Adaptive and Intelligent Web-based Educational Systems

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Adaptive and intelligent Web-based educational systems (AIWBES) provide an alternative to the traditional "just-put-it-on-the-Web" approach in the development of Web-based educational courseware (Brusilovsky & Miller, 2001). AIWBES attempt to be more adaptive by building a model of the goals, preferences and knowledge of each individual student and using this model throughout the interaction with the student in order to adapt to the needs of that student. They also attempt to be more intelligent by incorporating and performing some activities traditionally executed by a human teacher - such as coaching students or diagnosing their misconceptions. The first pioneer intelligent and adaptive Web-based educational systems were developed in 1995-1996 (Brusilovsky, Schwarz, & Weber, 1996a; Brusilovsky, Schwarz, & Weber, 1996b; De Bra, 1996; Nakabayashi, et al., 1995; Okazaki, Watanabe, & Kondo, 1996). Since then many interesting systems have been developed and reported. An interest to provide distance education over the Web has been a strong driving force behind these research efforts. The research community was helped by the provision of a sequence of workshops that brought together researchers working on AIWBES, let them learn from each other, and then advocate the ideas of this research direction via on-line workshop proceedings (Brusilovsky, Henze, & Millán, 2002; Brusilovsky, Nakabayashi, & Ritter, 1997; Peylo, 2000; Stern, Woolf, & Murray, 1998). A number of interesting AIWBES that were reported at early stages of their development during these workshops have since achieved the level of maturity. This double special issue capitalizes on the results of these workshops and assembles a collection of papers that represents the state of the art in the development of AIWBES.

The goal of this introductory article is to provide a more systematic view to the variety of modern AIWBES and to discuss the role and the place of the AIWBES research stream in the field of Artificial Intelligence in Education (AI-Ed). It provides a brief overview of known AIWBES technologies classified by the field of their origin. It also attempts to distill the new design paradigm behind modern AIWBES and to compare this paradigm with a traditional design paradigm that has been dominating the field of AI-Ed for the last 15 years.

ADAPTIVE AND INTELLIGENT TECHNOLOGIES FOR WEB-BASED EDUCATIONAL SYSTEMS

The kind of advanced Web-based educational systems that this introduction attempts to review are most often referred to as adaptive Web-based educational systems or intelligent Web-based educational systems. These terms are not really synonyms. Speaking about *adaptive*

systems we stress that these systems attempt to be different for different students and groups of students by taking into account information accumulated in the individual or group student models. Speaking about *intelligent systems* we stress that these systems apply techniques from the field of Artificial Intelligence (AI) to provide broader and better support for the users of Web-based educational systems. While the majority of systems mentioned in this introduction can be classified as both intelligent *and* adaptive, a solid number of systems fall in exactly one of these categories (Figure 1). For example, many intelligent diagnosis systems including German Tutor (Heift, & Nicholson, 2001) and SQL-Tutor (Mitrovic, 2003) are non-adaptive, i.e., they will provide the same diagnosis in response to the same solution to a problem regardless of the student's past experience with the system. From another side, a number of adaptive hypermedia and adaptive information filtering systems such as AHA (De Bra, & Calvi, 1998) or WebCOBALT (Mitsuhara, Ochi, Kanenishi, & Yano, 2002) use efficient, but very simple techniques that can hardly be considered as "intelligent". The reason to focus on both intelligent and adaptive systems in this issue is that that the intersection is still large, the borders between "intelligent" and "non-intelligent" are not clear-cut, and both groups are certainly of interest for AI in Education (AI-Ed) community.
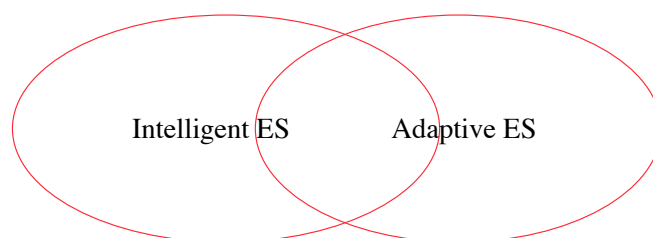

Fig. 1. Relationship between adaptive and intelligent educational systems

Existing AIWBES are very diverse. They offer various kinds of support for both students and teachers involved in the process of Web-enhanced education. To help in understanding this variety of systems and ideas, the author's earlier review of adaptive hypermedia (Brusilovsky, 1996) suggested focusing on *adaptive and intelligent technologies*. By adaptive and intelligent technologies we mean essentially different ways to add adaptive or intelligent functionality to an educational system. A technology usually can be further dissected into finer-grain *techniques* and *methods*, which correspond to different variations of this functionality and different ways of its implementation (Brusilovsky, 1996).

