Chapter 4

WEB-BASED ADAPTIVE EDUCATIONAL SYSTEMS

Towards an evaluation and design support framework

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Abstract Intelligent Tutoring Systems and the evolution of Adaptive Hypermedia have opened the way for the emergence of Web-based Adaptive Educational Systems (AES). However, AES have not yet been sufficiently tested for ill-structured knowledge domains. In the first part of this chapter we examine the question of applicability of AES for constructivist-oriented instruction in such domains. More specifically, we identify the basic problems related to this question, we analyze them and, for each case, we identify and propose conditions that are instrumental for the implementation of AES for ill-structured domains. In the second part of the chapter, we propose an evaluation and design support framework for AES. The objective of the proposed framework is to help evaluate and design AES that are suitable for ill-structured domains and able to support introductory level learning when needed. The work is based mainly on recommendations from Cognitive Flexibility Theory (CFT) and the Framework for Contextual Analysis of Technology Based Learning Environments. Using these recommendations, we present a three-step approach, according to which we first determine fundamental design decisions, transform these into evaluation criteria and finally evaluate architectural mechanisms of AES against the criteria identified. Efficient architectural mechanisms may be leveraged in the design of new, better AES.

Key words: Web-based Adaptive Educational Systems, Ill-structured Knowledge Domains, Cognitive Flexibility Theory

1 INTRODUCTION

This chapter begins with the question of *applicability of Web-based Adaptive Educational Systems (AES) for constructivist-oriented instruction when the knowledge domain is ill-structured (e.g. History, Humanities, etc).* The importance of this question is due to the following: (a) The foundation of web-based educational systems is hypertext. However and despite all the hype, effectiveness of hypertext-based instruction has been strongly contested (e.g. [Kotze98]). (b) In addition, a number of reasons for instruction failures in ill-structured domains have been identified (cf. [Spiro96]). Thus, although several AES exist, one can argue that certain problems should be first resolved for efficient application of AES in ill-structured domains. We analyze this question into three basic sub-problems presented in Section 2. For each problem we identify some important issues and produce some initial conclusions for the implementation of AES for ill-structured domains. Hence, this paper proposes that such systems can be suitable, if some basic conditions, reported here, are met. Most of these conditions are of a general nature and independent of a specific instructional theory – they stem from the ill structure of the knowledge domains. In order to define an evaluation framework, we narrow our scope and focus on one theory of instruction, Cognitive Flexibility Theory (CFT). This theory is devised with ill-structured domains and hypertext technology in mind. In Section 3.1 we detail the objectives of the proposed framework and outline a three-stage process for defining the framework. Following this process, in Section 3.2 we organize Hypertext design decisions derived directly from CFT or from implementing adaptive functionalities not inherent in CFT. In Section 3.3, we combine these design decisions with features of AES identified in Section 2. As a case study on the proposed framework, we evaluate two AES, AHA and KBS-Hyperbook, and present the evaluation results in Section 3.4.Part of this work was presented in the 2nd Hellenic Conference with International Participation, Patras, Greece [Papaterpos00].

2 SELECTING AES FEATURES SUITABLE FOR ILL-STRUCTURED DOMAINS

2.1 AES, Constructivism and Ill-Structured Domains

Sub-problem A: Are there any characteristics of AES that make them suitable for constructivist instruction in ill-structured domains? What types of AES are more suitable?

2.1.1 Definition of AES

We first need to adopt a definition of AES. We define AES as learning environments (typically hypermedia based) on the web, capable of adapting instruction (e.g. content delivery, user assistance, etc) to the learner's skills,

needs and goals. According to [Brusilovsky98a], Web-based Adaptive Educational systems inherit from traditional Intelligent Tutoring Systems (ITSs) and Adaptive Hypermedia Systems (AHSs). ITSs typically partition the information space in knowledge about the domain, knowledge about the user and teaching strategies to support individualized learning. Adaptive Hypermedia Systems typically engage in content and navigation adaptation, altering the link structure and the node contents of the hypertext that contains the educational material. The following classification of AES based on their goal, is due to [Brusilovsky98a]:

- *Curriculum Sequencing (or instructional planning):* Provide the learner with the most suitable individually planned sequence of knowledge units and learning tasks
- *Intelligent analysis of student solutions:* Identify in the student's solution of a problem what exactly is wrong or incomplete and which incorrect knowledge may be responsible for the error.
- *Interactive problem solving support:* Provide the student with intelligent help on each step of problem solving - from giving a hint to executing the next step for the student.
- *Example-based problem solving:* Help students by suggesting them the most relevant cases (examples previously explained or problems solved by them earlier).
- *Adaptive presentation technology:* Adapt the content of a hypermedia page to the user's goals, knowledge and other information stored in the user model.
- *Adaptive collaboration support:* use system's knowledge about different users (stored in user models) to form a matching collaborating group.
- *Adaptive navigation support technology:* Support student navigation and orientation in hyperspace by changing the appearance of visible links (sort, annotate or partly hide links).

