The Past, the Present and the Future of adaptive E-Learning

An Approach within the Scope of the Research Project AdeLE

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Abstract:

In consideration of AdeLE (Adaptive e-Learning with Eye Tracking), a research project with the aim to develop and implement a solution framework for personalised e-learning based on real-time user behaviour, this paper examines the main approaches to adaptive e-learning based on a research on the history of adaptive instructional learning. Furthermore, an exemplary selection of systems resulted by these mainstreams and classified to the most important types is introduced. Concerning the examination of adaptive models and systems in the field of e-learning, we want to introduce our approach to adaptive e-learning for the research project AdeLE.

1 Introduction

Adaptive e-learning is often meant to be new or in an early development stage (e.g. see [Dietinger 2003]), but the historical development of the basic principles and realised systems are often ignored as a result of inconsistent definitions of terms or missing links between technical approaches and theoretical aspects coming from other domains like pedagogy or didactics. In particular, the problem concerning unfamiliar terms like programmed instruction, adaptive instructional design, etc. prohibits a holistic view on adaptive e-learning.

AdeLE, a research project carried out by the Department of Information Design at the University of Applied Sciences (FH JOANNEUM) and the Institute for Information Systems and Computer Media (IICM) at the Graz University of Technology, Austria, aims to research on adaptivity in the field of e-learning and to develop an innovative framework for personalised adaptive e-learning. In context of the research project this paper examines the main approaches to adaptive e-learning according to two central aspects: First, the theoretical models and their historical development are treated closer. Second, the most common types of systems implementing one or more of these approaches are pointed out and described closer. Based on the insights of this examination, the theoretical model of adaptive e-learning within the scope of the *AdeLE* research project is presented.

2 Historical Overview about different Approaches

With respect to the theoretical models of adaptive e-learning, four main approaches which are used to give a historical overview can be identified: the **macro-adaptive** approach, the **aptitude-treatment interaction** approach, the **micro-adaptive** approach and the **constructivistic-collaborative** approach. The first three approaches are restricted to an old-fashioned view on e-learning and focus on the content and the learning process itself. With respect to new learning theories and technology, the last approach treats topics like constructivism and adaptive collaboration. All four approaches will be discussed closer in the following subsections.

2.1 Macro-adaptive approach

The **macro-adaptive approach** – which can be tracked back to the early 1900s – addresses adaptation of instructions on a macro-level by allowing different alternatives in selecting a few main components such as learning objectives, levels of detail, delivery system, etc. In this approach, instructional alternatives are selected mostly on basis of the student's learning goals, general abilities, and achievement levels in the curriculum structure.

[Como et al. 1983] provides a **taxonomy** for systematic guidance, where the selection of instructional meditation depends on learning objectives (e.g. developing new skills or compensating students' weaknesses) and student aptitudes such as intellectual abilities and prior achievement, cognitive and learning styles, academic motivation and personality.

[Glaser 1977] reports about a more **praxis-oriented model** for a macro-adaptive e-learning system which supports defining preconditions for learning content, developing the appropriate competencies, adapting to the students' learning styles and achieving different types of instructional objectives according to individual needs or abilities.

2.2 Aptitude-treatment interaction approach

This approach treats adaptation of instructional strategies to specific student's characteristics. As suggested by [Cronbach 1957], an e-learning environment serving a wide range of students requires a wide range of environments suited for optimal learning of the individual. This strategy termed as **aptitude-treatment interaction (ATI)** proposes different types of instructions or even different media types for different students. Several studies have been conducted to find linkages between learning and aptitudes. The most important classes of learner characteristics can be summarized with the following ones: intellectual abilities, cognitive styles, learning styles, prior knowledge, anxiety, achievement motivation, and self-efficiency. Nevertheless, only a few experiences about the benefit for e-learning are researched.

One aspect of the ATI approach is the user's control over the learning process according to the abilities of the students by giving them full or partial control over the style of the instruction or the way through the course. [Snow 1980] defines **three levels of control**, complete independence, partial control within a given task scenario, and fixed tasks with control of pace. Several studies have shown that the success of different levels of learner control is strongly dependent on the students' aptitudes, e.g. it is better to limit the control for students with low-prior knowledge.

Despite the problems of the ATI approach, faith in this approach is still alive and the research is going on. [Carrier et al. 1988] proposes an eight-step model to provide practical guidance for applying the ATI model to the **design of courseware**. According to this model, the course designer has to identify objectives, specify the tasks, define the relevant learner characteristics with regard to the target group, determine how to adapt the instructions and design alternative treatments. This model seems to be the most praxis-oriented within the ATI research, the other ATI approaches are considered to be very theoretical, problematic or time-consuming.

