Adaptive Instructional Systems

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CONTENTS

Definition .........................................................................................................................................................................470
History of Adaptive Instructional Systems ..................................................................................................................470
Different Approaches to Adaptive Instructional Systems ..........................................................................................471
Macro-Adaptive Instruction ............................................................................................................................................471
Aptitude–Treatment Interactions ..................................................................................................................................472
An Eight-Step Model for Designing ATI-Based Courseware ..................................................................................472
Limitations of ATI .......................................................................................................................................................472
Micro-Adaptive Instruction ........................................................................................................................................473
Micro-Adaptive Instructional Models ..........................................................................................................................473
Intelligent Tutoring Systems ......................................................................................................................................474
Applying ATI to Micro-Level Adaptive Systems ...........................................................................................................474
Adaptive Hypermedia Systems ............................................................................................................................475
AHS Taxonomies ..........................................................................................................................................................476
Limitations and Challenges ...........................................................................................................................................476
Adaptive Systems Supporting Specific Pedagogical Approaches .................................................................................477
Constructivist Adaptive Systems ...................................................................................................................................477
Contingent Teaching Systems ........................................................................................................................................478
Motivation-Based Adaptive Systems ..........................................................................................................................478
Metacognition-Based Adaptive Systems .........................................................................................................................478
Collaborative Learning Systems ...................................................................................................................................479
Conclusion ......................................................................................................................................................................479
References .................................................................................................................................................................479
ABSTRACT
Adaptive instruction embodies all instructional forms that accommodate the needs and abilities of different learners. This chapter summarizes five approaches to adaptive instruction: (1) macro-adaptive instruction; (2) aptitude–treatment interactions (ATI-based); (3) micro-adaptive instruction, including intelligent tutoring systems (ITSSs); (4) the adaptive/adaptable hypermedia/Web-based system (AHS); and (5) specific pedagogy-centered systems. These approaches are presented in historical order, beginning with macro-adaptive systems. For each approach, its characteristics and representative systems are discussed. Although each has its own distinctive properties, some similarities can be found among the approaches. Due to the development of information and communication technology (ICT), the structural functions of recent adaptive systems are significantly more powerful than earlier ones. New Web-based systems have functions that simultaneously provide customized learning experiences to masses of individual learners. The challenges now facing researchers and developers are to optimally integrate many different theories, principles, and strategies of learning and instruction with system functions and to prove empirically the effects and value of these systems in real-world environments.

KEYWORDS
Adaptive hypermedia systems (AHSs): Combining micro-adaptive systems and hypermedia systems to provide adaptive/adaptable, hybrid features by presenting learners with choices, along with guidance.
Adaptive instructional systems: Any forms of educational intervention aimed at accommodating individual learner differences.
Aptitude–treatment interactions (ATIs): Adapting specific instructional procedures and strategies to specific learner characteristics (or aptitudes).
Macro-adaptive systems: Allowing different alternatives for choosing instructional goals, curriculum content, and delivery systems, by grouping students.
Micro-adaptive systems: Diagnosing the learner’s specific learning needs during instruction and providing instructional prescriptions for the needs.

DEFINITION
A central and persistent issue in educational technology is the planning and provision of instructional environments and conditions that fit and support individually different educational goals and learning abilities (Park, 1996). In general, instructional approaches and techniques that are geared to meet the needs of individually different students in developing knowledge and skills required to learn a task are called adaptive instruction (Corno and Snow, 1986). Accordingly, any form of instruction is adaptive, whether it is delivered by teachers or in a technology-based format, if it accommodates different student learning needs and abilities.

Adaptive instruction has a long history and has been implemented in various forms and settings, from group-based, classroom instruction to Web-based, open space instruction. The development of computer technology has provided a powerful tool for developing and implementing sophisticated instructional systems from diagnostic assessment tools to tutoring systems generating individually tailored instructional prescription. Recent advances in information and communication technology (ICT) allow for the delivery of individually customized information and instruction to mass audiences simultaneously. This mass individualization has been increasingly popular and important in education and training communities (De Bra et al., 2004; Karagiannidis et al., 2001; van Merriënboer, 2005).

HISTORY OF ADAPTIVE INSTRUCTIONAL SYSTEMS
The long history of efforts in adapting instruction to an individual student’s needs and abilities has been documented by many researchers (Corno and Snow, 1986; Federico et al., 1980; Glaser, 1977; Reiser, 1987; Tobias, 1989; Wang and Lindvall, 1984). Since at least the fourth century B.C., adapting has been viewed as a primary requirement for successful instruction (Corno and Snow, 1986), and adaptive tutoring was the common instructional method until the mid-1800s (Reiser, 1987). Even after graded systems were adopted, the importance of adapting instruction to individual needs was continuously emphasized. Dewey, for example, in his 1902 essay, Child and Curriculum, deplored the then current emphasis on a single kind of curriculum development that produced a uniform, inflexible sequence of instruction (Dewey, 1902/1964). Thorndike (111) argued for a specialization of instruction that acknowledged differences among pupils within a single class as well as specialization of the curriculum for different classes. Since then, various approaches and methods have been proposed to provide adaptive instruction to individually different students (for early systems, see Reiser, 1987).
Since Cronbach (1957) declared that a united discipline of psychology would be interested in not only organisms but also interactions between organisms and treatment variables, numerous studies have been conducted to investigate what kinds of student characteristics should be considered in adapting instruction and how instructional methods and procedures should be adapted to those characteristics (Cronbach, 1967; Cronbach and Snow, 1977; Federico et al., 1980; Snow and Swanson, 1992). Whereas early instructional systems considered only one or two variables, newer adaptive systems using computer technology implement models that have multiple layers, each with many variables. Each adaptive system lies along this complexity continuum, but they can be clustered into several types according to their approaches.

