a certain theory of learning styles (or they do not make them explicit), except theoretical and empirical justification [14]. The criteria to select the learning style model is that apart from the theoretical and empirical justification, it should possess assessment instruments, describe the didactic strategies associated with each category of learning styles, and be appropriate for the learning context as well as its cost [66]. Moreover, Merrill [55] suggests that in case the modality of adaptation is adopted to learning styles for didactic systems (live- or technology-based), it is necessary to select the appropriate didactic strategies with the learning goal of teaching and, secondary, on the basis of these strategies, we can choose the most appropriate strategy for every one of the learning styles. According to [27], the learning styles will be more effective for the learners when the technology fits didactic design principles as well as the application of pedagogical criteria is also necessary for choosing the most appropriate learning style model for the AEHS or ITS that will be developed. In Table 2, we can see AEHS/ITS using learning style for adaptation (16 out of 35). From these systems, only one uses the learning style both for adaptive presentation and adaptive collaboration (TANGOW/WOTAN). Also, the MOT only uses Kolb's learning style model (Diverger and Converger). We consider that the learning style 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 [58].

1.3 Learning Theories, Didactic Strategies, and Domain of Applications in AEHS/ITS

Different didactic strategies, learning theories, and domain of applications have been used in AEHS/ITS 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 learner model, the domain knowledge, the didactic model, and the adaptive engine. Table 2 lists the main AEHS/ITS and the learning style model, learning theories or didactic strategies, and domain of applications they use.

Looking through Table 2, we can conclude that the kind of adaptive and intelligent techniques that the AEHS/ITS support mainly depend 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 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 on the preferences of students for graphical versus textual; while ELM-ART II 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 and 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 will be used in the development of an AEHS/ITS.

1.4 Design Principles of the MATHEMA

Open issues regarding the design of AEHS include [34]:

1. *The learner modeling*: Content, structure of the learner model, and learner diagnosis.
2. *Didactic design*: Domain knowledge (content, structure, and representation), assessment process, feedback, and collaboration.
3. *Adaptive engine*: Selection of appropriate adaptive and intelligent techniques depending on the learner and the context, and learner control issues.
4. *Authoring process*: Facilitation of the use of AEHS in real conditions and exploitation of standards (IMS, SCORM, and LOM).
5. Evaluation of the efficiency and effectiveness of the adaptation.

In this paper, we mainly focus upon the issues regarding the didactic design and the selection of appropriate adaptive and intelligent techniques depending on the learner and the context.

1.4.1 Didactic Design

diSessa [21] suggests that physics is best taught through experiments, labs, demonstrations, and visualizations which help the students to understand physical phenomena conceptually. Based on diSessa's suggestion, we design the MATHEMA by choosing didactic approaches in the frame of constructivism in order to help students learn physics conceptually. Students 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 [15]. Even advanced students have difficulty grasping nonintuitive, abstract concepts such as those found in electromagnetism [28]. It is possible, therefore, for the students to have misconceptions and learning difficulties when studying electromagnetism. Indicatively, we present two *common misconceptions* in electromagnetism that have been documented by [49] and [2]:

- The students 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.
- A constant magnetic field changes the speed (magnitude of velocity) of a charged particle which moves in it.

Also, Bagno and Eylon [2] refer that the students have difficulty in determining the direction of the *Lorentz* force.

While teaching in the frame of constructivist environment, it is necessary to take students' misconceptions and learning difficulties into consideration by using different teaching strategies and activities in order to support them to reconstruct their own cognitive models, and design a

TABLE 2
AEHS/ITS and Learning Style Models, Learning Theories, or Didactic Strategies, and Domain of Applications that They Use

	Learning Style Model	**Learning Theories or Didactic Strategies**	**Domain of Applications**
ACE [70]	------	Examples-based, Text reading, Learning by doing	Mathematical functions
ActiveMath [54]	------	Active and exploratory learning, Use of (mathematical) problem solving methods	Mathematics
ADAPT [30]	Extended Curry's onion model of learning style theories [18]	N/A	Domain –Independent
AES-CS [75]	Witkin's field dependence / independence [79]	Instructional tactics [40]	Multimedia technology systems
AHA ! [19]	Honey and Mumford's learning style [37]	Example-oriented, Activity-oriented, Explanation-oriented	Domain –Independent, Authoring of AEH systems
ALE [69]	Felder-Silverman Inventory of learning Styles	Strategies to accommodate different learning styles by assigning pedagogical weights to the content block types	Learning Management Systems, Authoring of AEH
ALICE [42]	------	Prerequisite-based learning (essential, supported)	Introduction to Java
Anatom-Tutor [5]	------	Task analysis [29].	Anatomy
Arthur [31]	Auditory, Visual, Tangible and combinations of them	Mastery learning [7], Multiple didactic styles	Computer Science Programming
AST [68]	------	Learning by examples, reading texts, learning by doing	Introductory Statistics
CAMELEON [46]	Felder-Silverman Inventory of learning Styles [25]	Strategies to accommodate different learning styles	Domain-Independent
CS383 [14]	Felder- Silverman Inventory of learning Styles	Media selection based on learner's learning style	Computer Systems
DCG [77]	------	Generic Task Model [76]	Domain-Independent
ELM-ART [10] & **ELM-ART II** [78]	------	Programming based on examples (example-based problem-solving, learning by examples)	Computer Science, Programming in LISP
Flexi-OLM [47]	Felder-Silverman Inventory of learning Styles (Sequential, Sensing, and Visual)	Sequential: Lectures. Sensing: Index, Ranked. Visual: All except textual	C Programming
Hypadapter [36]	—-	Learning by examples, Operations oriented	Common LISP
ILASH [4]	Felder-Soloman Inventory of learning Styles [26]	Summarizing and Questioning strategies	Studying of Waves
INSPIRE [59]	Honey and Mumford's learning style	Elaboration Theory [64], Component Display Theory [55]	Computer Architecture, Programming Introduction
InterBook [11]	—-	N/A	Domain-Independent, Authoring of adapting contents
ISIS-Tutor [9]	—-	Guided exploration learning, Problem solving, Study of examples	Learning of CDS/ISIS language
iWeaver [80]	Dunn and Dunn's learning style model [22]	Strategies to accommodate different learning styles, Media experiences and learning tools	Java programming language
KBS Hyperbook [57]	—-	Goal-based learning, Project-based learning	Domain-Independent, Authoring of Educational Hypermedia Books
Knowledge-Sea II [24]	—-	Lecture-to-Tutorial Oriented (slides, examples, questions, simulation, etc.)	C Programming
LSAS [3]	Felder-Soloman Inventory of learning Styles (Global and Sequential)	Advanced organizers [1], More structured lessons (sequential) Interviews and summaries (global)	N/A
MANIC [71]	—-	Preferences for graphic versus textual information	Unix network programming
MetaDoc [8]	—-	N/A	Administration of AIX operating system
MOT [17]	Kolb's Learning Style Inventory (Diverger and Converger) [45]	Adaptive strategies based on ingredients, Different learners with different presentation and ordering.	Domain-Independent, Authoring system
ProSys [60]	—-	Project-based [74] and Case-based [6] learning theories	Domain-Independent
PUSH [38]	—-	N/A	Software development with SDP method
SMILE [72]	Honey & Mumford's learning style	Learning by doing	Hypermedia
TANGOW [13]	—-	Theory presentation first or Practical presentation first, Task-based	Domain-Independent, Authoring of Adaptive Courses
TANGOW/WOTAN [61]	Sensing-Intuitive dimensions of Felder-Soloman Inventory of learning Styles	Theory presentation first or Practical presentation first, Example-oriented (sensing), Exposition-based (intuitive), Task-based.	Domain -Independent, Authoring of Adaptive Courses
VC Prolog Tutor [63]	—-	Design of problem solving [39].	Prolog
WHURLE [56]	Felder-Silverman Inventory of learning Styles	Conditional transclusion of chunks appropriate to each learner, Visual-Verbal preferences of learning style	Domain -Independent, Deliver System