2.3 Micro-adaptive approach

The third main approach to adaptive instructional learning addresses **adaptation of instructions on a micro-level** by diagnosing the student's specific learning needs during instruction and providing instructional prescriptions for these needs. Researchers have attempted to establish micro-adaptive instructional models using on-task rather than pre-task measures. Monitoring the user's behaviour and performance, such as response errors, response latencies, emotional states, etc. can be used for optimizing instructional treatments

and sequences on a very refined scale (see [Frederico 1983]). The oldest model for the micro-adaptive approach is the idea of programmed instruction originally applied by [Pressey 1926].
Using technology, a number of **micro-adaptive instructional models** have been developed which differ from programmed instruction techniques by implementing a particular model or theory of learning. A micro-adaptive model uses the temporal nature of learner abilities and characteristics, especially the dynamically changing ones. As described by [Suppes et al. 1976], most micro-adaptive models adjust learning content during instruction on the basis of a quantitative representation of learner traits. With respect to existing models such as the mathematical model, the trajectory model, the Bayesian model, the algorithmic approach, and so forth, micro-adaptive instructional learning is mainly capable to adapt to a few instructional variables, e.g. to the amount of content to be presented or the presentation sequence of the content.

Adaptive e-learning in terms of the micro-adaptive approach is comparable to a one-on-one tutoring and has to be separated in two main processes: The first part can be characterised as a **diagnostic process** assessing learner characteristics, e.g. aptitudes or prior knowledge, and indices of the task, like difficulty level, content structure or conceptual attributes (see [Rothen et al. 1978]). The second part of micro-adaptive instruction can be described as a **prescriptive process** optimizing the interaction between the learner and the task by systematically adapting the composition and sequencing of learning content to the students' aptitudes and recent performance. It is necessary to define a strategy for selecting the optimal amount of instruction and time to achieve a given objective.

Another aspect of micro-adaptive instructional learning is **response sensitivity**. Basically, computer-based learning systems apply to simple student-computer interactions such as multiple-choice, short-answer types, etc. Until the late 1960s, technology was not far enough to implement response-sensitive diagnostic and prescriptive algorithms outside a laboratory, but the development of computers and other digital devices, like eye-trackers, provide powerful tools for enhancing response sensitivity in micro-adaptive learning systems.

Finally, **interactive communication** is an important element in adaptive instruction. The development of a powerful instructional system requires a communication model which considers the process of interactions between the student and the tutor. Therefore, [Seidel et al. 1969] defines two channels for the learning process, the teaching channel to provide the content and the assessment channel to observe the learning progress.

2.4 Constructivistic-collaborative approach

The forth approach focuses on modern aspects about how an e-learning system can be used within the learning process and follows the constructivistic pedagogical approach. An important element of this approach is the usage of collaborative technologies which are considered often as essential component of e-learning (see [Lennon et al. 2003]). During the eighties and early nineties, adaptive computer-based instructions focused mainly on the acquisition of conceptual knowledge and procedural skills (see [Andriessen et al. 1999]). Computer-based learning systems are criticised by many researchers for their limited ranges and adaptability of teaching actions compared to rich tactics and strategies employed by human expert teachers. In the late nineties, researchers began to examine approaches such as collaborative and constructivistic learning, motivational competence, etc. in adaptive instructional systems.

By the means of the **constructivist learning theory**, the learner plays an active role in the learning process constructing his own knowledge through experiences in a context in which the target domain is integrated. [Akhras et al. 2000] argues that constructivistic learning may benefit from a system's intelligence including mechanisms of knowledge representation, reasoning, and decision making. Therefore, an adaptive system enables learning by focusing on how knowledge is learned and should consider the context, learning activities, cognitive structures of the content, and the time extension.

Some new adaptive e-learning systems take account of students' **motivational factors** combining the instructional plan with a "motivational" plan. As pointed out by [Wasson 1990], the instructional planning can be divided into two streams, a content planning for selecting the next topic to teach and a delivery planning for determining how to teach the selected topic. Motivational components should be considered within delivery planning.

A new pedagogical approach of adaptive instructional systems is to support **collaborative learning activities** which can be a powerful learning experience as proven by studies. [Soller 2001] identified five characteristics of effective collaborative learning: participation, social behaviour, performance analysis, group processing and conversation skills, and primitive interaction. Based on these characteristics, she listed components for a collaborative learning system, such as a collaborative learning skill coach, an instructional planner, a student or group model, a learning companion, and a personal learning assistant. Using such components, adaptive e-learning can be extended from an individual learner to a group of learners.