DIFFERENT APPROACHES TO ADAPTIVE INSTRUCTIONAL SYSTEMS

Efforts to develop and implement adaptive instruction have taken five different approaches. Depending on available resources and constraints in the given situation, adaptive instruction can be designed using one or more of these approaches. The first approach is to adapt instruction on a macro-level by allowing alternatives in instructional goals, depth of curriculum content, delivery systems, etc. Most adaptive instructional systems developed as alternatives to the traditional lock-step group instruction in school environments have taken this approach. The second approach is to adapt specific instructional procedures and strategies to specific student characteristics. Because this approach requires the identification of the most relevant learner characteristics (or aptitudes) for instruction and the selection of instructional strategies that best facilitate the learning process of the students with those characteristics, it is based on aptitude–treatment interaction (ATI). The third approach is to adapt instruction on a micro-level by diagnosing the student’s specific learning needs during instruction and providing instructional prescriptions for the needs. Intelligent tutoring systems (ITSs) are an example of this approach. The fourth approach is adaptive hypermedia and Web-based systems (AHSs). Although this approach can be considered as an extension of ITS, it has several new features. First, most AHSs apply adaptive/adaptable (hybrid) features by allowing users to initiate their choices, along with guidance (Cristea and Garzotto, 2004). Second, whereas previous adaptive systems are closed corpus systems confined to the program, most AHS applications are Web-based, open corpus systems which allows the possibility of utilizing other Web resources. The fifth is a group of systems that were developed based on specific pedagogical approaches. The pedagogical approaches applied in these systems include constructivism, motivation theory, social learning theory, and metacognition.

Although they are presented as five different approaches, some overlaps exist between categories. Further, an adaptive instructional system may contain characteristics of more than one approach. Also, although this review is intended to be comprehensive, it is certainly not complete. Several relevant endeavors in the field—for example, applications of cognitive load theory to adaptive instruction—are not included in this review because these systems are in the early stages of development.

MACRO-ADAPTIVE INSTRUCTION

Initial attempts at homogeneous grouping had minimal effect because the groups seldom received different kinds of instructional treatments (Tennyson, 1975). In the early 1900s, a number of adaptive systems were developed to better accommodate different student abilities, such as the Burke plan, Dalton plan, and Winnnetka plan (Reiser, 1987). The notion of mastery learning was also fostered in the Dalton and Winnnetka plans.

Several macro-adaptive instructional systems were developed in the 1960s, 1970s, and 1980s (for a review, see Park and Lee, 2003). Examples of macro-adaptive instructional systems include Keller’s Personalized System of Instruction (PSI) (Keller and Sherman, 1974), the Program for Learning in Accordance with Needs (PLAN) (Flanagan et al., 1975), Mastery Learning Systems developed by Bloom and his associates (Block, 1980), Individually Guided Education (IGE) (Klausmeier, 1975), and Individually Prescribed Instructional System (IPI) (Glaser, 1977). Although many macro-level systems have been criticized as being unsystematic, they were practiced in many school classrooms for a long time, and some systems are still used. The Adaptive Learning Environments Model (ALEM) developed by Wang and her associates (Wang, 1980; Wang and Lindvall, 1984; Wang et al., 1995; see also http://www.nwrel.org/scpd/catalog/ModelDetails.asp?ModelID=8) is still implemented in many schools. Another sample of macro-level approaches is the PLATO Learning Management (PLM) system; PLM was a computer-managed instructional (CMI) system with functions to diagnose student learning needs and
prescribe instructional activities appropriate for those needs. The PLM could evaluate each student’s performance on a test and provide specific instructional prescriptions (Hart, 1981).

As Glaser (1977) pointed out, the development and implementation of an adaptive instructional program in an existing system were complex and difficult. This problem may be the primary reason why most macro-adaptive instructional systems have not been used as successfully and widely as hoped. Computer technology, however, provides a powerful means to overcome at least some of the problems encountered in the development and implementation of adaptive instructional systems.

**APTITUDE–TREATMENT INTERACTIONS**

Cronbach (1957) suggested that facilitating educational development for a wide range of students requires a wide range of environments suited to their optimal learning. He proposed prescribing one type of instructional sequence for a student with certain characteristics and another type for a student with different characteristics. This strategy has been based on aptitude–treatment interactions (ATIs). Cronbach and Snow (1977) defined *aptitude* as any individual characteristic that increases or impairs the student’s probability of success in a given treatment, and they defined *treatment* as variations in the pace or style of instruction.