learning environment where they can construct their ideas by themselves. How to engage younger students in complex physics thinking is a challenge, but simulations provide one intriguing way to engage students in the study of abstract, complex physical phenomena [21]. Computer simulations have been shown to be effective in fostering conceptual change [53]. The cognitive conflicts arising from the simulations lead the learners to discover possible misconceptions and reconstruct their own cognitive models [33].

Much of the current work in cognitive psychology has shown that students learn better when engaged in solving problems [51]. According to Concari et al. [16], 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 [67], educators should consider to stimulate the basic purposes of schooling curiosity, exploration, problem solving, and communication. 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 all the above into consideration, we adopt the following didactic approaches in the MATHEMA: *questions, demonstrations, presentation of theory and examples, exercise solving, and problem solving through experimentations with simulations, explorations, guided discovery, and collaboration.* The learning goal of explorations and guided discovery didactic approaches is to motivate the students to self-direct their learning process to learn how to apply knowledge and generally develop higher order thinking. An exploration is a structured lab where the student makes predictions about a body's (e.g., particle) motion, then runs the simulation to compare the actual result with the predicted result. Guided questions help the students refine their mental models of physics [32]. Exploration activities can be supported through a hypermedia-form presentation of the educational material, simulations linked with specific activities, and collaboration in team projects [33]. 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 others.

In order to support multiple didactic strategies in a constructivist environment, we choose Kolb's Experiential Learning Theory (ELT) [44]. Kolb's ELT is a holistic theory of learning whereby social knowledge is created and recreated in the personal knowledge of the learner through the grasping and transforming experience. Kolb has suggested the *Learning Cycle* that includes four stages. Each stage is approached with different didactic approaches. According to Kolb, the students having better learning outcomes should go through all the stages many times.

Kolb's ELT is also a theory of cognitive learning styles that proposes four learning styles: *Diverger, Assimilator, Converger, and Accommodator.* Divergers have the ability to view concrete experiences from a number of perspectives. Assimilators have the abilities to formulate theories and prefer abstract concepts. Convergers have strength on the practical applications of ideas. Accommodators have strength in doing things. Cognitive psychologists such as Piaget, Bruner, Harvey, Hunt, and Schroeder have identified the concrete-abstract continuum as the main dimension along which human cognitive growth occurs [81]. Kolb considers that the Divergers and Accommodators have *concrete* "learning style" and the Convergers and Assimilators have *abstract* "learning style." These two dimensions represent the major directions of cognitive development identified by Piaget. Some students may grasp abstract concepts readily while others need concrete imagery to learn [81]. Concrete dimension enables the learners to register information directly through their five senses: sight, smell, touch, taste, and hearing. When they are using their concrete ability, they are dealing with the obvious, the "here and now." They are not looking for hidden meanings, or making relationships between ideas or concepts, and they may also communicate in a direct, literal, no-nonsense manner. Abstract dimension allows learners to visualize, conceive ideas, and understand or believe in what they cannot actually see. When learners are using their abstract ability, they are using their intuition, their imagination, and they are looking beyond at something which is of more subtle implication.

Moreover, 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 [43], [45].

Kolb proposes a learning style model that we adopt because it meets all the criteria of the most appropriate learning style model proposed by Sampson and Karagiannidis:

Empirical justification: Kolb's learning style model is supported by Kolb's ELT and some empirical studies performed by Svinicki and Dixon [73] and Harb et al. [35].

Assessment instrument: Kolb's learning style model is supported by Kolb's Learning Style Inventory (LSI) questionnaire [45], which consists of 12 multiple-choice questions, so it makes its use easy for senior high school students or beginners in higher education. In the MATHEMA, Kolb's LSI questionnaire apart from the identification of the four learning styles that we mentioned above, is used to distinguish between abstract and concrete learners with the aim of adaptive group formation for collaborative tasks.

Description of didactic strategies: Svinicki and Dixon, and Harb et al. have described the most appropriate didactic approaches for each stage of Kolb's learning cycle in their papers [73], [35], accordingly.

Appropriation of the context: We conducted a research [58] on the subject of electromagnetism, based on Kolb's ELT and the researches of Svinicki and Dixon [73], Harb et al. [35]. We designed the educational material according to didactic approaches of Table 3. Didactic strategies and educational material were adapted by the MATHEMA to the students according to their learning style. The results of this research showed that the participants improved their performances a lot [58].