3 Types of Systems

This section examines existing e-learning systems and technologies by means of the previously introduced theoretical approaches for adaptive instructional learning. Pure macro-adaptive systems and hybrid solutions (computer-managed instructional systems, intelligent tutoring systems and adaptive hypermedia systems) are, respectively, presented. Finally, some interesting modern technologies and solution approaches, which currently extend the functionality of traditional e-learning systems, are pointed out.

3.1 Macro-adaptive instructional systems

Early attempts of adaptive instruction followed the basic ideas of the macro-adaptive approach because students were simply tracked by grades or scores from ability tests. In the early 1900s a number of adaptive systems were developed to accommodate different student abilities in a better way. [Reiser 1987] describes some of these early projects such as the **Burke plan**, the **Dalton plan**, and the **Winnetka plan**, where students were allowed to go through the materials at their own pace. Since macro-adaptive instruction is regularly used within a class, it often includes elements like explaining or presenting specific information, asking questions to monitor the learning process, and providing appropriate feedback for students.

In 1963, a macro-adaptive system called the **Keller plan** was developed at the Columbia University (see [Keller 1968]). This system provided personalisation for each student and offered features like required mastery to proceed to the next unit, usage of textbooks and workbooks, etc. The system **Program for Learning in Accordance with Needs (PLAN)** realised in 1967 provided students with options for selecting different instructional objectives and learning materials (see [Flanagan et al. 1975]). In the early 1970s, more than 100 elementary schools participated in this program.

A more comprehensive macro-adaptive instructional system, called **Individually Guide Education (IGE)**, was developed at the University of Wisconsin in 1965 (see [Klausmeier 1976]). In IGE, instructional objectives are first determined for each student on basis on academically profile including diagnostic assessments, previous achievements, and other aptitude and motivation data. This information about the student allows the teacher to determine necessary guidance and select alternative instructional materials, e.g. text, audiovisuals, and group activities, as well as interactions with other students.

According to [Glaser 1977], the **Individually Prescribed Instructional System (IPI)** was developed at the University of Pittsburgh in 1964 to provide students with adaptive instructional environments. In the IPI, diagnoses are made before, while and after a unit to adapt the instruction to prior knowledge and learning objectives and to determine the

student’s mastery. Extending the IPI with more varied types of diagnosis methods, remedial activities, and instructional prescriptions, the **Adaptive Learning Environments Model (ALEM)** was developed, as pointed out in [Wang 1980]. This system provides extended features like a mighty instructional management, guidance for parental involvements at home in learning activities, procedures for team teaching and group activities, etc.
These macro-adaptive instructional programs just described, are representative examples that have been used in existing educational systems. Most of these initiatives have had a common practice in many school classrooms for a long time, although the adaptive procedures have been mostly unsystematic and primitive, as shown in the last section.

3.2 Computer-managed Instructional Systems

Another type of system following the macro-adaptive approach is the class of **Computer-managed Instructional (CMI)** systems. As described in [Park et al. 2003], CMI systems have functions to diagnose student learning needs and prescribe instructional activities appropriate for these needs. For example, the Plato Learning Management (PLM) system provides tests on different levels of instruction, such as an instructional module, a lesson, a course, and a curriculum. According to the performance of a student, specific instructional prescriptions like repeating the assessment or the whole unit, offering additional instructions for a course, etc. are provided. When mastery of all objectives in the module has been reached, a student may proceed to the next module.
CMI systems provide many important macro-adaptive instructional features allowing the instructor to monitor and control the student’s learning activities. However, [Ross et al. 1988] describes the development of a CMI system implementing features of **macro- and micro-adaptive models**. In contrary to other macro-adaptive instructional systems and programs, CMI systems are much more effective in terms of adaptive e-learning.

3.3 Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITS) are adaptive instructional systems developed with the application of AI techniques. [Shute et al. 1995] mentions that ITSs are developed to resemble the process of the one-on-one learning process between the teacher and a student. ITSs have to represent the content to be thought, implement the instructional strategy and provide mechanism for understanding what the student does and does not know. These features can be summarised with the following components: the **expertise module** evaluating the student’s performance and generating instructional contents, the **student-modelling module** assessing the student’s current state and determining his conceptions and reasoning strategies, and the **tutoring module** selecting instructional material and presenting it.
[Tennyson et al. 1988] proposes a **two-level model of adaptive instruction** combining micro-adaptive instructions and aptitude variables: First, this computer-based model allows the expertise module to establish conditions of instruction based on the learner’s characteristics. Second, the tutoring module provides moment-to-moment adjustment of instructional conditions by adapting the amount of information, example formats, display time, sequence of instruction, etc. The micro-level adaptation takes place on the learner’s on-task performance. The procedure itself can be considered as response sensitive.
AI methods can be used for the representation of knowledge or natural language dialogues to adapt the contents to the student and allow a more flexible interaction with the system. ITS techniques provide powerful tools for effectively capturing the learning and teaching process. However, critics of ITS claim that developers have failed to incorporate many valuable learning principles and instructional strategies by researchers and educators. Theoretical issues about how to learn and teach with emerging technology, including AI, remain the most challenging problems.