**An Eight-Step Model for Designing ATI-Based Courseware**

Carrier and Jonassen (1988) proposed an eight-step model to provide practical guidance for applying the ATI-based model to the design of computer-based instructional (CBI) courseware. This model is basically a modified systems approach to instructional development (Dick and Carey, 1985; Gagné and Briggs, 1979): (1) Identify objectives for the courseware, (2) specify task characteristics, (3) identify an initial pool of learner characteristics, (4) select the most relevant learner characteristics, (5) analyze learners in the target population, (6) select final differences (in the learner characteristics), (7) determine how to adapt instruction, and (8) design alternative treatments. Carrier and Jonassen (1988) also listed important individual variables that influence learning, such as prior knowledge, cognitive styles, and personality variables. For instructional adaptation, they recommended several types of methods: (1) remedial,

(2) capitalization/preferential, (3) compensatory, and (4) challenge. This model seemingly has practical value; however, without theoretically coherent and empirically traceable links among different learner variables and without clearly defined types and levels of learning requirements and instructional strategies for different tasks, the mere application of this model is not likely to produce better results than those of nonadaptive instructional systems.

**Limitations of ATI**

Since Cronbach (1957) made his proposal, relatively few studies have found consistent results to support the paradigm. As shown in several reviews of ATI research (Berliner and Cahen, 1973; Corno and Snow, 1986; Cronbach and Snow, 1977; Tobias, 1976), intellectual abilities and other aptitude variables were used in many different studies to investigate their interactions with a variety of instructional treatments; however, no convincing evidence was found to suggest that such individual differences were useful variables for differentiating instructional treatments in a homogeneous age group (Glaser and Resnick, 1972; Tobias, 1987).

The inconsistent findings of ATI studies prompted researchers to reexamine the paradigm and propose alternative approaches. According to Tobias (1976, 1987, 1989), a number of limitations and problems in the ATI-based model have been proposed; for example:

- The abilities assumed to be most effective for a particular treatment may not be exclusive (Cronbach and Snow, 1977).
- Abilities required by a treatment may shift as the task progresses (Burns, 1980; Federico, 1983).
- ATIs validated for a particular task and subject area may not be generalizable to other areas (Peterson, 1977; Peterson and Janicki, 1979; Peterson et al., 1981).
- ATIs validated in laboratory experiments may not be applicable to actual classroom situations (Tobias, 1976, 1987, 1989).

Another criticism is that ATI research has tended to be overly concerned with exploration of simple input/output relations between measured traits and learning outcomes (DiVesta, 1975). Because individual difference variables are difficult to measure, the validity and reliability of the measures can be a problem in adapting instruction to the individual differences; however, research in ATI has continued.
Recently, several studies have been conducted to control learning environments using computers; for example, Maki and Maki (2002) examined the interactions of student comprehension skills with course format (online vs. lecture format). After examining the interactions among particular learning types, exploratory behavior, and two different learning environments (rule application vs. rule induction), Shute and Towle (2003) introduced an adaptive e-learning model utilizing ATI.

MICRO-ADAPTIVE INSTRUCTION

Researchers have attempted to establish micro-adaptive instructional models using on-task measures rather than pre-task measures. On-task measures of student behavior and performance, such as response errors, response latencies, and emotional states, can be valuable sources for making adaptive instructional decisions during the instructional process. Such measures taken during the course of instruction can be applied to the manipulation and optimization of instructional treatments and sequences on a much more refined scale (Federico, 1983). Thus, micro-adaptive instructional models using on-task measures are likely to be more sensitive to the student’s needs.

A typical example of micro-adaptive instruction is one-on-one tutoring. The tutor selects the most appropriate information and tutoring method for the student based on his or her judgment of the student’s learning needs and abilities (Bloom, 1984; Kulik, 1982). As the one-on-one tutorial process suggests, two essential elements of micro-adaptive instruction are the ongoing diagnosis of the student’s learning needs and the prescription of instructional treatments based on the diagnosis (Hansen et al., 1977; Holland, 1977; Landa, 1976; Rothen and Tennyson, 1978). Instructional researchers or developers have different views about the variables, indices, procedures, and actions that should be used in the diagnostic and the prescriptive processes (Atkinson, 1976; Rothen and Tennyson, 1977).

Micro-Adaptive Instructional Models

Unlike macro-adaptive models, micro-adaptive models are dynamic and use the temporal nature of learner abilities and characteristics (e.g., current knowledge, motivation level) as a major source of diagnostic information on which instructional treatments are prescribed. By including more variables related to instruction, a typical micro-adaptive model provides a better control process than a macro-adaptive model or programmed instruction in responding to the student’s learning needs (Merrill and Boutwell, 1973). As described by Suppes et al. (1976), micro-adaptive models typically use a quantitative representation and trajectory methodology. An important feature of a micro-adaptive model is the timeliness and accuracy for determining and adjusting learning prescriptions during instruction.