Moreover, in the development of the MATHEMA, we take care of the quality and the content of the courses, to improve the learners' achievement.

TABLE 3
Didactic Approaches Implemented by the MATHEMA

Learning Style	Didactic Approach
Diverger	Questions, Demonstrations (through Visualizations)
Assimilator	Presentation of Theory and Examples
Converger	Exercise Solving
Accommodator	Activity (problem solving through experimentation with simulations, explorations, guided discovery, and collaboration)

1.4.2 Adaptive and Intelligent Techniques

In order to support all the didactic approaches that we mentioned above, taking into consideration the learner attributes and the content as well as to enrich the adaptive functionality of the MATHEMA, we implemented the following techniques: *curriculum sequencing, adaptive presentation, adaptive navigation support, adaptive group formation and peer help, and interactive problem solving support.* In general, the MATHEMA is a learning system that dynamically generates courses of electromagnetism. The aspects of students that the MATHEMA uses for adaptation are: *learning goal, knowledge level, total performance, prior knowledge, learning style, abstract or concrete dimension of learning style, preference for visual and/or verbal feedback* [62], *and preference for the kind of navigation.*

Curriculum sequencing. The concepts of learning goal in the 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 [64], 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 [59].

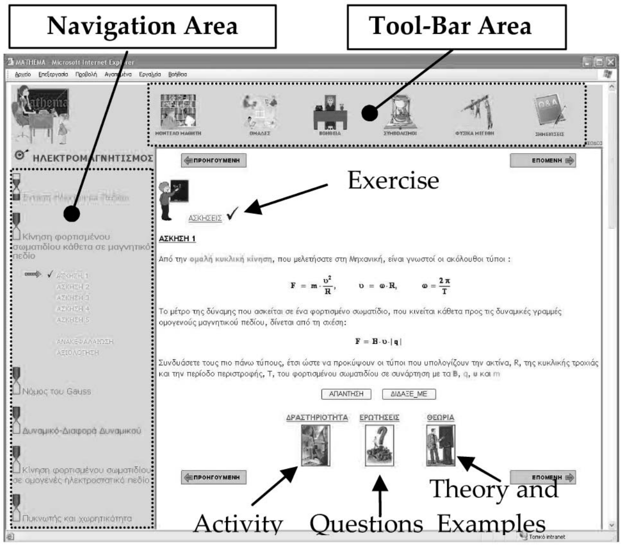
Adaptive presentation. Taking into consideration all those that we refer to in the first three paragraphs of Section 1.4.1., the researches of Svinicki and Dixon [73], Harb et al. [35], as well as our own research that we mentioned above, we consider that the most appropriate didactic approaches that match with each of the student's learning style are those presented in Table 3. The adaptive presentation of the educational material according to the students' learning style, when they follow the four stages of Kolb's learning cycle, is done with the following didactic strategies:

Diverger.

1. *Questions, Demonstrations;*
2. *Presentation of Theory and Examples;*
3. *Exercise Solving;*
4. *Activity.*

Assimilator.

1. *Presentation of Theory and Examples;*
2. *Exercise Solving;*
3. *Activity;*
4. *Questions, Demonstrations.*



ΑΣΚΗΣΗ 1

Από την ομαλή κυκλική κίνηση, που μελετήσατε στη Μηχανική, είναι γνωστοί οι ακόλουθοι τύποι :

$$F = m \cdot \frac{\upsilon^2}{R}, \qquad \upsilon = \omega \cdot R, \qquad \omega = \frac{2\pi}{T}$$

Το μέτρο της δύναμης που ασκείται σε ένα φορτισμένο σωματίδιο, που κινείται κάθετα προς τις δυναμικές γραμμές ομογενούς μαγνητικού πεδίου, δίνεται από τη σχέση:

$$F = B \cdot \upsilon \cdot |q|$$

Συνδυάσετε τους πιο πάνω τύπους, έτσι ώστε να προκύψουν οι τύποι που υπολογίζουν την ακτίνα, R, της κυκλικής τροχιάς και την περίοδο περιστροφής, T, του φορτισμένου σωματιδίου σε συνάρτηση με τα B, q, υ και m

Fig. 1. Educational material adapted to a "Converger" student.

Converger.

1. *Exercise Solving;*
2. *Activity;*
3. *Questions, Demonstrations;*
4. *Presentation of Theory and Examples.*

Accommodator.

1. *Activity;*
2. *Questions, Demonstrations;*
3. *Presentation of Theory and Examples;*
4. *Exercise Solving.*

Fig. 1 shows how our system applies the didactic strategy for a "Converger" student. It presents an exercise to be solved by the student, 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. However, the student is free to choose the next educational material to study.

Adaptive navigation support. In adaptive navigation support, the MATHEMA helps students avoid the "lost in hypermedia" syndrome by offering them the following techniques: direct guidance, link annotation, link hiding, and link sorting.

Adaptive group formation and peer help. In exploratory environments, in which the students participate in experiments, we consider that it is very important for them to collaborate, so that they will share their experience, opinions, and findings. Consequently, the group formation is necessary. Thus, the MATHEMA enforces the learner's learning by involving an adaptive group formation and peer help technique. For this purpose, our system creates a priority list of possible candidate mates for a certain student, taking into account his/her learning style, his/her candidate mates' learning style, and total performance as well.

In this paper, we mainly focus upon the interactive problem solving support implemented by our system. The rest of the paper is organized as follows: In Section 2, we describe the interactive problem solving support by presenting the framework of the activity and an application of this framework in supporting students solving a problem in electromagnetism. In Section 3, we present the experimental study with senior high school students. In Section 4, we summarize the most significant points of our work and we refer to our future plans.

