Towards a constructivist approach in the design of Adaptive Educational Systems

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Abstract: In this paper we present a web-based adaptive educational system, named ProSys, designed on principles for project-based and case-based learning. The initial phase of the formative evaluation of the system is also presented. In ProSys, learners undertake a project and the system offers a variety of learning aids to support learners complete the project including a library of authentic cases. These cases are structured in a way that reflects the domain conceptual structure and they are graphically annotated providing individualized navigation advices to learners. Moreover, through the interaction with ProSys, learners are proposed to follow a sequencing of learning activities that assist them in understanding the issues implicit in the problem they have to face. Based on the main design principles for project-based curricula a group of ten experts evaluated the design rational of ProSys. The report of this study included positive aspects of the design, problems identified, and recommendations for possible modifications or extensions.

Introduction

The primary principle of adaptive instruction is that learners will be able to achieve their learning goals more efficiently, when pedagogical procedures accommodate their individual differences (Federico 1999). The development of web-based Adaptive Educational Systems (Brusilovsky & Peylo 2003) in which learners are individually supported in accomplishing their personal learning goals and at the same time they are allowed to control when, what and how to learn, requires a deep understanding of the learning and instructional processes. To this end, it is important to consider adaptation within the framework of modern learning theories and models, and thoroughly enhance learner control opportunities over the instructional process (Lawless & Brown 1997). Especially constructivist theories acknowledge the importance of learner control over the learning process and claim that learners can only interpret information in the context of their own experiences. Constructivist learning environments engage learners in meaning making (knowledge construction) having as a focus a problem, a question, or a project (Jonassen 1999). However, one of the problems that learners face in constructivist learning environments is what strategies to employ, how to start and proceed with the problem they have to face.

Our research is at the crossroad of adaptive educational systems and constructivist learning environments. We have developed an adaptive educational system, named ProSys (Project-based System) in which learners are engaged in authentic tasks in order to attain specific learning goals. ProSys maintains a learner model for each particular learner and apply this model to provide individualized navigation advices to learners. Through the interaction with the system, learners are proposed to follow a sequencing of learning activities in the form of a learning cycle, generate ideas, make assumptions, test their ideas and experiment on real conditions using the domain concepts. In this paper, we present the main functionality of ProSys as well as the results of an expert review conducted to evaluate the design rational of ProSys according to the main design principles for project-based curricula as these have been proposed by (Barron et al. 1998).

The ProSys learning environment

ProSys (http://hermes.di.uoa.gr:8080/prosys) is a web-based adaptive learning environment designed to support traditional classroom-based teaching as a supplementary resource. Projects are used as a building element in organizing learners' study: learners select a topic and then the system proposes them to start working on a project in order to master the main concepts of this topic.

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The design rational of ProSys combines project-based, cased-based and adaptive learning. The main functionality of ProSys is aligned with the four principles proposed by Barron et al. (1998) for designing, implementing and evaluating *project-based* curricula: (a) defining learning-appropriate goals; (b) providing scaffolds that support both student and teacher learning; (c) ensuring frequent opportunities for formative self-assessment and revision; (d) developing social organizations that promote participation and result in a sense of agency. In particular, ProSys incorporates a learning cycle, i.e. a sequence of learning activities and aids (such as a case library and individualised navigation advices) designed on the above principles, that contribute to learners' overall understanding of the problem or their ability to complete the project, reflect on and monitor their learning. Learners may follow the cycle in the order proposed starting from the "Introduction" stage or work with the ones they prefer or need to. Below, through the presentation of the cycle, we use a real project in which learners should use the Internet to search for information about doping on athletes (topic: Search engines on the Internet), to better illustrate the different stages of the cycle. Especially, the sequencing that the cycle proposes has been inspired by Star Legacy Cycle (Schwartz et al. 1999), and consists of the following stages:

- At first, several clues are provided that aim to help learners develop a more concrete vision of the context and challenges that they will face through their project ("Introduction" stage). Through several questions learners are stimulated to submit their ideas about the general context described. For example, learners *observe* five different images - the first one illustrates runners during a race, the second and third ones illustrate pills and medicine, and the last two are the main screens of two different search engines, *submit* their opinion about the common topic of these images, and then *check* what their peers have suggested and *evaluate* them (provide one of the characterizations "Agree", "Disagree", "Indifferent").
- Then info about the project such as time restrictions, the place, the necessary resources, is provided in an innovative way and learners are stimulated to answer specific questions about the subject of the project and submit their proposals ("Project Description" stage). For example, at this stage learners *read* or *hear* a story accompanied by a real dialogue that includes all the aforementioned information. Then, learners *answer* to several questions about the subject of the project, available means and constraints posed, and *propose* an analogous project that they would prefer to work on. Afterwards they are able to see and *evaluate* their peers' opinions.
- At the next stage ("Generate Ideas" stage) learners, through appropriate driving questions, are stimulated to think how they would face different issues of the project which reflect the main learning goals posed, and submit their ideas. This way learners may assess what they already know and what they need to learn more about. For example, for the goal "how to define appropriate keywords for efficient search on the Internet" the driving question would be "propose four keywords as representative of your project that you would use in searching the Internet". After learners *submit* their answers to the driving question, they are able to see and *evaluate* their peers' proposals.
- Next, learners are provided with educational content relative to the project ("Multiple Perspectives & Research" stage). The content includes the main domain concepts accompanied by several modules such as cases (in the form of examples or exercises), theory presentations and exercises. Learners, through their study, are provided with individualized navigation advices based on their knowledge level and progress. At this stage learners are expected to *explore* and *study* the content provided in order to deal with the different concepts involved in the project or overcome an impasse in achieving their goals. They can also *self-assess* their knowledge by completing the exercise-cases, providing the solution or the step solution part which is missing (see below how the cases are constructed), self-evaluating their understanding on specific content modules, submitting automatically corrected exercises.
- At the final stage ("Solution and Evaluation" stage), learners reflect on their ideas proposed at the "Generate Ideas" stage. They are asked to test their ideas in an authentic environment, reconsider their initial ideas proposed at the "Generate Ideas" stage, and argument on their final proposals. For example, at this stage learners *propose* four new keywords about their project, *use* them to search the Internet and *evaluate* the results based on the total number of sites returned and the appropriateness of the three first sites. Then learners are asked to *reconsider* their initial proposals at the "Generate Ideas" stage, change or keep them, and *argument* on their final proposal.

The building element of the educational content provided at the "Multiple Perspectives & Research", is authentic *cases* that reflect different perspectives of the project. Cases are interpretations of experiences. Cases, as stories do, have several subcomponents (Kolodner & Guzdial 2000): (a) the setting, the actors and their goals: the description of the problem that the case encounters, (b) the solution, (c) a sequence of events, i.e. the different steps that an expert followed to solve the problem, (d) explanations linking results to goals and the means of achieving them, (e) results of the proposed solution. In ProSys, learners are provided with two types of cases: example-cases and exercise-cases that play the role of formative assessment tasks. In the latter, the solution part (subcomponent b) or the different steps followed (subcomponent c) is missing, and the learner is proposed to complete it. The educational content is comprised of modules which are organised around the main domain concepts, and characterized by different attributes, such as type (example-cases, exercise-cases, theory presentations, exercises), the concept on which they focus, priority (based on “prerequisite” relations of the underlying concepts), difficulty level, and the cognitive function that they support (Remember, Understand, Apply, Analyze (Mayer 2002)).

In Fig. 1, the main screen of ProSys is shown. It is divided into three different areas to better support the system’s functionality: Navigation area, Project Manipulation area, Toolbar. The learning cycle is visually represented through a puzzle in the Navigation area (see Fig. 1 – The Learning Cycle) providing learners with access to the different stages of the learning cycle (each part of the puzzle is a link to a stage).

With regards to the *adaptive dimension* of the system, ProSys (a) denotes the next stage of the learning cycle that the learner is proposed to visit (see Fig. 1 – a mark appears on the proposed stage on the Learning Cycle), and (b) provides individualized navigation advice through the content at the “Multiple Perspectives & Research” stage based on the knowledge level and progress of the learner. In more detail, ProSys supports the learner’s orientation and navigation through the hypermedia content structure which appears below the learning cycle (see Fig. 1 – Hypermedia Content Structure). In particular, learners are informed about their location in the domain (the active link is in bold), the modules they have already mastered (marked with a checkmark), the concepts/modules they are ready to study based on the concept priority - the difficulty level - the cognitive function of the modules and the learner’s progress (two state icons are associated with the concepts/modules: coloured icons denote that a concept/module is recommended for study, while black and white icons appear next to the rest of the concepts/modules). Moreover, the different icons that accompany each educational material module reflect its type (see Fig. 1 – the first icon on the left of each module) and the cognitive function it supports (see Fig. 1 – the second icon on the left of each module, i.e. a ladder with a bullet on specific steps). Thus, the system allows learners to decide, on the basis of the provided information, what content may be best to proceed with.