3.4 Adaptive Hypermedia

In the early 1990s, **Adaptive Hypermedia Systems (AHS)** inspired by ITSs were born. AHSs try to combine adaptive instructional systems and hypermedia-based systems, where adaptive and user-model-based interfaces were integrated into hypermedia systems (see [Eklund et al. 2000]). An AHS should be based on hypertext link principles, have a domain model and be capable of modifying some visible or functional parts of the system on basis of the information contained in the user model. AHSs have been employed for educational systems, e-commerce applications, information systems, and help systems. Because of its popularity and accessibility, the Internet is focussed by most adaptive systems since 1996.

Adaptive hypermedia methods mainly can be divided into two areas of adaptation, the **content-level adaptation** or adaptive presentation, where the content is assembled or presented in different ways or orders (see [De Bra 2000]), and the **link-level adaptation** or adaptive navigation support, where links are generated according to different methods like direct guidance, adaptive sorting, adaptive annotation, and link hiding, disabling and removal (see [Brusilovsky 2000]). As an example for direct guidance, the system ELM-ART generates additionally dynamic links to connect to the next most relevant node to visit. In contrary, the HYPERTUTOR system hides links which are not relevant for the user's current task. InterBook and AHM are other examples for hypermedia systems applying the annotation technique, where links are named according to the user's knowledge.

The introduction of hypermedia has had a great impact on adaptive instructional systems. While other kind of adaptive systems cannot be realised without programming skills, the adaptive courses for AHS can be created with recent authoring tools, e.g. like SmexWeb. However, there are some limitations of AHS: Usually they are theoretically or empirically not well founded. Also, [De Bra 2000] points out that the user may be guided to pages not relevant or not understandable for the user, if prerequisite relationships in AHS are wrong or omitted by the user. Furthermore, evaluation the learner's state of knowledge is the most critical factor for the successful implementation of an AHS.

3.5 Other technologies in the field of adaptive e-learning

As new pedagogical approaches and technologies came up, adaptive e-learning was extended by innovative systems. The paradigm of **constructivistic learning** brought up systems like Intelligent Constructivistic Environment for Software Engineering learning (INCENSE) as described by [Akhras et al. 2000]. INCENSE is capable of analysing a time-extended process of interaction between learner and a set of software-engineering situations to provide a learning situation based on the learner's goals to support further processes of learning experiences rather than acquisition of target knowledge. As described by [Garcia et al. 2001], HERMANA, a dynamic background library, can be used in terms of constructivistic learning to provide dynamic and up-to-date knowledge managed by experts.

[Gredler 2003] gives an overview about **games and simulations**, which can be used to mediate a model to the learner or provide a journey through a domain on a playful way. Adaptation can be realised by different levels of complexity, levels of speed, or even tutoring components. As examples like Underwater SeaQuest or SimCity point out, these kinds of elements are not only applicable for children, but also for grown-ups.

Systems considering the **motivational state** of the learner try to incorporate gaze, gesture, nonverbal feedback, etc. to detect and increase students' motivation. For example, COSMO includes a pedagogical agent that can adapt its facial expression, its tone of voice, its gesture, etc. during its interactions with learners. Another system named MORE detects the student's motivational state and reacts to motivate distracted, less confident or discontented students (see [du Boulay et al. 2001]).

Finally, systems implementing **adaptive collaborative e-learning** can be classified in terms of the system's application. Computer-based collaborative tasks (CBTC) like the Envisioning

Machines support group learning and group activity by presenting a task for the group and providing collaboration via intelligent coaching. Cooperative tools (CT) like the Case-based Reasoning Tool or the Writing Partner describe systems that may take over some of the burden of lower-order tasks while students work with higher-order activities. Furthermore, intelligent cooperative systems (ICS) like DSA and PeoplePower can be seen as an intelligent cooperative partner, a co-learner or a learning companion. Computer-supported collaborative learning (CSCL) systems serve as communication interface such as chat tool or discussion group, which allows students to involve collaboration. Systems of this category provide the least adaptability to learners.