2 INTERACTIVE PROBLEM SOLVING SUPPORT

2.1 Problem Solving Foundations

Different kinds of tasks are typically involved in collaborative learning activities. One of them, eventually the most eminent, is problem solving, taking place in appropriate situations and collaborative learning settings that permit a mutual engagement of participants in a coordinated effort to solve the problem together [65]. Problem solving varies in at least three different dimensions: 1) problem type, 2) problem representation, and 3) individual differences. The problem solving has four characteristics as described by [51]:

1. Problem solving is *cognitive*. It occurs internally, and thus, can only be inferred indirectly by the person's actions.
2. Problem solving is a *process*. It involves representing and manipulating knowledge in the problem solver's cognitive system.
3. Problem solving is *directed*, that is, the problem solver's processing is guided by his/her goals.
4. Problem solving is *personal*. The solver's individual knowledge and skills help determine the difficulty or ease with which obstacles to solutions can be overcome.

Jonassen [41] began to describe the range of problem solving learning outcomes by distinguishing between well-structured and ill-structured problems in terms of their didactic design requirements. Didactic designs for well-structured problems are rooted in information processing theory, but the didactic designs for ill-structured problems necessarily share assumptions with constructivism and situated cognition. Ill-structured problems are complex problems that cannot be solved by a simple algorithm. Such problems do not necessarily have a single correct answer, but require learners to consider alternatives and to provide a reasoned argument to support the solution that they generate. Information processing theories conceive of learning outcomes as generalized skills that can be applied across content domains, while constructivism and situated cognition argue for the domain specificity of any performance, and therefore, recommend embedding instruction in some authentic context.

In a problem solving environment, the learner is encouraged to solve the problem, which is set in a real-world framework and is interesting, challenging, and complex for the learner. In order to solve a problem, the learners have to discover or learn new knowledge either individually or together in groups, analyze relevant information obtained from different sources, think critically, creatively, reflectively, and flexibly, trying out alternate solutions to both cognitive and social problems, and discuss the solution with others. physics instructors and teachers generally accept that problem solving leads to an understanding of the subject [50].

Interactive problem solving support is a more recent and powerful technique [12]. Systems implementing this technique may monitor the actions of the students, understand them, and use this understanding to provide help and to update the student model [12]. The AEHS supporting this methodology are the ActiveMath [54] and ELM-ART II [78].

ActiveMath is an intelligent learning environment on the Web. It provides high-quality Web presentations of mathematical documents, intelligent selection of content items to achieve learning goals, search for text and mathematical objects, copy and paste of formula, and interactive exercises with learner inputs evaluated by classical computer algebra systems. ActiveMath design aims at supporting truly interactive, exploratory learning and assumes the student to be responsible for her learning to some extent. Therefore, a relative freedom for navigating through a course and learning choices is given to the students.

ELM-ART II was designed for learning programming in LISP and integrates a LISP compiler. ELM-ART II provides a unique example of *example-based problem solving support*. ELM-ART II contains "live examples" and short programming problems. In ELM-ART II, if the learners fail to solve a LISP programming problem, they can ask the system to diagnose the code of their solution and give detailed explanation of error. It also helps the learners to find the relevant examples from their previous experience by presenting an ordered list of examples based on their relevancy.

2.2 Problem Solving in the MATHEMA

A real interactive tutor is expected to be not only interactive, but also active. It should not sleep from one help request to another, but, instead, should be able to monitor what the student is doing and instantly react to errors. It simply cannot be implemented with the traditional server-side CGI interactivity and requires client-side interactivity based on Java [12]. Some systems as PAT-Online cannot actively watch the student's actions and can only provide help by request. The MATHEMA is supported by a client-server architecture (JSP, Servlets, JavaBeans, and JavaScripts) offering an appropriate environment for supporting problem solving activities. The MATHEMA has the capability to store the students' actions into the student model and to act accordingly, as well as it keeps statistical data about the students' actions.

In the MATHEMA, we designed and implemented the problem solving through an activity by making use of experimentation through *simulations, explorations* [32], *guided discovery* [52], and *collaboration* didactic approaches. The specific goal of the activity is to support the students to learn electromagnetism conceptually and overcome their possible misconceptions and learning difficulties [58].

2.2.1 The Framework of the Activity in the MATHEMA

At the beginning, the students are given by the system the learning goals, learning outcomes of the activity, and links to appropriate prerequisite knowledge. Also, links to other educational material (Questions, Theory, Examples, etc.) are given to the students according to didactic strategies that we mentioned above.

The general framework of the activity includes six steps as follows:

Step 1: Activation of prior knowledge.

The students are given the formulas they have already known from previous chapters of physics, and perhaps, they know how to use them (prior knowledge). In case that the students lack sufficient prior knowledge, the system offers them additional relevant knowledge through links to prerequisite knowledge. Also, students are given the main formulas of the lesson they are studying. Then, the students are asked to synthesize all the given formulas in order to extract formulas with the aim of calculating the values of certain physical quantities (or dimensions).

Step 2: Recognizing the restrictions on the parameters' values of extracting formulas in Step 1.

The students, through a guided dialog with the system, explore if they should set any restrictions on the values of parameters of the extracting formulas in Step 1.

Step 3: Application of extracting formulas in Step 1 and prediction of the kind of motion.

The students are asked to apply the extracting formulas in Step 1 in order to calculate the values of the corresponding physical quantities (or dimensions) in various values of parameters and to write them down. Moreover, they are asked to predict about the kind of motion.

Step 4: Working with the simulation.

The students are asked to set various values in parameters of physical quantities (or dimensions) related to a certain extracting formula in Step 1 to a given simulation, then to run it. They should write down the simulation results. Then, the students are asked to compare the simulation results with the calculated or predicted results in Step 3 in order to decide which values seem to be the correct ones.

Step 5: Collaboration in pairs of students.

The students collaborate in pairs, with the aim of sharing their experience, opinions, and findings and to write down the final results. A student who does not wish to collaborate with his/her peer can get round this step.

Step 6: Checking the results through a *guided dialog*.

The students through a guided dialog with the system check their final results that they believe as correct. The aim of the guided dialog is to detect the students' misconceptions and learning difficulties in order to help them to reflect and to reconstruct their own cognitive model. This step could be done either individually or collaboratively.