Most micro-adaptive models are primarily developed to adapt two instructional variables: the amount of content to be presented and the presentation sequence of the content. Representative examples of micro-adaptive instructional models are mathematical models, multiple regression models, Bayesian probability models, and structural/algorithmic models (for a comprehensive review, see Park and Lee, 2003). The Bayesian probabilistic model and the multiple regression model are designed to select the amount of instruction required to learn a given task using both pre-task and on-task information (Hansen et al., 1977; Park and Tennyson, 1980, 1986; Ross and Anand, 1986; Ross and Morrison, 1986; Rothen and Tennyson, 1977). The structural/algorithmic approach emphasizes that the sequence of instruction should be decided by the content structure of the learning task as well as the student’s performance history (Scandura, 1977a,b, 1983).

Regarding treatment variables, some studies (Hansen et al., 1977; Ross and Morrison, 1988) indicated that only prior achievement among pre-task measures (e.g., anxiety, locus of control) provides consistent and reliable information for prescribing the amount of instruction; however, subjects who received the amount of instruction selected based on both pre-task measures and on-task measures needed less time and showed higher test scores than subjects who received the amount of instruction based on only pre-task measures (Park and Tennyson, 1980). The results of the response-sensitive strategies studied by Park and Tennyson (1980, 1986) suggest that the predictive power of pre-task measures, including prior knowledge, decreases while that of on-task measures increases as the instruction progresses.

As reviewed above, a common characteristic of micro-adaptive instructional models is response sensitivity in diagnosing student learning needs and providing instructional prescriptions. Response-sensitive instruction has been used for a long time, from Crowder’s simple branching program (1959) and Atkinson’s mathematical model of adaptive instruction (1968) to intelligent tutoring systems. Until the late 1960s, technology was not readily available to implement the response-sensitive diagnostic and prescriptive procedures as a general practice outside the experimental laboratory (Hall, 1977).
Intelligent Tutoring Systems

Intelligent tutoring systems (ITSs) were developed with the application of artificial intelligence (AI) techniques. Because the goal of ITSs is to provide adaptive instruction by intelligently diagnosing students’ learning needs and progress in a response-sensitive manner, they are considered micro-level adaptive instructional systems. ITSs have three main components: a representation of the content to be taught (expert or domain model), an inherent teaching or instructional strategy (tutor or teaching model), and mechanisms for understanding what the student does and does not know (student model) (Akhras and Self, 2002; Shute and Psotka, 1996; Wenger, 1987). AI methods for the representation of knowledge (e.g., production rules, semantic networks, scripts frames) and problems make it possible for the ITS to generate and present knowledge to students based on their performance on the task rather than selecting the knowledge according to the predetermined branching rules. The capacity to make inferences about the cause of a student’s misconceptions and his or her learning needs allows the ITS to make decisions based on qualitative data, unlike most micro-adaptive models based on solely quantitative data.

Furthermore, ITS techniques provide a powerful tool for effectively capturing human learning and teaching processes. It has apparently contributed to a better understanding of cognitive processes involved in learning specific skills and knowledge (Shute and Psotka, 1996). Some ITSs provided research environments for investigating specific instructional strategies and tools for modeling human tutors and simulating human learning and cognition (Koedinger and Anderson, 1998; Seidel and Park, 1994; Shute and Psotka, 1996). Recently, ITSs were expanded to enhance metacognition (Aleven et al., 2001; White et al., 1999); however, it has been noted that ITS developers have failed to incorporate many valuable learning principles and instructional strategies developed by instructional researchers and educators (Park et al., 1987). Ohlsson (1987, 1993) and others criticized ITS and other computer-based interactive learning systems for their limited range and adaptability of teaching actions compared to rich tactics and strategies employed by human expert teachers. Cooperative efforts among experts in different domains, including learning/instruction and artificial intelligence, are required to develop more powerful adaptive systems using the ITS methods and techniques (Park and Seidel, 1989; Seidel et al., 1989).

Applying ATI to Micro-Level Adaptive Systems

To integrate the ATI-based approach in a micro-adaptive model, Tennyson and Christensen (1988; also see Tennyson and Park, 1987) proposed a two-level model of adaptive instruction based on the findings of their own research. First, this computer-based model allows the computer tutor to establish conditions of instruction based on learner aptitude variables (cognitive, affective, and memory structure) and context structure. Second, the computer tutor provides moment-to-moment adjustments of instructional conditions by adapting the amount of information, example formats, display time, sequence of instruction, instructional advisement, and embedded refreshment and remediation. The micro-level adaptation is based on the student’s on-task performance, and the procedure is response sensitive (Park and Tennyson, 1980). The amount of information to be presented and the time to display the information on the computer screen are determined through the continuous decision-making process based on on-task performance data. The selection and presentation of other instructional strategies (sequence of examples, advisement, and embedded refreshment and remediation) are determined based on the evaluation of the on-task performance.

Evidence shows that some aptitude variables (e.g., prior knowledge, interest, intellectual ability) are important predictors in selecting instructional treatments (Tobias, 1994; Whitener, 1989); however, some studies (Park and Tennyson, 1980, 1986) suggest that the predictive value of aptitude variables decreases as the learning process continues. In contrast, the diagnostic power of on-task performance increases because it reflects the most updated and integrated reflection of aptitude and other variables involved in the learning. The decrease in the predictive power of the premeasured aptitude variables and the increase in that of on-task performance can be represented as shown in Figure 37.1.

