Adaptive Educational Hypermedia Systems on the Web for the Didactics of Science and Technology

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Abstract

This doctoral dissertation deals with design and implementation issues of an Adaptive Educational Hypermedia System (AEHS). AEHS can be considered as the solution to the problems of traditional educational hypermedia systems.

More specifically, it deals with: (i) the design of an educational framework based on constructivism that it will guide the AEHS's educational decisions and the design of domain model. Also, it will set the goals and the functionality of adaptation, the feedback, the assessment, the participation of student in collaborative problem solving activities, and it also will determine the combination of adaptation techniques, taking into consideration the content and making the best of the learner's specific characteristics, (ii) the selection of the learning styles model, (iii) issues of sharing the control between the learner and the system, (iv) the selection of the appropriate adaptive navigation techniques, (v) a learner-centred method meta-adaptive navigation, (vi) the interactive problem solving support through the activities, (vii) a learner-centred method of adaptive group formation , and (viii) issues of adaptive presentation.

In the frame of this dissertation, we designed and implemented the AEHS MATHEMA that combines the constructivist, the socio-cultural and the meta-cognitive didactic models, and it also supports the individual and collaborative learning. The didactic strategies supported by the MATHEMA based on Kolb's learning styles model. The general aim of the MATHEMA is to support senior high school learners or novices of higher education, through an interactive and constructivist educational material, in learning science individually and/or collaboratively, and overcoming their possible misconceptions and learning difficulties. At the current version, appropriate educational material has been developed for the learning of electromagnetism.

The adaptive and intelligent techniques supported by the MATHEMA are: curriculum sequencing, adaptive presentation, adaptive and meta-adaptive navigation, interactive problem solving support, and adaptive group formation.

At the end of this dissertation, researches for the development and the formative assessment of the MATHEMA, the conclusions and the future research are presented.

Researches indicated that the senior high school students increase their performance by studying the MATHEMA. Also, the formative assessment of the MATHEMA indicated that almost all its functions are useful and user-friendly.

Dissertation Advisor: P. Georgiadis, Professor.

Dissertation Summary

This dissertation is referred to:

(i) the design of an educational framework based on constructivism that it will guide the AEHS's educational decisions and the design of domain model. Also, it will set the goals and the functionality of adaptation, the feedback, the assessment, the participation of student in collaborative problem solving activities, and it also will determine the combination of adaptation techniques, taking into consideration the content and making the best of the learner's specific characteristics,

(ii) the selection of the learning styles model, proper for the specific application, among of all those that have been proposed by various psychologists as well as the design of adaptation on the basis of learning style model,

(iii) issues concerning the effective design of the learners' involvement in the educational process and issues of sharing the control between the learner and the system, in a clear way, taking into consideration the learner's needs and current state of his/her model,

(iv) the selection of the appropriate adaptive navigation techniques, so that the learner to assist during his/her navigation according to his/her Web experience and knowledge level of current goal,

(v) a learner-centred method of meta-adaptive navigation, so that the learner to assist in his/her selection of the most appropriate navigation technique suited to his/her profile,

(vi) the interactive problem solving support through the activities which are based on modern approaches in teaching combining individual and collaborative learning,

(vii) a learner-controlled method of adaptive group formation so that the learner to have the ability in selection of the appropriate collaborator among them that the system suggests to him/her by a priority list that it creates taking into account his/her learning style and learning style and knowledge level of his/her collaborators,

(viii) issues of adaptive presentation.

This dissertation supports the learning process based on individual and collaborative constructivist environments. The main aim is the design of an educational framework based on constructivism that it will guide the AEHS's educational decisions and the design of domain model. Also, it will set the goals and the functionality of adaptation, the feedback, the assessment, the participation of student in collaborative problem solving activities, and it also will determine the combination of adaptation techniques, taking into consideration the content and making the best of the learner's specific characteristics.

b) Innovations of dissertation

According to this framework we designed the Web based AEHS MATHEMA which supports appropriate adaptive and intelligent techniques (curriculum sequencing, adaptive presentation, adaptive and meta-adaptive navigation, interactive problem solving, and adaptive group formation). From those techniques the innovative ones are:

- the adaptive navigation techniques (direct guidance, adaptive links hiding, adaptive link annotation, and adaptive link sorting) which assist the student in his navigation according to his/her Web experience and knowledge level of current goal,
- the meta-adaptive navigation technique in which the student is assisted in his/her selection of the most appropriate navigation technique suited to his/her profile,
- the interactive problem solving support through the activities which are based on modern approaches in teaching combining individual and collaborative learning,
- a learner-controlled method of adaptive group formation in which the learner have the ability in selection of the appropriate collaborator among them that the system suggests to him/her by a priority list that it creates taking into account the learner learning style and learning style and knowledge level of his/her collaborators.