In Step 2, the *guided dialog* is carried out in three phases as follows:

Step 2/Phase 1: Exploration—*The students are given the values of parameters and the formulas to calculate the values of certain physical quantities (or dimensions), and he/she is asked to explore if these values of parameters should be restrictions. Then, he/she is asked if he/she agrees or disagrees that the given values of parameters are restrictions by choosing "Yes" or "No." If he/she chooses "Yes," then the system proceeds to the Step 3 of the activity, if "No," then the system proceeds to the Phase 2 of the dialog.*

Step 2/Phase 2: Presentation—*The system presents the values of the physical quantities (or dimensions) calculated by the formulas for the given values of parameters and the student is asked if he/she agrees or disagrees with these calculated values by choosing "Yes" or "No." If he/she chooses "Yes," then the system proceeds to Step 3 of the activity, if "No," then the system proceeds to Phase 3 of the dialog.*

Step 2/Phase 3: Explanation—*The system explains to the student why the given values of the parameters are restrictions.*

In Step 6, the *guided dialog* is carried out in four phases as follows:

Step 6/Phase 1: *The student 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 (we later call it final result) and the corresponding value or the kind of motion that he/she received from the simulation (we later call it simulation result).*

The cases that the system examines are four as follows:

1. *If the final result is equal to (or the same as) the simulation result, then the system informs the student that the final result is correct and also explains to him/her why it is correct.*
2. *If the final result is correct and the simulation result is not correct, then the system informs the student that his/her result is correct and it also explains to him/her which possible reasons made the simulation result incorrect. So, the system induces the student to repeat Step 4 of the activity.*
3. *If both results are not correct, then the system informs the student that both results are not correct, so it induces the student to repeat all the steps of the activity.*
4. *If the final result is not correct and the simulation result is correct, then the system proceeds to Phase 2 of the dialog.*

Step 6/Phase 2: *In case the student's wrong result is either due to a wrong mathematical formula or due to the wrong use of the correct mathematical formula that calculates the physical quantity (or dimension), the system presents the correct mathematical formula to the student and additional help about its application. The student is asked to calculate the physical quantity (or dimension) again and to choose the correct one from among the given answers. The other answers are possible common misconceptions or learning difficulties. If the student again chooses a wrong answer, then the system proceeds to Phase 3 of the dialog. If the student chooses the correct answer, then the system returns to Phase 1 of the dialog so that the student will check any other result.*

Step 6/Phase 3: *The system gives the student an explanation, by using mathematical arguments, why the answer is not correct. Then, the system asks the student if he/she insists on his/her point of view, and if the student chooses "Yes," then the system proceeds to Phase 4 of the dialog; if "No," then the system returns to Phase 1 of the dialog so that the student can check any other result.*

Step 6/Phase 4: *The system gives the student a different explanation why the answer is not correct by using arguments based on the experience that the student obtained through the simulation. Then, the system asks the student 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.*

It is important to point out that all the steps of the activity are not obligatory and the student has the freedom to go back anywhere in the system or to skip

TABLE 4
Calculations of the Values of Radius and Period

Number of Question	Value of particle charge, q (C)	Value of particle velocity, v (m/s)	Value of radius, R (m)	Value of period, T (s)
1	0μC	0		
2	0μC	2		
3	+2μC	0		
4	+2μC	2		
5	+2μC	4		
6	-2μC	0		
7	-2μC	2		
8	-2μC	4		

the activity any time he/she likes. The system keeps in the student model all the pages that the student had already visited, and it reminds him/her about his/her visits any time it is required.

2.2.2 Examples from the Guided Dialog

In our research, the activity that the students carried out through the MATHEMA belongs to the section of electromagnetism entitled: *Motion of a charged particle perpendicular to the direction of a uniform magnetic field.* The problem that the students are asked to solve is:

(STEP 1) *Synthesize the mathematical formulas listed below in order to extract the formulas of radius, R, and period, T, of the particle circular motion.*

$$\mathrm{F} = \frac{\mathrm{m} \cdot \mathrm{v}^2}{\mathrm{R}}, \quad \mathrm{v} = \omega \cdot \mathrm{R}, \quad \omega = \frac{2\pi}{\mathrm{T}}, \quad \mathrm{F} = \mathrm{B} \cdot \mathrm{v} \cdot |\mathrm{q}|. \tag{1}$$

(STEP 2) *Apply the following pairs of values, q and v, in order to calculate the radius R and period T. If certain values of the radius R and/or period T are zero, infinite, or indeterminable, then the given values of q and v are restrictions.*

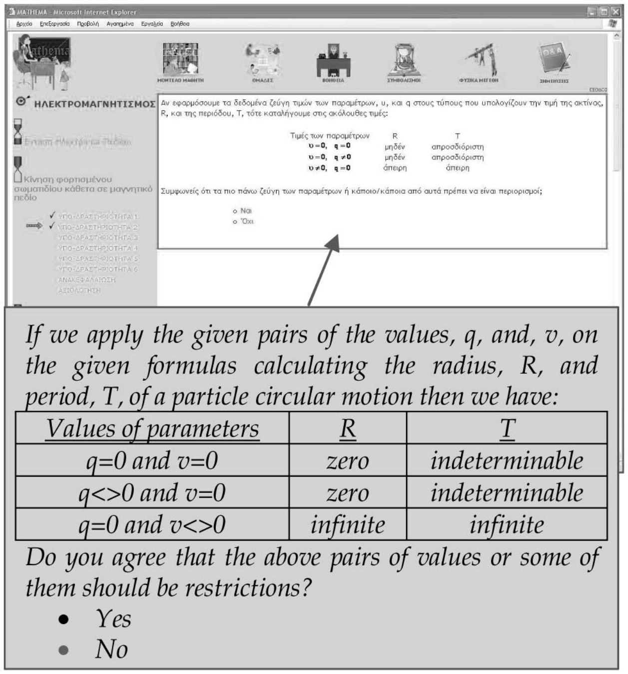
1. *$q = 0$ and $v = 0$.*
2. *$q <> 0$ and $v = 0$.*
3. *$q = 0$ and $v <> 0$.*

(STEP 3) *Apply the values of the parameters, q and v, of Table 4 on the formulas of the radius R and period T, and calculate the corresponding values of radius R and period T of the particle circular motion; predict the motions of the particle for the same parameters (no motion, clockwise circular motion, anticlockwise circular motion, and rectilinear motion). The number of questions in Table 4 corresponds to each pair of particle velocity v and particle charge q that are intended to identify various misconceptions and learning difficulties of the students. Given values: $B = 2T$ and $m = 1$ mg.*