Figure 37.1 Predictive power of aptitudes and on-task performance.
In the two-stage approach, the student is assigned initially to the best instructional alternative based on the aptitude measured prior to instruction, and then response-sensitive procedures are applied as the student’s response patterns emerge to reflect his or her knowledge or skills on the given task. A representative example of this two-stage approach is the Bayesian adaptive instructional model. As the process for estimating student learning needs continues using a Bayesian probability model, the value of the pretest performance data becomes less important and recent performance data become more important. The effectiveness of the two-stage approach has been empirically supported (Park and Tennyson, 1980, 1986).

**ADAPTIVE HYPERMEDIA SYSTEMS**

In the early 1990s, when researchers incorporated the concepts of hypermedia/hypertext with intelligent tutoring systems, adaptive hypermedia systems (AHSs) were born (Beaumont, 1994; Brusilovsky et al., 1996; De Bra et al., 2005; Fischer et al., 1990; Gonschorek and Herzog, 1995; Hohl et al., 1996; Kay and Kummerfeld, 1994). An AHS utilizes hyperlinks, and its technical approach, including a user-model-based interface, is similar to an ITS; however, AHSs differ from both micro-adaptive systems (including ITSs) and conventional hypermedia systems in terms of adaptability/adaptivity.

In general, computer-based instructional systems that allow the user to choose certain parameters and adapt the behavior of these systems are referred to as learner-controlled instruction (Williams, 1996) or adaptable systems (Cristea and Garzotto, 2004; Fink et al., 1998; Opperman, 1994), whereas adaptive systems in which behaviors are automatically based on the user’s needs are referred to as program-controlled (system-controlled) instruction, or adaptive systems.*

Conventional hypermedia learning environments are nonadaptive, as they provide the same content and the same set of links to all learners; however, they are adaptable because links or tasks to be presented next are determined by the learner’s actions. Adaptability without adaptivity may lead the learner along a poor path (Steinberg, 1991; Williams, 1996). Unlike conventional hypermedia environments, an AHS is adaptive, providing content and links based on the individual user’s needs and characteristics; for example, the next button in an AHS may not be different in appearance but it will take different users to different pages (Schwarz et al., 1996).

Traditional micro-adaptive instructional systems are adaptive but not adaptable. They control the instructional process and activities based on an evaluation of student learning needs and abilities, but they do not allow students to control the process of adaptation. In contrast, most AHSs allow users to initiate their own choices; for example, an AHS might provide a suggested set of most relevant links based on the system’s assessment of the user’s needs and characteristics (Brusilovsky, 1994).

Because an AHS includes both learner and program control, it is also referred to as an adaptive/ adaptable hybrid system (Cristea and Garzotto, 2004). Oppermann developed and tested the adaptive/adaptable system Flexcel. He concluded that adaptivity and adaptability should receive benefits from each other (Oppermann, 1994).

Another difference between AHSs and micro-adaptive systems is that, except for a few early AHSs developed before the advent of the Web, AHSs are Web based. As Brusilovsky (2003) pointed out, when using the Web platform course instructors or developers can use not only the closed corpus course material in the system but also open corpus Web sources. Open corpus Web sources were not available for previous adaptive systems.

Since the mid-1990s, with the advent of the Web, AHSs have grown rapidly (Brusilovsky, 2001). Now, the Web is the choice of all AHSs, and AHSs are now referred to as adaptive Web-based hypermedia or Web-based adaptive hypermedia. Due to its large variety of users, the Web is an ideal candidate for adaptivity and has served as a platform for AHS research and development (Brusilovsky, 2000). Many AHSs have been developed for education and training purposes, such as hypermedia, e-learning, virtual museums, and online information systems (Brusilovsky, 2003; Cristea, 2005). AHS research and development have been extended to the development of AHS authoring tools, such as Multibook (Steinacker et al., 1998), InterBook (Brusilovsky et al., 1998), ACE (Specht and Oppermann, 1998), KBS Hyperbook (Henze and Nejdl, 1999, 2001), AHA! (De Bra et al., 2003), ADAPTS (Brusilovsky and Cooper, 2002), WHURLE (Moore et al., 2004), and SmexWeb (Albrecht et al., 2000). Also, the functions of AHSs have been improved, from the application of simple one-layered, knowledge-based user models to sophisticated multiple-layered user models (Brown et al., 2005).

* These definitions of the words adaptive and adaptable are not employed universally; for example, Leutner (2004) referred to learning environments that are macro-adaptive as adaptable and those that are micro-adaptive as adaptive.
AHS Taxonomies

In 1997, the Adaptive Hypertext and Hypermedia Discussion forum (Eklund and Sinclair, 2000) defined adaptive hypermedia systems as “all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible and functional aspects of the system to the user.” More specifically, an adaptive hypermedia system should: (1) be based on hypermedia or hypertext, (2) have a user model, (3) have a domain model, and (4) be modifiable (adaptive) based on information contained in the user-model (Eklund and Sinclair, 2000).