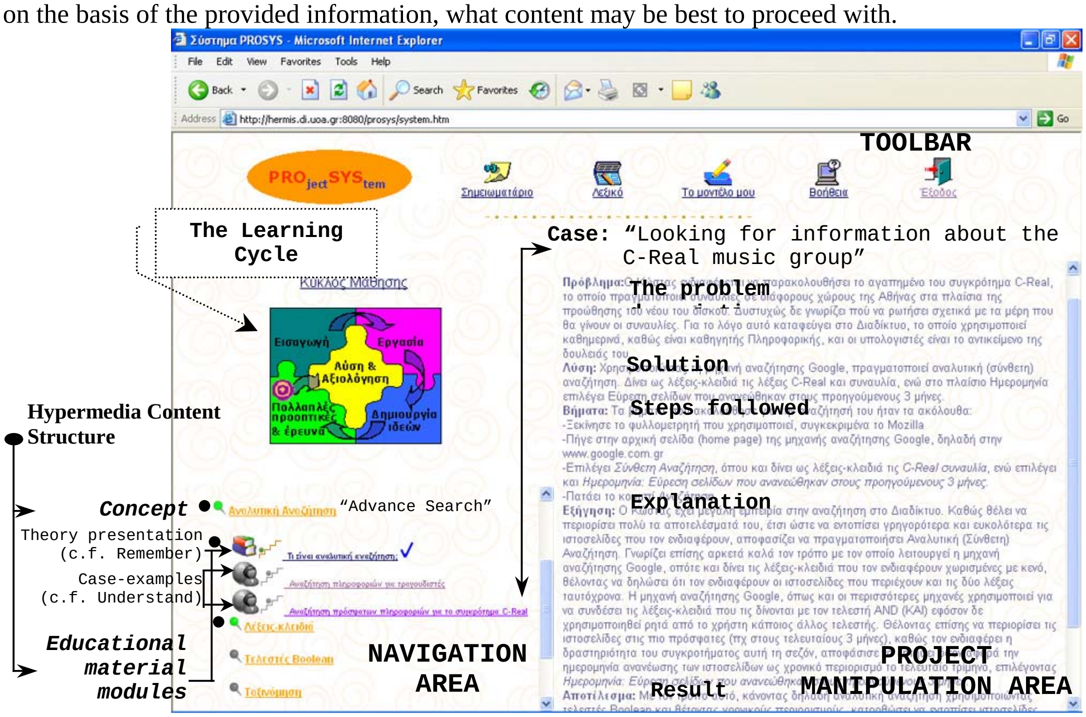

Figure 1: A screenshot of ProSys at the “Multiple Perspectives & Research” stage. In the Project Manipulation Area appears the case-example “Looking for information about the C-Real music group” including the “Problem”, “Solution”, “Steps”, “Explanation”, “Result” parts. In the Navigation Area appears the hypermedia content structure: the concept “Advance Search” has been expanded followed by a theory presentation (corresponding to the cognitive function - c.f. “Remember”) and two case-examples (c.f. “Understand”). The icons of the theory presentation appear in colour denoting that this module is recommended for study (coloured icons are marked with a bullet for clarity).

During learners’ interaction with the system, a learner model is maintained for each particular learner. By opening the learner model to the learner, we aim to stimulate learners reflect on their learning process and enhance self-regulation (Bull & Kay 2005). Currently the learner model of ProSys maintains the following info: (a) the learner's opinions and arguments as these were submitted at the first three stages of the learning cycle – history of the learner's "ideas", (b) the learner's evaluations of their peers' opinions/proposals as these evaluations were submitted at the first three stages of the learning cycle – history of the learner's "comments", (c) the educational material that the learner successfully or unsuccessfully studied and info about the way this was estimated, i.e. through automatically corrected assessment exercises or learner's notification, (d) the concepts of the subject matter that the learner has successfully studied and the difficulty level, the cognitive function, the priority of the corresponding material that s/he has already studied.