(STEP 4) *Set the values of q and v of Table 4 to the simulation and run it. Then, compare the calculated or predicted results with simulation results and explain the differences.*

(STEP 5) *Collaborate with your mate.*

(STEP 6) *Check your final results.*



Αν εφαρμόσουμε τα δεδομένα ζεύγη τιμών των παραμέτρων, υ, και q στους τύπους που υπολογίζουν την τιμή της ακτίνας, R, και της περιόδου, T, τότε καταλήγουμε στις ακόλουθες τιμές:

Τιμές των παραμέτρων	R	T
$\upsilon = 0$, $q = 0$	μηδέν	απροσδιόριστη
$\upsilon = 0$, $q \neq 0$	μηδέν	απροσδιόριστη
$\upsilon \neq 0$, $q = 0$	άπειρη	άπειρη

Συμφωνείς ότι τα πιο πάνω ζεύγη των παραμέτρων ή κάποιο/κάποια από αυτά πρέπει να είναι περιορισμοί;

○ Ναι
○ Όχι

If we apply the given pairs of the values, q, and, v, on the given formulas calculating the radius, R, and period, T, of a particle circular motion then we have:

Values of parameters	*R*	*T*
q=0 and v=0	*zero*	*indeterminable*
q<>0 and v=0	*zero*	*indeterminable*
q=0 and v<>0	*infinite*	*infinite*

Do you agree that the above pairs of values or some of them should be restrictions?

- *Yes*
- *No*

Fig. 2. System presents the values of radius, R, and period, T, corresponding to the given values of parameters.

As examples, we present the *guided dialogs* done between the system and the student named Yiannis in Steps 2 and 6. The *guided dialog* in Step 2 was done as follows:

Step 2/Phase 1: System: *Apply the following pairs of values, v and q, in order to calculate the radius R and period T. If certain of the values of the radius R and period T are zero, infinite, or indeterminable, then the corresponding values of q and v are restrictions.*

q	*v*	$R = \frac{m \cdot v}{B \cdot \lvert q \rvert}$	$T = \frac{2 \cdot \pi \cdot m}{B \cdot \lvert q \rvert}$
0	*0*		
<>0	*0*		
0	*<>0*		

Are the above pairs of values or some of them restrictions?

- *Yes*
- *No*

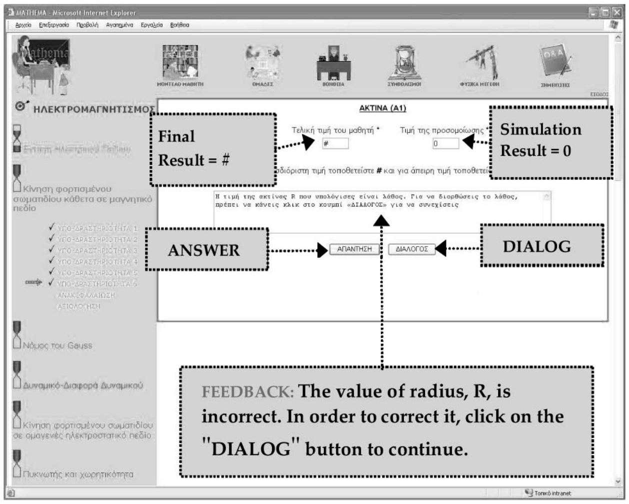
Yiannis' answer: *No.*

Step 2/Phase 2: System: see Fig. 2.

Yiannis' answer: *No.*

Step 2/Phase 3: System: No Lorentz force is exerted on the particle because in the formula $\mathrm{F_L} = \mathrm{B}\ \mathrm{v}\ |\mathrm{q}|$, either $\mathrm{v} = 0$, or $\mathrm{q} = 0$, or both of them are zero giving the Lorentz force total result as zero. So, since in these certain cases, no Lorentz force is exerted on the particle; hence, we have no circular motion. Consequently, the given pairs of values must be restrictions.

In order to explain how the dialog for Step 6 is done, we present the number 6 of questions of Table 4: *Which is the value of the radius R of a charged particle with mass $m = 1$ mg and charge, $q = -2\ \mu C$ that it remains motionless ($v = 0\ m/s$) in a uniform magnetic field with a magnetic induction, $B = 2T$?*



Τελική τιμή του μαθητή * #

Τιμή της προσομοίωσης * 0

διόριστη τιμή τοποθετείστε # και για άπειρη τιμή τοποθετεί

Η τιμή της ακτίνας R που υπολόγισες είναι λάθος. Για να διορθώσεις το λάθος, πρέπει να κάνεις κλικ στο κουμπί «ΔΙΑΛΟΓΟΣ» για να συνεχίσεις

Final Result = #

Simulation Result = 0

ANSWER

DIALOG

FEEDBACK: **The value of radius, R, is incorrect. In order to correct it, click on the "DIALOG" button to continue.**

Fig. 3. Yiannis has written down the final and simulation results on the check forms, and he has taken feedback.

This question is intended to identify a common misconception that the students usually have about this section of electromagnetism which is: *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* [49], so as to help them overcome this.

The *guided dialog* in Step 6 of the activity between the system and Yiannis for checking the result was done as follows:

Step 6/Phase 1: In Fig. 3, we can see the results that Yiannis has written down on the check forms. The final result is equal to indeterminable (it is symbolized with a # symbol) and the simulation result is equal to zero. Also, Yiannis received feedback when he clicked on the "ANSWER" button.

Step 6/Phase 2: The system suggests to Yiannis to calculate again the value of the radius R, and to select an answer (Fig. 4).

Yiannis' answer: *Infinite*.