Related work

i) Interactive problem solving support

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 for 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 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 learners to find the relevant examples from their previous experience by presenting an ordered list of examples based on their relevancy.

ii) Adaptive group formation

Students’ personal features are taken into account by many researchers for forming student groups. Gogoulou et al. (2007) presented the *OmadoGenesis* tool that accommodates learners’ characteristics (gender, ethic background, motivations, attitudes, interests, etc.) in the formation of pure homogeneous, pure heterogeneous or mixed groups; that is, groups that satisfy heterogeneity for specific learners' characteristic and homogeneity for another characteristic. The OmadoGenesis tool implements three algorithms: one for pure homogeneous groups, one for pure heterogeneous groups and one based on the concept genetic algorithms for homogeneous, heterogeneous and mixed groups. Muehlenbrock (2006) combines information from learner profiles and information on the learner context. This combination has a potential of improving the quality of the grouping. It allows for the ad-hoc creation of learning groups, which is especially useful for peer help for immediate problems, by reducing the risk of disruptions. It also leverages the forming of face-to-face learning groups based on the presence information. The context sensing has been tested with a set of experiments, and a distributed application has been developed that helps teachers form groups. Potentially, other context information can be used to improve the group formation, such as agenda information from personal calendars, or the availability of preferred communication channels. The building of learning groups could also be enriched by information available on the experience from past collaborations, which could be provided by peers but also from a teacher if available. Furthermore, in addition to the topic of the collaboration, the group formation could include information on the type of support needed, among others.

Some researchers form students' groups according to students' learning styles. Papanikolaou et al. (2006) form students' groups based on their learning style by using the Honey and Mumford's learning style categorization and the visual/verbal dimension of Felder-Silverman model aiming at the collaboration in the formation of concept maps.

Examples in adaptive group formation and/or peer help include forming a group for collaborative problem solving (Ikeda et al., 1997), for finding the most competent peer to answer a question (McCalla et al., 1997) or for self-, peer-and collaborative-assessment process (Gouli et al., 2006). Ikeda et al suggest the *Opportunistic Group Formation* to form collaborative learning group dynamically and context-dependently. When the system detects the situation for a learner to shift from individual learning mode to collaborative learning mode, it forms a learning group each of whose members is assigned a reasonable learning goal and a social role which are consistent with the goal for the whole group. McCalla et al presented a practical approach for just-in-time workplace training that uses artificial intelligence techniques to extend informal peer help networks to a broader scale. They have developed a system called *PHelpS* that is a situated, peer-supported, AI-based approach to training in procedural, task-oriented domains. PHelpS supports workers as they perform their tasks, offers assistance in finding peer helpers when required, and mediates communication on task-related topics. Gouli et al developed the *PECASSE* system, which implements self-, peer- and collaborative-assessment in a Web-based educational setting by offering facilities for group formation, collaboration of learners, activity submission, review process, assignment of assessors, revision of the activity, and evaluation of assessors. Peer assessment refers to those activities of learners in which they judge and evaluate the work and/or the performance of their peers.

Until recently, most support for group formation in CSCL systems was based on learner profile information such as gender, class and other features of the learner. In traditional classrooms, the teachers group students in work teams, but in CSCL systems, group formation can be performed either by the teacher (in classroom or using the information stored in the system) or automatically by the system (Carro et al., 2003). Carro et al use adaptation techniques to dynamically generate adaptive collaborative Web-based courses in their *TANGOW* system. These courses are generated at runtime by selecting, at every step and for each student, the most suitable collaborative tasks to be proposed, the time at which they are presented, the specific problems to be solved, the most suitable partners to cooperate with and the collaborative tools to support the group cooperation. This selection is based on the users' personal features, preferences, knowledge and behaviour while interacting with the course.

If the group formation is done by the system, it can be done randomly or by taking into account personal features included in the user and group models (Read et al., 2006). Read et al designed and implemented the *COPPER* system, where individual and collaborative learning are combined within a constructivist approach to facilitate second language learning. The adaptive group formation algorithm dynamically generates communicative groups based on the linguistic capabilities of available students, and a collection of collaborative activity templates. Students initially work individually on certain linguistic concepts, and subsequently participate in authentic collaborative communicative activities.