Expert Review

As formative evaluation helps to improve several aspects of the design as part of an iterative process, we have already conducted two different studies in order to evaluate the design of ProSys. The first was a pilot study conducted in a classroom-based environment with students, in order to investigate how understandable and manageable the whole procedure was by young people, and gather authentic cases to be incorporated in the system. The second study was an expert review in which expert reviewers were asked to evaluate ProSys and determine conformance with a list of design principles for project-based curricula. The expert review conducted in September 2005 with a group of ten experts who were instructors and researchers working on the development of computer-based educational systems. The goals of the study were to (a) investigate whether the design of the ProSys prototype conforms with the four design principles for project-based curricula proposed by (Barron et al. 1998) and (b) get appropriate feedback from experts. The outcome of this study was a report including positive aspects of the design, problems identified, and recommendations for possible modifications or extensions.

The *data analysis* of the expert review was based on questionnaires and interviews. We followed the heuristic evaluation method and, as Shneiderman (2005) suggests, it is quite important, the experts to be familiar with the design principles they should evaluate and able to interpret and apply them. To this end, a preparation phase, i.e. a meeting that lasted 4 hours, was organised which aimed to place the reviewers in the situation most similar to the one intended users will experience. Then, system designers and experts discussed on the main design principles for project-based curricula and how these were followed in the design of ProSys. Then, a questionnaire that evaluates how the design principles reflect on ProSys, was administered. The reviewers had one week to work with the system in the time and place of their choice in order to evaluate the system and return the questionnaire. At the last phase of the expert review, one of the system designers interviewed the experts (most of them in groups of two) in order to pursue specific issues of concern and ascertain the universality of comments appearing in the questionnaires.

Measurement Development/Results

The questionnaire developed was divided in four sections, each one including a brief presentation of the corresponding design principle for project-based curricula and closed items evaluating how well specific issues of ProSys confront to this principle. Most of the items were followed by open-ended questions where the experts were asked to argument about their selections and propose possible extensions/modifications. Below, we present for each design principle proposed by (Barron et al. 1998), the evaluation goals posed and the results of the expert review.

The first design principle suggests "defining *learning-appropriate goals* that lead to deep understanding: project-based learning experiences are frequently organized around a driving question (Blumenfeld et al. 1991) which should be crafted to make connections between activities and the underlying conceptual knowledge that one might hope to foster, aiming to deepen the students' understanding. Providing learning-appropriate goals, helps create a need for students to understand the how and why of a project". In particular, the experts were asked to evaluate the effectiveness of the driving questions included in several stages of the learning cycle of ProSys in presenting the learning goals of the project and linking learners' activities with the underlying conceptual knowledge of the domain.

Interesting comments/suggestions resulting from the expert's answers and their interviews:

- All the experts agree that the "Generate Ideas" and "Solution and Evaluation" stages include specific *driving questions* which actually support learners in acknowledging the learning goals of the project and making connections between their activities and the domain concepts.

- Three of the experts suggested that linking the driving questions with content and/or additional resources is necessary in order to support learners (especially novices) produce alternative proposals.

The second design principle suggests: "providing *scaffolds* that help a novice to solve a problem, carry out a task, or achieve a goal which would be beyond his unassisted efforts, such as (a) those that function to communicate process; (b) those that provide coaching; (c) those that elicit articulation. Scaffolds are designed to help students understand the relevance of particular concepts to activities in the world and to support inquiry skills (i.e. the abilities of students to research topics to advance their understanding and to collaborate and communicate with others in the furtherance of this goal), deep understanding (the ability to explain phenomena, rather than simply describe various procedural activities that are part of one's project), and the reflection on one's idea in relation to others'". In particular, the experts were asked to evaluate the role of (a) the *learning cycle* and the different stages, in communicating the process of dealing with a project, (b) the *content* and the *adaptive navigation support* offered in coaching learners through their study and eliciting articulation, (c) a variety of functions in cultivating *inquiry skills* (d) the *Open Learner Modeling* approach adopted in enhancing *reflection* on the learning process.