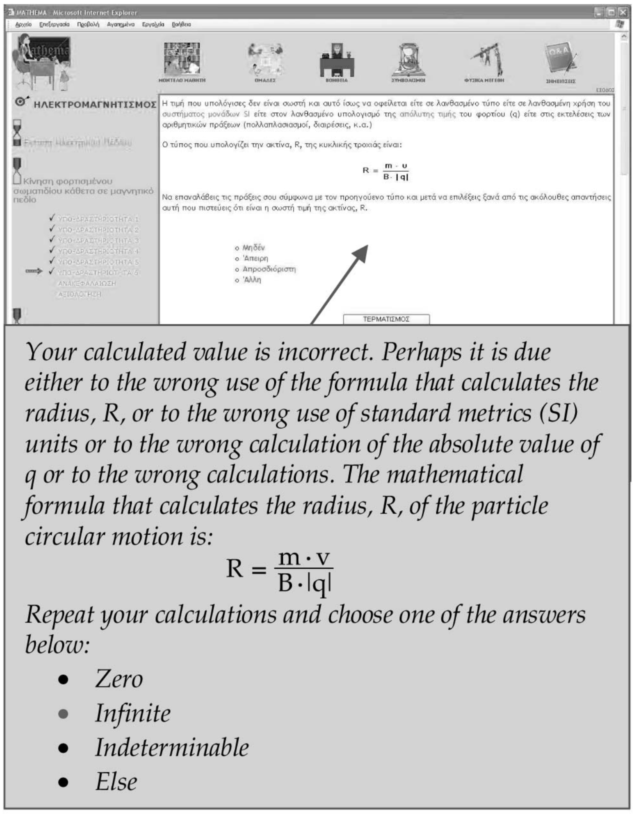
Step 6/Phase 3: System: *Generally, the value of a fraction is infinite if the numerator is not zero or infinite and the denominator is zero. So, the value of the radius R is infinite if the numerator is not zero or infinite, and the denominator is zero. However, since the value of linear velocity v is zero, the numerator is zero. Also, B and q are not zero, so the denominator is not zero. Consequently, the value of radius R is not infinite but is zero.*

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

- *Yes*
- *No*

Yiannis' answer: *Yes*.

Step 6/Phase 4: *System: During your study of simulation you might have concluded that the radius R of the circular motion 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.*



Η τιμή που υπολόγισες δεν είναι σωστή και αυτό ίσως να οφείλεται είτε σε λανθασμένο τύπο είτε σε λανθασμένη χρήση του συστήματος μονάδων SI είτε στον λανθασμένο υπολογισμό της απόλυτης τιμής του φορτίου (q) είτε στις εκτελέσεις των αριθμητικών πράξεων (πολλαπλασιασμοί, διαιρέσεις, κ.α.)

Ο τύπος που υπολογίζει την ακτίνα, R, της κυκλικής τροχιάς είναι:

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

Να επαναλάβεις τις πράξεις σου σύμφωνα με τον προηγούενο τύπο και μετά να επιλέξεις ξανά από τις ακόλουθες απαντήσεις αυτή που πιστεύεις ότι είναι η σωστή τιμή της ακτίνας, R.

- Μηδέν
- Άπειρη
- Απροσδιόριστη
- Άλλη

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 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 choose one of the answers below:

- *Zero*
- *Infinite*
- *Indeterminable*
- *Else*

Fig. 4. Calculation of the radius value again, and choice of an answer.

3 EXPERIMENTAL STUDY

The main purpose of this experimental study was to investigate the effectiveness of the framework of the activity on the learning of electromagnetism by the senior high school students. The research questions we examined in this research are: *Are the learning performances of students improved when they carry out the activity? Do the students perceive their wrongs and revise their points of view? Do the students justify their choices and accept that they must set restrictions on the values of parameters of formulas?* The experiment was conducted in a Technical High School in Philadelphia, Athens, Greece, in January 2007. The entire processes of the research lasted 24 days. In the first week, we gave the pretest to the students. In the second week, we gave a demonstration about Interactive physics by presenting the main operations of the simulations that we have designed for the experimental study in order to facilitate the students in their exploration. Also, we described the environment of the MATHEMA. In the third week, the students carried out the activity through the MATHEMA. The experiment with the activity in the classroom lasted two didactic hours. In the fourth week, the students were given the posttest and the questionnaire to express their opinions about our system.

3.1 Experimental Design

3.1.1 *Participants*

Twelve 18-year-old students participated in the experiment. The reason why we chose 12 students is the limitation of the school laboratory (the laboratories in Greek public high schools are usually equipped with 12-14 computers).

3.1.2 Material and Instruments

1. *AEHS MATHEMA and Interactive Physics*. The students studied the activity through the MATHEMA as well as by using the Interactive Physics software to run the simulations we have designed for this experiment. Also, the pre-/posttest was incorporated in the MATHEMA. The system contains eight pages for the activity. Also, the system contains three pages for the prerequisite knowledge (e.g., circular motion, uniform magnetic field, etc.). For the activity, the system supports 24 guided dialogs concerning the questions of Table 4 (eight for checking the results of radius, eight for checking the results of period, and eight for checking the results of motions), and one for the set of restrictions. In addition, the system contains a dictionary of physics terms and help for more information about the system.
2. *Questionnaires*. We gave the students a questionnaire to fill in after the experiment, in order to express their opinion about our system.
3. *Pre-/Posttests*. The assessment of the students' learning performance is performed through assessment tests before and after the experiment. The pretest and the posttest for the activity included five questions of identical form. These questions are intended to detect misconceptions and learning difficulties of students before and after the experiment. For example, a question to detect a misconception is the following: *If a particle which has no charge ($q = 0$) is moving with a velocity $v = 2\ m/s$, perpendicular to the direction of a uniform magnetic field, then its value of radius R of the circular trajectory is:*

    1. *zero,*
    2. *infinitive,*
    3. *determinable (a certain value), and*
    4. *indeterminable.*

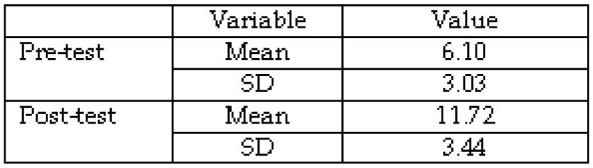
    The pretest was given to the students before the experiment. The posttest was given to the students five days after the experiment.

3.1.3 Experimental Procedures

In our experimental study, the activity that the students carried out through the MATHEMA belongs to the section of electromagnetism entitled: *Motion of a charged particle perpendicular to the direction of a uniform magnetic field.* The learning outcomes that were presented by the MATHEMA to the students are that the students will be able to:

1. *Synthesize* given mathematical formulas of the electromagnetism in order to *extract* the formulas of radius R and period T of the particle circular motion.
2. *Set restrictions* on the values of parameters of the extracting formulas through the *guided dialog* with the system.