An earlier review (Brusilovsky, 1999) identified five major technologies used in AIWBES (Figure 2). These technologies have immediate roots in two research fields that were well established before the Internet age – Adaptive Hypermedia and Intelligent Tutoring Systems (ITS). Since their application in the Web context was relatively straightforward, these technologies were the first to appear in AIWBES and can be considered as "classic" AIWBES technologies. According to their origin, the review (Brusilovsky, 1999) grouped the five classic technologies into *Adaptive Hypermedia technologies* and *Intelligent Tutoring technologies* (Figure 2). The review also identified and grouped into "Web-inspired" AIWBES technologies some new technologies that appeared on the Web more recently and had almost no direct roots in pre-internet educational systems. The lack of examples of Web-inspired technologies at the time

of writing the review (Brusilovsky, 1999) did not allow further classification of these technologies.

In this introductory article we follow the review (Brusilovsky, 1999) in grouping together similar AIWBES technologies and identifying the roots of these technologies. We leave the set of classic Adaptive Hypermedia and Intelligent Tutoring technologies intact but subdivide the original group of Web-inspired technologies into three groups: Adaptive Information Filtering, Intelligent Class Monitoring, and Intelligent Collaboration Support. The five resulting groups of technologies and their fields of origin are shown in Figure 3. Table 1 provides a good overview of these five groups listing technologies and sample systems for each of the groups. It also helps the reader understand the role of the papers presented in this special issue (shown in bold in Table 1) in the overall context of work on AIWBES. The remaining part of this section describes briefly the technologies group by group while also introducing the papers of this special issue.
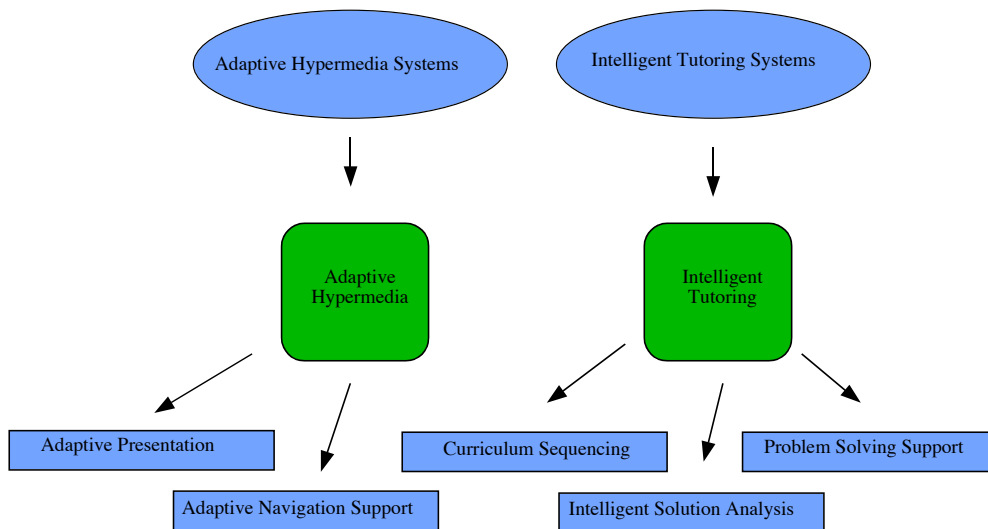