Brusilovsky (1996) developed the first taxonomy of AHSs which distinguishes two areas of adaptation: (1) adaptation of the content of the page, called content-level adaptation or adaptive presentation, and (2) behavior of the links, called link-level adaptation or adaptive navigation support. The goal of adaptive presentation is to adapt the content of a hypermedia page to the learner’s goals, knowledge, and other information stored in the user model. The techniques of adaptive presentation are to adapt the content of a page accessed by a particular user to the user’s current knowledge, goals, and other characteristics or to provide not only text but also a set of various multimedia items. The goal of adaptive navigation support is to assist learners in finding their optimal paths in hyperspace by adapting link presentation and functionality to the goals, knowledge, and other characteristics of individual learners. Direct guidance; sorting; annotation; link hiding, disabling, and removal; and link generation are ways to provide adaptive links to individual learners (Brusilovsky, 2000, 2003, 2004; Brusilovsky and Pesin, 1994, 1998; Brusilovsky and Rizzo, 2002; Brusilovsky and Vassileva, 1996; De Bra, 2000; Kayama and Okamoto, 1998).

Brusilovsky’s taxonomy was refined by others. Cristea and Calvi (2003) presented three layers of adaptation from direct adaptation techniques (low level), adaptation language (medium level), and adaptation strategies (high level). The low level is based on Brusilovsky’s taxonomy, the medium level refers primarily to goal- or domain-oriented adaptation techniques, and the high level refers to adaptation techniques for detecting learner’s information-processing strategies and cognitive styles (Brown et al., 2005; Calvi and Cristea, 2002; Cristea and Calvi, 2003; Cristea and De Bra, 2002). My Online Teacher (MOT) is a representative sample of AHS authoring tools that have integrated the three layers of adaptation techniques (Brown et al., 2005; Cristea and Calvi, 2003).

Limitations and Challenges

As reviewed earlier, two features distinguish AHSs from micro-adaptive systems: (1) adaptivity/adaptability and (2) open corpus learning environments. However, these features impose new challenges. Williams’ comprehensive review (1996) of learner-controlled vs. program-controlled instruction revealed that learner-controlled (adaptable) systems and program-controlled (adaptive) systems have different strengths and weaknesses. According to Williams, each type of system is more effective than the other for some people and under certain conditions (for those conditions, see Williams, 1996). This finding suggests that a system with the combined functions of adaptability and adaptivity would be more effective than a system with only adaptable or adaptive functions. AHSs were developed to provide hybrid systems; however, decisions about how to design adaptive/adaptable systems are still made on an ad hoc basis without an adequate theoretical or empirical rationale for the design of these hybrid systems (Avergiou et al., 2004; Cristea and De Bra, 2002). Adaptivity has risen to a new level; the question now is how to balance adaptivity and adaptability in a system.

A conceptual model for adaptable/adaptive systems can be found in Park’s (1996) proposal of on-task adaptive learner-control (see Figure 37.1), in which learners have more freedom in choosing learning activities as the instruction progresses. In the beginning stage of learning, the student’s familiarity with the subject knowledge and its learning requirements would be relatively low, and the student would not be able to choose the best strategies for learning. As the instruction and learning continue, however, the student’s familiarity with the subject and ability to learn it would increase, thus enabling the student to make better decisions in selecting strategies for learning the subject. This argument is supported by research (Carrier, 1984; Ross and Rakow, 1981; Seidel et al., 1978; Snow, 1980). An on-task adaptive learner control system will decide not only when is the best time for giving the learner-control option but also what kind of control options (e.g., selection of contents, learning activities) should be given based on the student’s on-task performance.

Cristea and Garzotto (2004) identified a set of design variables or problem classes to develop a taxonomy of adaptive/adaptable educational hypermedia: learner model, instructional strategy, instructional view, detection mechanism, and adaptation mechanism. Also, they provided typical problems that a developer might face and design guidelines for each of the problems. Although the guidelines are not yet complete, the taxonomy can be used as a starting point.
for establishing the design standards of adaptive/adaptable systems, including methods and procedures (Cristea and De Bra, 2002). Empirical study should be conducted to validate and refine these standards.

Web-based AHSs may or may not utilize open corpus resources in the Web; however, designing an AHS that utilizes the open corpus hyperspace is a challenging task. Brusilovsky (2003) pointed out that simply providing external links to multiple sources is not considered adaptive support for students. An important question is how the system provides adaptive open resources for students. Many systems and techniques have been developed to expose users to information relevant only to them (Hanani et al., 2001). Several Web-authoring tools, such as WHURLE (Moore et al., 2004) and KBS Hyperlink (Henze and Nejdl, 2001), generate hyperlinks not only inside of the lesson but also to external Web resources based on learners’ previous activities. The adaptive Web recommendation (AWR) system is also another method for providing adaptive navigation support technologies for open corpus learning environments (Brusilovsky, 2004). Whereas typical AHSs attempt to adapt to various aspects of the users and provide a rich set of adaptive navigation support techniques in closed learning environments, AWRs focus on one aspect—user interest—and provide relevant external links. Web Knowledge Sea was developed utilizing AWR techniques (Brusilovsky, 2004; Brusilovsky and Rizzo, 2002). Providing adaptive navigational support is another important issue not only for the development of adaptive systems but also for the development of information and communication technology. With the steadily growing Semantic Web, which provides a generic structure for producing machine-processable Web content (see http://www.w3.org/2001/sw), adaptive navigational support will become more feasible.