In the following paragraphs, based on the hypermedia nature of the Web and on features of ill-structured domains, we attempt to identify suitable classes of AES.

2.1.2 Ill-structured domains

An ill-structured knowledge domain is one in which the following two properties hold ([Spiro96]):

1) Each case or example of knowledge application typically involves the simultaneous interactive involvement of multiple, wide-application conceptual structures (multiple schemata, perspectives, organizational principles, and so on), each of which is individually complex (i.e., the domain involves concept- and case-complexity).
2) The pattern of conceptual incidence and interaction varies substantially across cases nominally of the same type (i.e., the domain involves across-

case irregularity). For instance, in well-structured domains like math or physics, application of the same principles or abstract concepts in similar cases (problems) provides equally similar results. The same does not necessarily hold for an ill-structured knowledge domain such as History, Medicine, and so on.

2.1.3 Constructivism and Hypertext – the need for adaptivity

The exact nature of constructivism is one of the broadest and most discussed issues in instructional technology. It is a general feeling that constructivist approaches dominate today's research, especially for systems operating on the World Wide Web. We believe that at least two important features of the Web make it appealing for constructivist learning. The first is its operation as a communication medium that allows activities like peer learning even over large distances and in asynchronous fashion. The second is the fact that the key Web technology is hypertext.

Constructivism, in contrast to behavioristic pedagogy, stresses the importance of generating understanding versus training for performance ([Henze99a]). Generating understanding requires partition of the knowledge domain in declarative, procedural and structural knowledge [Eklund95]. When hypertext structures are based on structures of learning, or cognitive models, within the learner [Eklund95], they promote understanding of structural knowledge, which is the important link between declarative and procedural knowledge. To that end, constructivist instructional theories like Cognitive Flexibility Theory can be employed for effective Hypertext design.

It seems that the non-linear nature and the web-like structure of hypertext render it appropriate for representing complex structural knowledge and thus play an important role in constructivist Computer Based Instruction (CBI). However, use of hypertext for learning has been contested in a series of studies and empirical evaluations. A number of studies emphasize user disorientation problems in hypertext (e.g. [Nielsen90] - perhaps the most cited paper in this field). Compared to more traditional CBI models, two drawbacks of hypermedia can be identified: (1) the deterministic nature of linking (links are unconditional) and (2) the fact that hypertext traversal, especially in WWW applications, is referential (elicited by the user) and not contextual (decided by performance information on the student) ([Kotze98]). It appears that the question of whether the non-linearity of hypermedia is effective for instruction should be replaced by several more specific questions, such as *who, in what and how does non-linearity help*. Individuals vary in skills, preferences, and degree of familiarity with information technology. These differences make individuals more or less likely to take advantage of systems like hypertext, which are based on choice and self-organization ([Rouet92]). It is such problems that curriculum sequencing and adaptive presentation/navigation AES attempt to solve, through the production of individualized instruction with the correct ratio of learner control and user guidance.

2.1.4 Ill-structured domains and AES

From the classification of AES presented in Section 2.1.1, it appears that AES classes are grouped into two main areas: problem solving support and adaptation of delivery of instruction. AES that provide problem-solving support are applicable in well-structured domains; AES techniques like building bug libraries and modifying correct examples to match user errors and perceive user misconceptions can be used to support problem solving [Beck99]. However, when the domain is ill structured, problem solving support, as implemented in a series of ITSs, is very difficult and costly to implement. This is more evident if the knowledge domain lacks well-established formalisms (contrary to domains such as math or physics) and teacher-learner interaction is typically carried out in natural language. The problem solving process is difficult to model and perhaps impossible (with today's technologies) to simulate with a machine. It seems very difficult to see a system like ANDES [Conati99], used to coach problem solving, in a complex domain like History. For such reasons, we see curriculum sequencing and its variations (adaptive presentation and adaptive navigation) as the most promising and realistic candidates for implementing successful AES in ill-structured domains.

Conclusions: Hypertext is a promising means for constructivist learning, but its use leads to problems that may be solved through the deployment of curriculum sequencing, adaptive presentation and adaptive navigation AES. Such hypertext-based systems allow moderation of learner-control vs. learner guidance in navigation and provide for better user orientation. Furthermore, ill-structured domains pose several important problems that are hard to solve for systems that provide problem-solving support and analysis of student solutions.

2.2 The effect of ill-structured domains on the design of AES

Sub-problem B: How are the basic features of AES affected by an ill-structured domain?

In order to identify basic features of interest, we first examine an AES reference model and three state-of-the-art AES in Section 2.2.1. The features identified are discussed in section 2.2.2.

2.2.1 An AES reference model and three state-of-the-art systems

There are two main approaches for building an AES on the Web. The first is to create a WWW interface on an existing ITS and the second is to construct an Adaptive Educational System specific for the WWW. Since we are concentrating on curriculum sequencing and adaptive presentation and navigation AES, and since very few ITS use adaptive hypermedia (cf. [Brusilovsky98a]), we shall focus on the second approach. Following the

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