Fig. 2. Classic AIWBES technologies and their origins

Major *Intelligent Tutoring* technologies are: curriculum sequencing, intelligent solution analysis, and problem solving support. All these technologies have been well explored in the field of ITS. The goal of *curriculum sequencing technology* is to provide the student with the most suitable individually planned sequence of topics to learn and learning tasks (examples, questions, problems, etc.) to work with. It helps the student find an "optimal path" through the learning material. In the context of Web-based education (WBE), curriculum sequencing technology becomes very important due to its ability to guide the student through the hyperspace of available information. Curriculum sequencing was one of the first to be implemented in such early AIWBES as ELM-ART (Brusilovsky, et al., 1996a) and CALAT (Nakabayashi, Maruyama, Koike, Fukuhara, & Nakamura, 1996). Among the systems featured in the special issue ELM-ART (Weber, et al., 2001) and KBS-Hyperbook (Henze, et al., 2001) provide two good examples of curriculum sequencing. In ELM-ART sequencing is implemented in the form of a recommended link and an adaptive "next" button. In KBS-Hyperbook it is implemented as a suggested learning path.
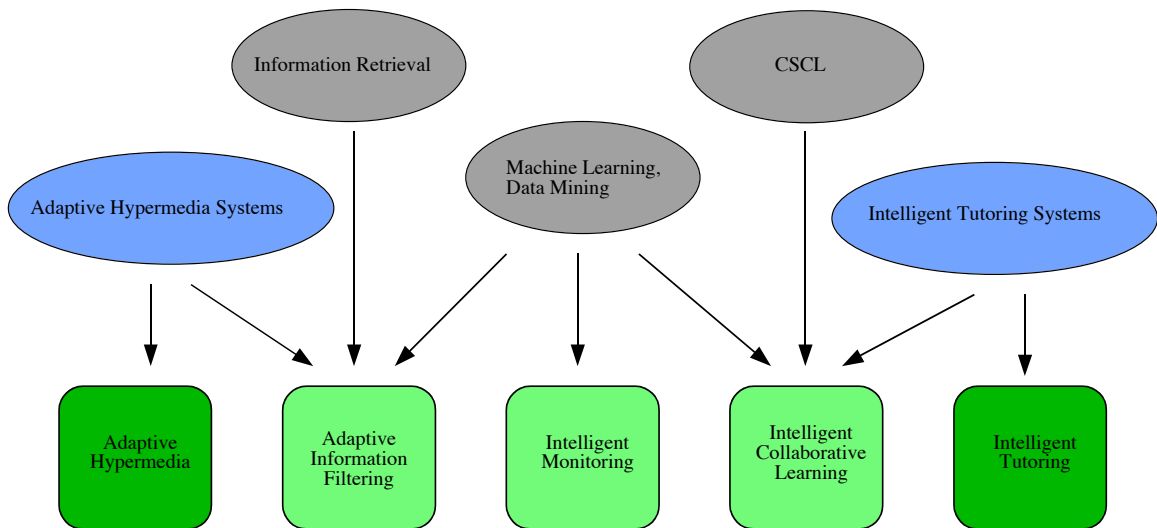
Fig. 3. Five groups of modern AIWBES technologies

Intelligent solution analysis deals with students' solutions of educational problems (which can range from a simple question to a complex programming problem). Unlike non-intelligent checkers which can only tell whether the solution is correct or not, intelligent analyzers can tell what is wrong or incomplete and which missing or incorrect pieces of knowledge may be responsible for the error. Intelligent analyzers can provide the student with extensive error feedback and update the student model. Due to its low interactivity and natural match to Web form-submission interface, this technology was also one of the first to be implemented on the Web in such early AIWBES as ELM-ART (Brusilovsky, et al., 1996a) and WITS (Okazaki, et al., 1996). The systems SQL-Tutor (Mitrovic, 2003), German Tutor (Heift, et al., 2001) and the most recent version of ELM-ART (Weber, et al., 2001) presented in this special issue demonstrate several ways of implementing intelligent solution analysis on the WWW.