Reusability, a long-standing problem in computer-based adaptive instructional systems, continues to plague those working with AHSs. Until recently, AHSs were domain-specific applications in particular systems only; therefore, it was difficult to reuse the technology in one system for the development of another system. Research is currently in progress to develop adaptation technology for establishing uniform standards (Brusilovsky, 2003; Cristea, 2004; de Assis et al., 2004). The Minerva project is an example. The goal of the project was to establish a European platform of standards, guidelines, techniques, and tools for user-model-based adaptability and adaptation (see http://wwwis.win.tue.nl/~acristea/html/Minerva/). This standardization effort is expected to address the reusability issue. Meta-adaptive models and adaptation standard techniques for AHSs have been tested (de Assis et al., 2004).

**ADAPTIVE SYSTEMS SUPPORTING SPECIFIC PEDAGOGICAL APPROACHES**

Andriessen and Sandberg (1999) noted that adaptive computer-based instruction mainly focuses on the acquisition of conceptual and procedural knowledge, identification of common misconceptions in specific domains, and interactions between the program (or tutor) and students. As mentioned earlier, adaptive instructional systems were criticized for their limited range of teaching actions compared to human expert teachers. Researchers began to incorporate more complex pedagogical approaches, such as constructivist learning, contingent learning strategies, motivational competence, metacognitive strategies, and collaborative learning in adaptive instructional systems. These five adaptive approaches are not mutually exclusive, but they can be distinguished from one another in terms of their primary thrust. Although researchers are applying other pedagogical approaches to adaptive instructional systems, these five were selected to provide an overview of the impact of pedagogical approaches on the field.

**Constructivist Adaptive Systems**

Constructivist learning theories emphasize active roles for learners to construct their own knowledge through experiences in a learning context in which the target domain is integrated. To implement constructivist principles into computer-based learning environments, researchers developed the concept of intelligent learning environments (ILEs), which emphasize the facilitatory role of the system as opposed to the tutoring role (Akhras, 2004; Brusilovsky, 1994).

Most adaptive instructional systems utilized representation of knowledge, inference of the learner’s state of knowledge, and planning of instructional steps (Akhras and Self, 2000). Akhras and Self argued that “alternative views of learning, such as constructivism, may similarly benefit from a system intelligence in which the mechanisms of knowledge representation, reasoning, and decision making originate from a formal interpretation of the values of that view of learning” (p. 345). Constructivist intelligent systems shift the focus from a model of what is learned to a model of how knowledge is learned (Akhras and Self, 2000).

To model this facilitatory role, researchers (Akhras, 2004; Akhras and Self, 2000, 2002) proposed four important considerations when designing these systems: situation-based contexts, learning interactions in situation, time-extended processes of interaction, and affordances of learning situations. Their
approach was implemented in INCENSE (INtelligent Constructivist ENvironment for Software Engineering learning). KBS Hyperbook is another example of constructivist AHS (Henze and Nejdl, 1999).

**Contingent Teaching Systems**

According to Vygotsky’s theory (1978), providing immediate and appropriately challenging activities and contingent teaching based on a learner’s behavior is important for that learner to progress to the next level of learning. He believed minimal levels of guidance are the best for learners. Recently, this theory has been applied in several different ways to computer-based instruction. As compared to traditional adaptive instruction, a contingent teaching system has no global model of the learner. A learner’s performance is local, and the situation is constrained by contingencies in the learner’s current activity. Because the tutor’s actions and reactions should be occurring in response to the learner’s inputs, the theory promotes an active view of the learner and an account of learning as a collaborative and constructive process (Wood and Wood, 1996). Contingent tutoring systems generally provide two assessment methods: model tracing and knowledge tracing (du Boulay and Luckin, 2001). The purpose of model tracing is to keep track of all of the student’s actions as the problem is solved and to flag errors as they occur. It also adapts the help feedback based on specific problem-solving contexts. The purpose of knowledge tracing is to choose the next problem that is appropriately challenging so the students can move in a timely but effective manner through the curriculum. Examples of contingent teaching systems include SHERLOCK (Lesgold, 2001; Lesgold et al., 1992), QUADRATIC tutor (Wood and Wood, 1999), DATA (Wood et al., 1998), Ecolab (Luckin and du Boulay, 1999), and M-Ecolab (Rebolledo Mendez et al., 2006).

**Motivation-Based Adaptive Systems**

Some new adaptive instructional systems take into account student motivation. Proponents suggest that a comprehensive adaptive instructional plan should consist of a traditional instructional plan combined with a motivational plan (del Soldato and du Boulay, 1995; du Boulay and Luckin, 2001; Wasson, 1990). De Vicente and Pain (2002) have developed a model called the *motivation model*, which diagnoses a student’s motivational state based on several variables (i.e., control, challenge, independence, fantasy, confidence, sensory interest, cognitive interest, effort, satisfaction). COSMO (Lester et al., 1999) supports a pedagogical agent that can incorporate nonverbal feedback and conversational signals such as its facial expression, its tone of voice, its gestures, and the structure of its utterances to indicate its own affective state and to increase students’ motivation during its interactions with learners.