In some AEH systems students are grouped according to their learning styles. In Martin & Paredes (2004) system, the default criteria for group formation consist of combining active students with reflective ones of Felder-Soloman model in similar percentages. They studied the impact of learning styles and group homogeneity/heterogeneity on the results obtained by students in collaborative tasks. Thus, they concluded that some dimensions of the learning style model, seem to affect the quality of the resulting work.

Results and Discussion

The general aim of the MATHEMA is to support senior high school students or novices of higher education, through an interactive and constructivist educational material, in learning science conceptually, individually and/or collaboratively, and overcoming their possible misconceptions and learning difficulties.

In order to implement the AEHS MATHEMA we adopted the constructivist, socio-cultural and meta-cognitive learning model. The didactic design of the MATHEMA supports the students:

- in construction of their knowledge,

- in recognition of their misconceptions and in correction of their errors through reflection,
- in selection and achievement of their learning goals, recognizing what they have already learned and what they be able to do by evaluating their progress of learning,
- by providing them the appropriate didactic strategies suited to their learning style,
- in development of their critical thinking,
- in their self-regulation,
- in collaboration through collaborative activities,
- by giving them motivations for their participation and,
- by giving them multiple representations for the improvement of their learning.

The didactic approaches adopted by the MATHEMA are: questions-visualization, exercises solving, theory and examples and problem solving activities. The adaptive presentation is done according to students' learning style.

For the design and implementation of innovative techniques in AEHS MATHEMA we studied the literature and we concluded to the following:

a) adaptive navigation techniques

There are a lot of AEHS. Some of them use one only adaptive technique (e.g., Knowledge Sea), while some of them use more than one technique (e.g., ISIS-Tutor, ELM-ART). Nothing of them suggests to learner any technique to begin his/her navigation according to his/her Web experience and knowledge level of current goal. After an extended literature review we found interesting researches concerning the difficulties that deal with the user of Web. Also, a lot of researches suggest the most appropriate navigation techniques for students who have anything, little or enough Web experience or anything, little or enough knowledge experience on the current goal.

Taking into consideration researches which suggest that not all of navigation techniques are appropriate for all learners and that the most significant role for the selection of navigation technique plays the Web experience and the knowledge level of the current goal of the learner, we decided to design the AEHS MATHEMA so that to support four navigation techniques (direct guidance, adaptive link annotation, adaptive link hiding, and link sorting) to assist learner during his/her navigation according to his/her Web experience and knowledge level on his/her current goal.

In AEHS MATHEMA, the first time that the learner logs in the system is called to declare his/her Web experience and knowledge level on his/her current goal. After the declaration, the system suggests for him/her the most appropriate navigation technique, according to his/her Web experience and knowledge level on his/her current goal. The system informs the learner about the navigation technique that suggests for him/her and explains the reasons why it suggests the particular navigation technique (e.g., to protect him from navigation problems). In addition, the system suggests to the learner to change the suggested navigation technique when he/she has fulfilled the terms of meta-adaptation.

b) meta-adaptive navigation

All the suggestions for meta-adaptation in literature are intended to the meta-adaptation which is based on the system (system-controlled) that decide the most appropriate navigation technique, for each learner and environment, and respectively acts.

So far, has not developed any system using a kind of meta-adaptation. Meta-adaptation in the MATHEMA is based on the learner (learner-controlled), where the system assists the learner make decision for the navigation technique suited better to him/her by presenting the advantages and disadvantages of navigation techniques supported by the system when the learner has fulfilled the terms of meta-adaptation. This proposition enhances the self-regulating learning offered by hypermedia.

The meta-adaptation engine of the MATHEMA, after of the succeeded assessments of the learner on n main concepts, considering that he/she has obtained adequate Web experience, appears a window on the screen which has information about advantages and disadvantages of each navigation technique. Then the learner decides if he/she will use the same navigation technique or he/she will select another navigation technique.

c) Interactive problem solving support

After an extended study of literature we found AEHS supporting this intelligent technique which are the ISIS-Tutor, ELM-ART and ActiveMath. From the study of those systems arises that they support the learner in:

- problem solving, errors correction and conceptual change,
- the development of his/her critical thinking,
- his/her reflection.

In addition, from the study of those systems arises that they do not support the learner in:

- constructivist type problem solving activities making the most of modern didactic approaches,
- individual and collaborative learning.