The goal of *interactive problem solving support* is to provide the student with intelligent help on each step of problem solving - from giving a hint to executing the next step for the student. Interactive problem solving support technology is not as popular in Web-based systems as in standalone intelligent tutoring systems – mainly due to implementation problems. As was demonstrated by pioneer systems, pure server-side implementations such as PAT-Online (Ritter, 1997) can not actively watch the student's actions and can only provide help by request. Pure client-side implementations such as ADIS (Warendorf, & Tan, 1997) have a complexity limit. The proper functionality and level of complexity to implement interactive problem solving support require client-server implementation such as AlgeBrain (Alpert, Singley, & Fairweather, 1999), but such systems are harder to develop. Among the systems featured in this special issue, ActiveMath (Melis, et al., 2001) implements interactive problem solving support in its Omega proof planer. In addition to that, ELM-ART (Weber, et al., 2001) provides a unique example of *example-based problem solving support* – a different low-interactive support technology that became quite promising in Web context.

Table 1
AIWBES technologies, their origin, and representative systems. Systems featured in the special issue are shown in bold.

Sources of AIWBES technologies	Technologies	Sample systems
Adaptive Hypermedia	Adaptive navigation support Adaptive presentation	AHA (De Bra, et al., 1998) InterBook (Brusilovsky, Eklund, & Schwarz, 1998) **KBS-Hyperbook (Henze, & Nejdl, 2001)** **MetaLinks (Murray, 2003)** **ActiveMath (Melis, et al., 2001)** **ELM-ART (Weber, & Brusilovsky, 2001)** INSPIRE (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, Submitted)
Adaptive Information Filtering	Content-based filtering Collaborative filtering	**MLTutor (Smith, & Blandford, 2003)** WebCOBALT (Mitsuhara, et al., 2002)
Intelligent Class Monitoring		HyperClassroom (Oda, Satoh, & Watanabe, 1998)
Intelligent Collaborative Learning	Adaptive group formation and peer help Adaptive collaboration support (coaches and monitors) Virtual students	PhelpS (Greer, et al., 1998) HabiPro (Vizcaíno, Contreras, Favela, & Prieto, 2000) **COLER (Constantino Gonzalez, Suthers, & Escamilla De Los Santos, 2003)** EPSILON (Soller, & Lesgold, 2003)
Intelligent Tutoring	Curriculum sequencing Intelligent solution analysis Problem solving support	VC-Prolog-Tutor (Peylo, Teiken, Rollinger, & Gust, 1999) **SQL-Tutor (Mitrovic, 2003)** **German Tutor (Heift, et al., 2001)** **ActiveMath (Melis, et al., 2001)** **ELM-ART (Weber, et al., 2001)**

Adaptive presentation and adaptive navigation support are two major technologies explored by *adaptive hypertext and hypermedia systems*. The goal of *adaptive presentation* technology is to adapt the content presented in each hypermedia node (page) to student goals, knowledge, and other information stored in the student model. In a system with adaptive presentation, the pages are not static but adaptively generated or assembled for each user. ActiveMath (Melis, et al., 2001) featured in this special issue provides one of the most advanced existing examples of adaptive presentation. In addition, ELM-ART (Weber, et al., 2001) demonstrates a special form of adaptive presentation - adaptive warnings about the educational status of the current page.

MetaLinks (Murray, 2003) demonstrates the use of adaptive presentation for "narrative smoothing".

The goal of *adaptive navigation support* technology is to assist the student in hyperspace orientation and navigation by changing the appearance of visible links. For example, an adaptive hypermedia system can adaptively sort, annotate, or partly hide the links of the current page to make it easier to choose where to go next. Adaptive navigation support shares the same goal with curriculum sequencing - to help students find an "optimal path" through the learning material. At the same time, adaptive navigation support is less directive and more "cooperative" than traditional sequencing: it guides students while leaving them the choice of the next knowledge item to be learned and next problem to be solved. In the WWW context where hypermedia is a basic organizational paradigm, adaptive navigation support becomes both natural and efficient. It was among the three earliest AIWBES technologies, explored in such systems as ELM-ART (Brusilovsky, et al., 1996a), InterBook (Brusilovsky, Schwarz, & Weber, 1996c), and De Bra's adaptive hypertext course (De Bra, 1996) and became arguably the most popular technology in AIWBES. Half of the systems presented in this special issue use this technology. KBS-Hyperbook (Henze, et al., 2001), ActiveMath (Melis, et al., 2001), and ELM-ART (Weber, et al., 2001) demonstrate several variants of adaptive link annotation. MLTutor (Smith, et al., 2003) uses link sorting and generation.