**Metacognition-Based Adaptive Systems**

Metacognitive skills enable students to assess their own learning processes. As ICT-based individualized instruction, including online learning environments, becomes increasingly prevalent, metacognitive and self-regulatory processes are becoming more important in the design of systems (Azvedo, 2005a,b; Quintana et al., 2005; Zimmerman and Tsikalas, 2005). In contrast, most early tutoring systems did not promote students’ metacognitive thinking (Carroll and McKendree, 1987).

White et al. (1999) argued that metacognitive processes can be easily understood and observed in a multi-agent social system that integrates cognitive and social aspects of cognition within a social framework. Based on this conceptual framework, they developed the SCIWISE program, which houses a community of software agents, such as an Inventor, an Analyzer, and a Collaborator. The agents provide strategic advice and guidance to learners as they undertake research projects and as they reflect on and revise their inquiry; therefore, students express their metacognitive ideas as they undertake complex sociocognitive practices. Through this exercise, students develop explicit theories about the social and cognitive processes required for collaborative inquiry and reflective learning (White et al., 1999).

Another example focusing on improving metacognitive skills is the Geometry Explanation Tutor (GET) developed by Alevin et al. (2001). They argued that self-explanation is an effective metacognitive strategy. Having students explain examples or problem-solving steps helps them learn with greater understanding (Alevin et al., 2003a,b; Chi et al., 1989). Alevin and his associates conducted experimental studies to test the effects of GET. The results provided positive effects on learning outcomes.

The ability to pursue help effectively and efficiently when needed is an important metacognitive skill. Alevin and his associates (Alevin et al., 2003c, 2006) also developed Help-Seeking Tutor Agent, which helps students become better help seekers. They embedded it within their adaptive instructional system, Geometry Cognitive Tutor, and tested whether Help-Seeking Tutor Agent helped students to be better help seekers and to learn better as a result (Alevin et al., 2004). The results showed that the more help-seeking errors students made with the system, the less they learned. Other research (Roll et al., 2006) revealed
that, although Help-Seeking Tutor Agent achieved positive effects because students followed its advice, students did not internalize the help-seeking principles.

**Collaborative Learning Systems**

One of new pedagogical approaches incorporated in adaptive instructional systems is collaborative learning (Söller et al., 2005). Effective collaboration with peers is a powerful learning experience; however, simply placing students in a group and assigning a task to the group does not produce a valuable learning experience for them (Söller, 2001). Teachers (tutors in computer-based systems) should provide strategies for students to experience collaborative learning effectively and interestingly. Through the use of an intelligent collaborative system, Söller (2001) identified five characteristics of effective collaborative learning behaviors: (1) participation, (2) social grounding, (3) performance analysis and group processing, (4) application of active learning conversation skills, and (5) promotive interactions. Söller and her colleagues (2005) developed a conceptual framework, the Collaboration Management Cycle, represented by a feedback loop for the five-phased behaviors.

Although collaborative learning systems are still in development (Jermann et al., 2004; Or-Bach and van Joolingen, 2004; Söller et al., 2005), their contributions to adaptive instructional systems will be significant; they not only facilitate student group activities but also help educators and researchers better understand group interactions and determine how to support collaborative learning better. Appropriate combinations of sound pedagogical approaches such as the ones described above with the structural features and functions of adaptive/adaptable systems will further improve the technical capacity and instructional effectiveness of the systems.

**CONCLUSION**

Adaptive instruction has a long history. Systematic efforts to develop adaptive instructional systems began in the early 1900s. Adaptive instructional systems have embodied different approaches: macro-adaptive, ATI-based, micro-adaptive (including ITS), and adaptive/adaptable hybrid systems, as well as other approaches that incorporate different pedagogical perspectives. Using interactive computer technology, a number of different micro-adaptive instructional systems have been developed; however, early applications were mostly in laboratory environments because of the limitations of their functional capabilities to handle complex learning and instructional processes.

Since the 1990s, with the advent of the Web and AHSs, adaptive instructional applications have moved out of the labs and into classrooms and workplaces. During the last decade, numerous AHS systems have been developed; however, the dearth of empirical evidence and weak theoretical foundations supporting their effectiveness (Shapiro and Niederhauser, 2004) remain as a hindrance for the wider use of the systems in school education and industry training. It is a difficult and challenging task to develop technically robust, theoretically sound, and empirically valid systems. Research and development on new pedagogical approaches in adaptive systems may provide stronger theoretical foundations for the development of future systems. AHS technology in collaboration with the Semantic Web may lead to standardized open adaptation technology for the development of future adaptive systems. If more theoretically sound and technically robust systems are developed, it becomes more likely that the effects of the systems will be supported in empirical evaluations.

**REFERENCES**


Adaptive Instructional Systems


Jung Lee and Ok-Choon Park


Adaptive Instructional Systems


* * Indicates a core reference.