4 Application for *AdeLE*

With respect to the research project *AdeLE*, we want to explain our perception of adaptive e-learning and point out components necessary for an ideal adaptive e-learning system.

4.1 An approach to an ideal model of adaptive e-learning

Adaptive e-learning has to consider the theoretical approaches from section 2:

- According to the macro-adaptive approach, it is necessary to provide a mighty curriculum allowing instructional elements like instructions, modules, lectures, courses, etc. and adaptation in terms of didactical aspects, such as different levels of detail, explanation models, interactivity levels, links to domains or tasks, possibilities for content aggregation, and rules for sequencing instructions. Learning objectives which have to be set up for each instructional element can be seen as constraints within such an enriched curriculum. Besides, conditions for a course, lecture or module can be defined before and after this instructional element.
- Derived from the ATI approach, it is necessary to extend the curriculum according to different target groups, e.g. by media types, sequencing rules, content aggregation and presentation, etc. Furthermore, the content also can consider the user's control about the learning process.
- The main impact for an ideal adaptive e-learning system comes from the micro-adaptive approach. Implementing a strategy to monitor the student's on-task performance and to adapt the learning process requires micro-adaptive models. According to [Park et al. 2003], the Bayesian probabilistic model seems to be ideal for selecting the amount of instruction determined by individual learning differences – aptitudes, prior knowledge, etc. –, while the algorithmic approach is useful for sequencing these instructions. Furthermore, the e-learning system has to care about response sensitivity and interactive communication with the students.
- Finally, the constructivistic-collaborative approach implies a lot of important aspects for adaptive e-learning. Next to the support of new pedagogical paradigms like constructivistic learning, an ideal e-learning system has to support motivational factors, e.g. by using motivating instructions like games or treating distracted, less confident or discontented student. Furthermore, it is important to consider meta-cognitive processes, e.g. special guidance, and collaborative learning activities, e.g. learning together with other students.

4.2 Components of an ideal e-learning system

According to our theoretical model of adaptive e-learning and with respect to existing systems types described in section 3, the ideal architecture of an adaptive instructional system can be divided in two main components:

- A CMI system excluding learning management functions can be seen as the ideal Learning Content Management System (LCMS) providing all necessary features concerning the learning content. Combining authoring tools and collaborative tools for instructional designers, such a system can be used to manage the extended curriculum considering the aspects of subsection 2.1. The learning content should be based on the specifications of a standard, such as SCORM (see [Mödritscher et al. 2004]).

- The Learning Management System (LMS) itself could be best realised by an AHS combined with ITS technology, e.g. an expertise and a tutoring component. The enriched learning content can be mediated by web-interface and the adaptation can be performed by aggregating and presenting instructions and by sequencing these instructions on basis of a didactical and a learner model. Furthermore, collaborative elements for the learning process are necessary.

Adaptivity itself can be implemented using AI techniques to derive rules from the content and the user's state. These rules are necessary for adapting the learning process to the needs of the student. Such a mechanism works for content aggregation and presentation, sequencing, level of control, motivational aspects as well as for collaborative activities. Learning styles and different learning theories like the Behaviourism or Cognitivism can be realised using content- and link-level adaptation. Furthermore, a dynamic background library offers support for constructivistic learning.

5 Conclusions and Future Work

As this paper points out, the idea of adaptive e-learning itself is not new. Examining single approaches of adaptive instructional learning, basic ideas and projects can be tracked back to the early 1900s, first realised systems can be found in the 1960s and 1970s. Apart from the classical approaches on content and the learning process, ideas like constructivistic learning or collaborative technologies which are at an early developmental stage can be considered as important aspect of adaptive e-learning.

Furthermore, it can be concluded that all four approaches have to be considered to receive a complete model for adaptive e-learning. Macro-adaptive models can be seen as essential basics for the teaching process. Some of the learners' aptitudes – just the most important variables for the learning process – can be combined with appropriate micro-adaptive models. The influences of new pedagogical developments and technologies need to be included to gain a holistic approach.

Considering all four approaches on adaptive instructional learning, the conceptual model of an ideal e-learning system within the scope of the research project *AdeLE* has been presented. Due to the extensive realisation of such an adaptive e-learning environment, only a few aspects can be implemented at all. However, the architectural design has to provide flexibility in terms of realising all aspects of the ideal system stepwise. Therefore, we plan to use the slightly modified e-learning specifications of the SCORM standard as well as a service-based architecture, the so-called Service-based Framework (SBF).

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