Adaptive information filtering (AIF) is a classic technology from the field of Information Retrieval. Its goal is finding a few items that are relevant to user interests in a large pool of (text-based) documents. On the Web this technology has been used in both search and browsing context. It has been applied to adapt the results of Web search using filtering and ordering and to recommend the most relevant documents in the pool using link generation. While the engines used by AIF systems are very different from adaptive hypermedia engines, at the interface level Web-based AIF most often use adaptive navigation support techniques. There are two essentially different kinds of AIF engines that can be considered as two different AIF technologies – content-based filtering and collaborative filtering. The former relies on document content while the latter ignores the content completely attempting instead to match the users who are interested in the same documents. Modern AIF extensively uses machine learning techniques, especially for content-based filtering. Being very popular in the field of information systems, AIF has not been used in educational context in the past. The amount of learning content was relatively small and the need to guide the user to most relevant material was well supported by adaptive sequencing and adaptive hypermedia. However, the Web with its abundance of non-indexed "open corpus" educational resources has made AIF very attractive for educationalists. MLTutor (Smith, et al., 2003) featured in this special issue presents one of the first interesting examples of applying content-based AIF to education. An educational example of collaborative AIF can be found in WebCOBALT (Mitsuhara, et al., 2002).

Intelligent collaborative learning is an interesting group of technologies developed at the crossroads of two fields originally quite distant from each other: computer supported collaborative learning (CSCL) and ITS. The recent stream of work on using AI techniques to support collaborative learning has resulted in an increasing level of interaction between these fields. While early work on intelligent collaborative learning was performed in pre-Web context (Chan, & Baskin, 1990; Hoppe, 1995), it's the Web and WBE that provided both a platform and an increasing demand for this kind of technology. In WBE the need for collaboration support tools is critical because students rarely (or never) meet in person. Intelligent technologies can dramatically extend the power of simple collaboration support tools (such as threaded discussion groups and shared whiteboards) provided by various course management systems. Currently we

can list at least three distinct technologies within the intelligent collaborative learning group: adaptive group formation and peer help, adaptive collaboration support, and virtual students. A good example of adaptive collaboration support is provided by COLER (Constantino Gonzalez, et al., 2003) featured in this special issue.

Technologies for *adaptive group formation and peer help* attempt to use knowledge about collaborating peers (most often represented in their student models) to form a matching group for different kinds of collaborative tasks. Early examples include forming a group for collaborative problem solving (Hoppe, 1995; Ikeda, Go, & Mizoguchi, 1997) and finding the most competent peer to answer a question (McCalla, et al., 1997). Both streams of work are expanding now. The pioneer teams have generalized and expanded their work (Greer, et al., 1998; Mühlenbrock, Tewissen, & Hoppe, 1998) and a number of new teams started research in this direction.

Technologies for *adaptive collaboration support* attempt to provide an interactive support of a collaboration process just like interactive problem support systems assist an individual student in solving a problem. Using some knowledge about good and bad collaboration patterns (provided by the system authors or mined from communication logs) collaboration support systems such as COLER (Constantino Gonzalez, et al., 2003) or EPSILON (Soller, et al., 2003) can coach or advise collaborating peers. This is a new but rapidly expanding direction of work that draws its ideas from classic ITS, CSCL and machine learning fields.

In contrast, *virtual students* technology is comparatively old. Instead of supporting learning or collaboration from a position of someone superior to students (a teacher or an advisor), this technology attempts to introduce different kinds of virtual peers into a learning environment: a learning companion (Chan, et al., 1990), a tutee, or even a troublemaker (Frasson, Mengelle, Aïmeur, & Gouardères, 1996). In the WBE context where students communicate mainly through low-bandwidth channels (e-mail, chat, forums) a virtual student becomes a very attractive embodiment to implement different support strategies. We expect more research in this direction and its further integration with *animated agents* and *intelligent collaboration support* streams.