The interactive problem solving activities in the MATHEMA make use of the following didactic approaches: experimentation through simulations, explorations, guided discovery and collaboration.

d) adaptive group formation

The most of systems in literature use several characteristics of learners to support adaptive group formation and they implement it based on a system-controlled design. That is, the system decides the group formation and the learners are informed the group that the system includes them without having the possibility to change it. An exception is the tool of Christodoulopoulos & Papanikolaou (2007) in which the group formation is done as follows: The system categorize the learners into groups and then it allows them to communicate with the educator for the purpose of negotiating of their group.

In the same research line with the systems that we study, the MATHEMA offers the adaptive group formation technique by supporting the learner to select the most appropriate learner through a priority list. The system makes use for adaptation the Kolb's learning styles and knowledge level of learners in the current goal.

The above-mentioned techniques we have concluded that they are innovative and upgrade the science.

Conclusions

In the frame of design of the MATHEMA conducted researches and the conclusions of those researches helped us to implement the innovative techniques of the MATHEMA.

The first research had as main purpose to explore if the suggested problem solving method facilitates the learners to deal with their misconceptions and learning misunderstanding.

The suggested problem solving method helped the participants:

- to compute of physical quantities and in correct using of right hand rule so that to predict the motion of particles,
- to comprehend their errors and revise their points of view,
- to be able to explain their choices, and
- to accept the restrictions of the formula usage.

According to the above conclusions we designed the next stage of our research through an interactive educational material taking into account the learning styles of the learners.

The second research had as main purpose the exploration whether the MATHEMA assists the learners in improvement of their performance when they collaborate in solving problems of electromagnetism.

The research questions were the following:

- Do the learners improve their performance when they study through the MATHEMA?
- Do the learners improve their performance when they carry out the problem solving activity?
- Are there differences among concrete-concrete, abstract-abstract and concrete-abstract groups when they curry out problem solving activities?

The conclusions arose from the second research are the following:

- the performance of participants is significantly improved when they study trough the MATHEMA ($F_{1,22} = 49.120$, $p = 0.000$),
- the concrete-concrete and abstract-abstract groups performed almost equivalently in problem solving activities but they performed significantly better than the concrete-abstract groups,
- in problem solving activities:
  (1). A Diverging (concrete) collaborates better with a Diverging (concrete) rather than an Assimilating (abstract).
  (2). An Assimilating (abstract) collaborates better with an Assimilating (abstract) rather than a Diverging (concrete).
  (3). A Converging (abstract) collaborates better with a Converging (abstract) rather than an Accommodating (concrete).
  (4). An Accommodating (concrete) collaborates better with an Accommodating (concrete) rather than a Converging (abstract).
  (5). A Diverging (concrete) collaborates better with an Accommodating (concrete) rather than a Converging (abstract).
  (6). An Assimilating (abstract) collaborates better with a Converging (abstract) rather than an Accommodating (concrete).
  (7). A Converging (abstract) collaborates better with an Assimilating (abstract) rather than a Diverging (concrete).
  (8). An Accommodating (concrete) collaborates better with a Diverging (concrete) rather than an Assimilating (abstract).

The results of the second research helped us to implement the adaptive group formation technique in the MATHEMA.

In the frame of formative assessment of the MATHEMA, we conducted a research for the assessment of functionality, usefulness and usability of the MATHEMA functions. The opinion of students of the Department of Informatics and Telecommunications of University of Athens is that almost all of the functions offered by the MATHEMA are useful and user-friendly. Also, the same students consider that the MATHEMA is an enjoyable environment (88,4%), facilitates the users' attention (90,7%) and gives opportunities in learning science (90,7%).

References

1. **Papadimitriou, A., Grigoriadou, M., & Gyftodimos, G.** (2009). Interactive Problem Solving Support in the Adaptive Educational Hypermedia System MATHEMA, *IEEE Transactions on Learning Technologies*, vol. 2, no. 2, pp. 93-106.
2. **Papadimitriou,A., Grigoriadou, M., & Gyftodimos, G.** (2009). Learning Electromagnetism Through the MATHEMA. *The International Journal of Learning*, vol. 16, issue 6, pp. 371-390.
3. **Papadimitriou, A., Gyftodimos, G., & Grigoriadou, M.** (2010). The

Learning Facilities and Adaptation Techniques of the MATHEMA. *The International Journal of Learning*, vol. 17, issue 1, pp. 155-172.