Interesting comments/suggestions resulting from the expert's answers and their interviews:

- All the experts agree that the different stages of the *learning cycle* succeed in gradually supporting learners to deal with the project, as at each stage learners are stimulated to concentrate on a specific task which is part of the project "solution". One of the experts remarked that the dependencies among the different stages are not apparent to learners, and he proposed to offer learners such information suggesting them alternative paths through the cycle and informing them about their consequences. Eight of the experts found that the way the first two stages of the cycle (after which learners are expected to have defined the project) are organised is innovative allowing learners to contribute to the project definition, change or adapt it to his/her individual interests and needs.
- All the experts agree that the *case library* is an innovative feature of the *content* design and that linking cases directly with the domain concepts supports learners in understanding the relevance of particular concepts to activities in the world. Alternative structures were also proposed by three experts such as to structure the cases based on (i) the different perspectives of the project and the problems that learners have to deal with, or (ii) different contexts, i.e. a quick review of the domain. Other interesting ideas coming from two experts were to allow learners (i) contribute in structuring the case library by connecting domain concepts with real world problems; (ii) individually or collaboratively author case-examples or complete case-exercises.
- All the experts found that the *adaptive navigation support* provided is a promising approach for increasing learners' awareness of their knowledge and supporting learners' navigation / orientation through the content. An alternative approach was proposed by three experts, who suggested to graphically annotate the content based on learners' activities or needs in dealing with different issues of the project.
- All the experts agree that opening the *learner model* to learners, informing them about their knowledge state and interaction with the system, is a powerful feature of the design that enhances learners' awareness of their knowledge and reflection on their learning. One of the experts proposed to extend the learner model to include more data about learners' interaction behaviour / submissions and enhance the visualisation of this information.

The third design principle suggests: "ensuring multiple opportunities for *formative self-assessment and revision*: systematic attempts to bring students in on the process with an emphasis on self-assessment that helps students develop the ability to monitor their own understanding and to find resources to deepen it when necessary (Brown et al. 1983). Learners get opportunities to test their mettle, to see how they are doing and to revise their learning processes as necessary". In particular, the experts were asked to evaluate the effectiveness of the assessment opportunities offered to: (a) stimulate learners to search for resources in order to deepen their understanding, (b) support learners in monitoring their own learning.

Interesting comments/suggestions resulting from the expert's answers and their interviews:

- All the experts found that the assessment activities offered such as the completion of case-exercises, may motivate learners to search the content or alternative resources cultivating inquiry skills. Furthermore, three of them suggested that appropriate feedback should augment each case stimulating learners to use specific additional resources, e.g. on the Web.
- Three of the experts proposed that appropriate feedback could further support self-evaluation, such as the incorporation of peer review activities in the content such as the evaluation of the exercise-cases or the final solution proposed at the "Solution and Evaluation" stage by peers.

The forth principle suggests: "developing *social structures* that promote participation and a sense of agency: breaking down the isolation of the classroom can be a powerful way to support learning through social mechanisms as not only do we learn from the varieties of feedback given, but we also learn about more effective ways to communicate our ideas. Different ways to support active, reflective learning such as small group interactions, opportunities to contribute, peer review, and having access to data about how others have thought about the same problem". In particular, the experts were asked to evaluate if particular interactions: (a) support active and reflective learning, (b) promote participation. Moreover, they were asked to evaluate the option offered to learners to see their peers' ideas only after submitting their own ideas.

Interesting comments/suggestions resulting from the expert's answers and their interviews are summarised below. All the experts agree that:

- submitting ideas on a shared database, reading and commenting on peers' ideas are useful activities towards the development of social structures.
- learners should be allowed to change their submissions whenever they wish to, but the system should keep track of learners' actions/submissions through the interaction with the aim to maintain a view of learners' cognitive activity as it unfolds.

Conclusions and Future Plans

The design approach incorporated in ProSys combines project-based, case-based and adaptive learning in order to build an authentic learning context in which learners undertake specific projects. On this constructivist approach learners are engaged in knowledge construction having as a focus a project, which is surrounded with various types of support such as a specific sequencing of learning activities to perform, a library with authentic cases, individualised navigation advices, access to their model, opportunities for reflection on the learning process.

Our future plans include redesign of ProSys based on the expert review results. Afterwards we intend to perform an empirical evaluation of the system with real users, i.e. adult learners to whom access to an educational web-based system is provided as a supplementary resource, and further investigate the usefulness of the particular design.

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