Intelligent class monitoring is another AIWBES technology motivated by WBE. In the WBE context a "remote teacher" can't see the signs of understanding and confusion on the faces of the students. With this severe lack of feedback it becomes hard to identify troubled students who need additional attention, bright students who need to be challenged, as well as the parts of learning material that are too easy, too hard, or confusing. WBE systems can track every action of the student, but it's almost impossible for a human teacher to make any sense of the large volume of data they are collecting. Intelligent class monitoring systems attempt to use AI to help the teacher in this context. This stream of work was pioneered by HyperClassroom (Oda, et al., 1998) that used fuzzy technology to identify "deadlocked" WBE students. Until recently, HyperClassroom was the only example in this class, but the last two years have brought a few other examples (Merceron, & Yacef, 2003; Romero, Ventura, Bra, & Castro, 2003). The earlier review (Brusilovsky, 1999) grouped intelligent class monitoring together with intelligent collaboration support. Now we argue that this stream of work has to have a group of its own since it focuses on different goals (teacher support) and relies on a different group of AI technologies (mainly data mining and machine learning). At the same time, a few systems (Chen, & Wasson, 2002; Mbala, Reffay, & Chanier, 2002) that monitor the collaboration process but report the problems to the teacher instead of influencing the very collaboration fall between intelligent class monitoring and collaboration support. Unfortunately, no examples of intelligent class monitoring are presented in this special issue and we are not able yet to identify different technologies within this class. We expect, however, that this stream of work will grow in the very near future.

ADAPTIVE AND INTELLIGENT WEB-BASED EDUCATIONAL SYSTEMS: A CHANGE OF AI-ED PARADIGM?

The analysis of adaptive and intelligent Web-based educational systems on the level of technologies reveals that they have a lot in common with pre-Web systems. Should we consider AIWBES simply as Web implementation of ideas explored earlier? Can we say that the only difference between Web and pre-Web adaptive and intelligent educational systems is the implementation platform? We claim that the difference between Intelligent Tutoring Systems of 1980 and 1990 and the new breed of Web-based systems that became popular at the end of 1990 is qualitative. While on the level of individual technologies we can easily see the similarity between Web and pre-Web systems, on the level of complete systems we can observe rather large differences in the *major focus* of these systems, their *application context*, and the overall *set of supported features*. The new platform and the new application context of Web-based systems are causing a major change of the *development paradigm*. Adaptive and intelligent Web-based educational systems are forming a new development paradigm in the field of Artificial Intelligent in Education.

If we analyze the variety of adaptive and intelligent educational systems developed since the birth of the AI-Ed field in 1970, we can distinguish at least three major development paradigms (Table 2). The motivation behind the earliest AI-Ed systems was to fix the obvious problems of the then dominant Computer-Assisted Instruction (CAI): provide more intelligent evaluation of student knowledge than traditional "yes-no" and "multiple-choice" questions and more adaptive sequencing of instructional fragments than traditional linear and branching approaches (Carbonell, 1970). These systems were called Intelligent CAI (ICAI) or AI-CAI. ICAI did not attempt to change the then well-established application context and major goal of CAI systems, that is transferring new knowledge to the student and ensuring its acquisition. Both CAI and ICAI were intended to replace all or part of traditional classroom instruction. The major intelligent technologies were sequencing (Brown, Burton, & Zdybel, 1973; Carbonell, 1970; Koffman, & Perry, 1976) and intelligent solution analysis (Brown, & Burton, 1978). The major computing platforms behind original CAI were classic mainframes and (later) mini-computers.

At the end of 1970 the new "tutoring" paradigm was established (Burton, & Brown, 1979; Clancey, 1979). It was later propagated by John Anderson's school and become dominant in 1980 and early 1990. The champions of the new paradigm claimed that the main job of AI-Ed systems is not to replace the teacher in the classroom in presenting new material, but to provide an individual tutor that can support the students in the process of solving educational problems and procedural knowledge formation. Since the old "AI-CAI" name was not relevant anymore, the new systems and the whole field adopted the name Intelligent Tutoring Systems (ITS). On the level of technologies the change was more gradual – the new technology of interactive problem solving support quickly became dominant while the relative amount of work on older technologies gradually decreased. The interest in sequencing decreased since most ITS refuse to deal with presentation of educational material leaving it to the human teacher. As for intelligent solution analysis, it was considered inferior to the new problem solving support technology: the real challenge was to develop fully interactive support. The change of the application context and the dominated technologies were supported (technology advocates may even say *driven*) by the change of the implementation platform from mainframes to personal computers with their capabilities to implement attractive problem solving interfaces.