4. **Papadimitriou, A., Gyftodimos, G.** (2007). Use of Kolb's learning cycle through an adaptive educational hypermedia system for a constructivist approach of electromagnetism, In proceedings of 4th WSEAS/IASME International Conference on Engineering Education, Crete Island, Greece, pp. 226-231.
5. **Papadimitriou, A., Grigoriadou, M., Gyftodimos, G.** (2008). Adaptive Group Formation and Interactive Problem Solving Support in the Adaptive Educational hypermedia System MATHEMA, In proceedings of 20th World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA 2008), Vienna, Austria, pp. 2182-2191.
6. **Papadimitriou, A., Gyftodimos, G., Grigoriadou, M.** (2009). "MATHEMA: A Constructivist Environment for Electromagnetism Learning." Proceedings of 8th IEEE International Conference on Advanced Learning Technologies (ICALT '09), I. Aedo, *et al.*(Eds.), New Jersey: IEEE, 2009, pp. 453-454.
7. **Papadimitriou, A., Gyftodimos, G., Grigoriadou, M.** (2009). "Adaptive Navigation Support and the Learner-Centered Meta-Adaptation in the Adaptive Educational Hypermedia System MATHEMA." Proceedings of 21th World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA 2009), Havai, Honolulu. Chesapeake, VA: AACE. pp. 1453-1462.
8. **Papadimitriou, A., Grigoriadou, M. & Gyftodimos, G.** (2010). MATHEMA: A Learner-Centered Design for Electromagnetism Learning. *In Proceedings of 22th World Conference on Educational Multimedia, Hypermedia and Telecommunications (ED-MEDIA 2010)*, Toronto, Canada, Chesapeake, VA: AACE. pp. 1249-1254.
9. **Παπαδημητρίου, Α., Γυφτοδήμος, Γ., Γρηγοριάδου, Μ., Γλέζου, Κ.,** (2007), *Αντιμετώπιση των παρανοήσεων και των δυσκολιών που προκύπτουν από το φορμαλισμό του ηλεκτρομαγνητισμού, με τη χρήση προσομοιώσεων*, Ζ' Πανελλήνιο Συνέδριο ΠΤΔΕ Πανεπιστημίου Αθηνών με θέμα: «Έρευνα και εκπαίδευση στις Φυσικές Επιστήμες στα

Παιδαγωγικά Τμήματα Δημοτικής Εκπαίδευσης» (υπό έκδοση).

10. **Παπαδημητρίου, Α., Γυφτοδήμος, Γ., Γρηγοριάδου, Μ.** (2009). *Μια δραστηριότητα βασιζόμενη σε σύγχρονες διδακτικές προσεγγίσεις για μια εποικοδομιστική προσέγγιση του ηλεκτρομαγνητισμού.* Πρακτικά $6^{ου}$ Πανελλήνιου Συνεδρίου Διδακτικής Φυσικών Επιστημών και Νέων Τεχνολογιών στην Εκπαίδευση με θέμα «Οι πολλαπλές προσεγγίσεις της διδασκαλίας των Φυσικών Επιστημών», σ.σ. 648-655.

11. **Παπαδημητρίου, Α., Γρηγοριάδου, Μ., Γυφτοδήμος, Γ.** (2009). *Διδακτικές στρατηγικές και εκπαιδευτικό υλικό του προσαρμοστικού εκπαιδευτικού συστήματος υπερμέσων MATHEMA.* Πρακτικά $5^{ου}$ Πανελλήνιου Συνεδρίου των Εκπαιδευτικών για τις ΤΠΕ στην Εκπαίδευση "Αξιοποίηση των Τεχνολογιών της Πληροφορίας και της Επικοινωνίας στη Διδακτική Πράξη", σ.σ. 732-741.

12. **Παπαδημητρίου, Α., Γυφτοδήμος, Γ., Γρηγοριάδου, Μ.** (2009). *Μια μαθητοκεντρική σχεδίαση εποικοδομιστικού τύπου για την εποικοδόμηση της γνώσης στον Ηλεκτρομαγνητισμό.* $1^{ο}$ Επιστημονικό συνέδριο Σ.Ε.Π. ΑΣΠΑΙΤΕ με θέμα: Η εκπαίδευση των εκπαιδευτικών της δευτεροβάθμιας επαγγελματικής και τεχνολογικής εκπαίδευσης στην Ελλάδα, Αθήνα, σ.σ. 536-545.