TABLE 5
Mean Scores and Standard Deviations of Means



	Variable	Value
Pre-test	Mean	6.10
	SD	3.03
Post-test	Mean	11.72
	SD	3.44

3. *Apply* the extracting formulas for the values of the parameters q and v listed in Table 4, in order to *calculate* the corresponding values of radius R and period T of the particle circular motion.
4. *Predict* the motions of the particle. For the prediction of the kind of particle motion, the students made use of the *right-hand rule*.
5. *Set* the values of the parameters of the extracting formulas, q and v, listed in Table 4, to a given simulation and to *run* it.
6. *Compare* the calculated (or predicted) results with the simulation results and *explain* the differences.
7. *Collaborate* with his/her peer for the correction of results.
8. *Revise* their possible mistaken beliefs or miscalculations through the *guided dialog* with the system.

3.1.4 Data Collection

In order to investigate the research questions, quantitative data were collected by the embedded in the MATHEMA evaluation test used as pretest and posttest. Also, data were collected from the responses of the students that our system keeps in the database. The questionnaire for the expression of students' opinions about our system was completed by hand with pencil and paper.

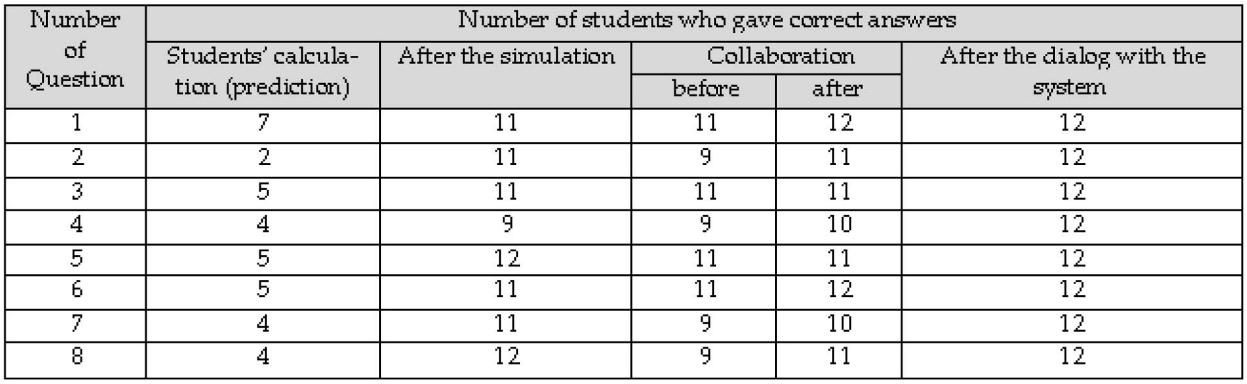
3.1.5 Analysis Method

For the analysis of results, because of the small number of the participants (less than 30), we make use of the independent two-sample t-test. The one sample is the pretest scores and the other sample is the posttest scores of the participants. A significant level of $p < .05$ was adopted for the study.

3.2 Results and Conclusions

In this paper, we present only the results for the radius R. The number of students who gave correct answers to the questions related to radius R of Table 4, for each step of the activity, is presented in Table 6. In the initial calculation (prediction), most of the students gave wrong answers. Also, some students gave wrong answers after the simulation. When the students were asked to write down the correct answers in tables, before their collaboration, some of them did not accept the simulation results as correct answers, but insisted on their calculations being correct rather than the simulated ones. The collaboration in pairs helped the students to correct some of their wrong answers but not all of them. After the *guided dialog* in Step 6 with the system, all the students gave correct answers.

TABLE 6
Students Who Gave the Correct Answers to the Questions of Table 4 for Each Step of the Activity



Number of Question	Number of students who gave correct answers				
	Students' calculation (prediction)	After the simulation	Collaboration before	Collaboration after	After the dialog with the system
1	7	11	11	12	12
2	2	11	9	11	12
3	5	11	11	11	12
4	4	9	9	10	12
5	5	12	11	11	12
6	5	11	11	12	12
7	4	11	9	10	12
8	4	12	9	11	12

The means (M) and standard deviations (SD) of the students' mean scores for the pre-/posttest are presented in Table 5.

The learning performance was measured by comparison of the pretest with the posttest scores of the students. The results indicate that: there was a significant difference in learning performance of students, $\mathrm{t}(22) = 4.26, \mathrm{p} = 0.00016$. That is, these results show that: *there was a significant improvement of learning performance of the students when they carried out the activity.*

Also, a qualitative analysis of the data collected by the responses of the students show that they: *1) perceive their wrongs and revise their points of view, 2) justify their choices, and 3) accept that they must set restrictions on the values of parameters of formulas.*

Moreover, taking the opinions of the students about our system into consideration, we improved it in the points where the students found difficulties or they were not interested in.

4 DISCUSSION AND FUTURE WORK

In AEHS, several adaptive and intelligent techniques have been applied to introduce adaptation. In general, these systems use combinations of the adaptive and intelligent techniques in order to enrich their adaptive functionality and enhance the support offered to learners. In this paper, we present the design principles of the MATHEMA have mainly concentrated upon the interactive problem solving that it supports.

So far, our AEHS has supported curriculum sequencing, adaptive presentation, adaptive navigation, interactive problem solving, and adaptive group formation and peer help techniques. The interactive problem solving through a certain framework of the activity as well as an application of the framework of the activity in electromagnetism are described in this paper in detail. An experimental study with senior high school students showed that the MATHEMA helps the students improve their performances.

In the future, we will design and investigate other activities in several sections of electromagnetism in order to support students to overcome their misconceptions and learning difficulties.

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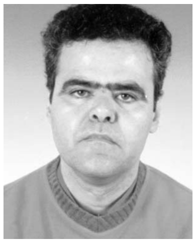

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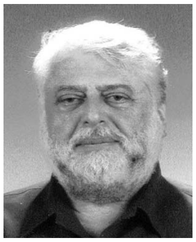

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