Table 2
Major AI-Ed paradigms compared

	AI-CAI Paradigm	ITS Paradigm	AIWBES Paradigm
Time span	1970-ies	1980-1990-ies	End of 1990-ies – 2000-ies
Goal	Replace primitive CAI in transferring knowledge	Support problem solving	Comprehensive support
Context	Classroom without teachers	Classroom with a facilitator or self-study	Impendent self-study
Learning material	All learning material inside the system, most often presentations, but also exercises and problems.	No presentation material inside the system, but problems are often included.	Rich learning material on-line: presentations, examples, problems.
Technologies	Curriculum sequencing and intelligent solution analysis are the core technologies.	No course sequencing or adaptive hypermedia. Interactive problem solving support is the core technology.	Extensive use of adaptive hypermedia. Curriculum sequencing and intelligent solution analysis become widespread again. A range of Web-inspired technologies appears.
System completeness	All systems focus on single intelligent technology.	Most systems focus on single intelligent technology.	Most systems focus on several intelligent technologies.
Platform	Mainframes and mini-computers.	Personal computers	WWW

What we observe right now is a new change of the paradigm also driven to some extent by the change of the platform and the application context. The motivating application context behind Web-based educational (WBE) systems is, naturally, Web-based education. In this context with no human teacher, tutor, or even peer nearby, the educational system has to provide a one-stop solution for all student's needs. The old CAI motivation to "deliver knowledge" came back into focus and even became dominant (though the new generation of WBE systems choose to deliver the necessary educational material using flexible hypertext rather than rigid CAI). This is well demonstrated by the subset of systems presented in this special issue – the majority of them include (or ever focused on) the delivery of on-line course material – with adaptation as in MetaLinks, KBS-Hyperbook, ActiveMath, ELM-ART, MLTutor or without it as in German Tutor. The need to support problem solving remained in focus. New needs specific to modern WBE became critical - such as the need to support collaborative work and the need to support the remote teacher working with the invisible class. This context caused the appearance of new

technologies as well as the change in the usage profile of known technologies. Adaptive sequencing became popular again – now together with adaptive hypermedia and adaptive information filtering. Intelligent solution analysis became more attractive than interactive problem solving support due to its natural fit to low-interactive HTTP protocol. Collaborative learning and class monitoring technologies became an interesting new target for the application of AI techniques. More important, the set of the needs supported by a single system as well as the set of technologies used in a single system has grown quite visibly. While almost all pre-Web systems have focused on one specific need championing and extending one of the known technologies, almost all AIWBES use several technologies and become more complete as "one-stop" educational systems. This trend is clearly demonstrated by ELM-ART system (Weber, et al., 2001) presented in this special issue. While ELM-PE (Weber, & Möllenberg, 1995), the prototype of ELM-ART was a purely problem solving support system, ELM-ART driven by WBE needs became a very versatile system supporting nearly all the needs of students and teachers.

THE PROMISES OF ADAPTIVE AND INTELLIGENT WEB-BASED EDUCATIONAL SYSTEMS

Adaptive and intelligent Web-based educational systems form a new and exciting stream of work in AI-Ed field. As demonstrated by the papers included in this special issue, the Web offers an opportunity to apply a much larger variety of AI technologies in educational context. It offers a number of new research challenges and a number of opportunities to fuse AI-Ed research with several neighboring fields. The Web also provides an excellent implementation platform for AI-Ed researchers. Systems developed on the Web have longer lifespan and better visibility. A research idea implemented in a Web-based system has much better chances to influence the research community than an idea simply presented in a paper. Moreover, AIWBES with their simplicity of access and visibility have much greater chances to influence practitioners working in the field of Web-based education. We expect that the ideas developed in these systems and the systems themselves will have a growing use in practical Web-based education. This will allow AI-Ed as a research field to provide a greater impact on the improvement of everyday educational process. As guest editors, we hope that the papers assembled in this special issue provide both a good overview of the emerging area and a good inspiration for the newcomers to the field.

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