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DESIGN PRINCIPLES FOR TEACHING SIMULATION WITH EXPLORATIVE LEARNING ENVIRONMENTS

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ABSTRACT

Teaching the highly complex domain of simulation requires well-elaborated strategies for efficient education. In this paper we present a well-structured approach to define the requirements for web-based simulation courses. Our approach is based on the Essen Learning Model (ELM) (Pawlowski 2000), a development model supporting the development and specification of learning environments. The results of the Essen Learning Model development process describe the requirements for a learning environment being used in a computer based simulation course for graduate student of business information systems.

1 INTRODUCTION

Due to the enormous amount of activities in the field of educational technologies, a variety of approaches, architectures, and systems have emerged in the last decades. Current development models for the utilization of new technologies in the educational sector are insufficient, because they either focus on technology (software development models) or on didactics, e.g., didactical models.

We developed and implemented the Essen Learning Model (ELM), a generic development model supporting development processes for Computer Supported Learning Environments (CSLEs) on three levels: development of curricula, learning sequences, and learning units. The use of the Essen Learning Model enables educators, project managers, and authors to efficiently develop and implement Computer Supported Learning Environments.

At first, we briefly describe the Essen Learning Model, focusing on its main processes on the different levels. For a detailed representation see (Pawlowski 2000).

For this paper, we focus on two classes of design principles:

- General design principles (GDPs):
  - Identifying *Learning objectives*, e.g., problem solving, teamwork, or domain specific concepts.
  - Determining *User characteristics*, e.g., knowledge, or skills.
- Explorative design principles.

We explain how to utilize these principles in the Essen Learning Model, resulting in standardized specifications for a learning environment.

Based on this classification, we identify adequate didactical methods for complex learning goals. The didactical method is based on a combined approach of explorative, collaborative, and problem-oriented learning.

Finally, we present our implementation of a web-based learning environment for our simulation course. The environment supports both face-to-face and distance learning phases of the course. Our experience has shown, that this approach significantly increases the motivation and the learning performance of the students.

2 THE ESSEN LEARNING MODEL (ELM)

2.1 ELM Development Model

The Essen Learning Model is a modular system (Figure 1), supporting development processes as well as the systems' use on different levels: The support of curriculum design (C-level), the development of learning sequences (D-level), and the development of learning units (E-level) (Pawlowski 2000). We distinguish between three abstraction levels: the *generic development model* provides knowledge for a variety of contexts. This generic model is customized depending on the users' needs and preferences, and transformed into a specific process model for each development project. The *process model* is implemented using the Architecture of Integrated Information Systems (ARIS) and provides a framework for educational technology projects. ARIS is a frame concept for a global description (modeling) of computer supported information systems covering the whole life-cycle range: from business process design to information technology deployment (Scheer 1998). The third level is the *result* of the development process in the form of certain implementations for each module.

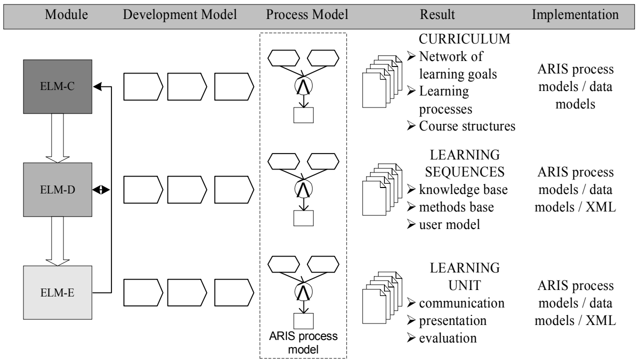

Figure 1: The Essen Learning Model

Figure 2 represents the main processes of the Essen Learning Model. The result of ELM-C is a detailed network of learning objectives and goals, determining structure and relations of learning sequences (courses). Based on these results, learning sequences are being developed in ELM-D. The focus of this phase is to find an adequate didactical method together with the right technology depending on learning objectives and user groups. Finally, single learning units are designed and implemented in ELM-E.

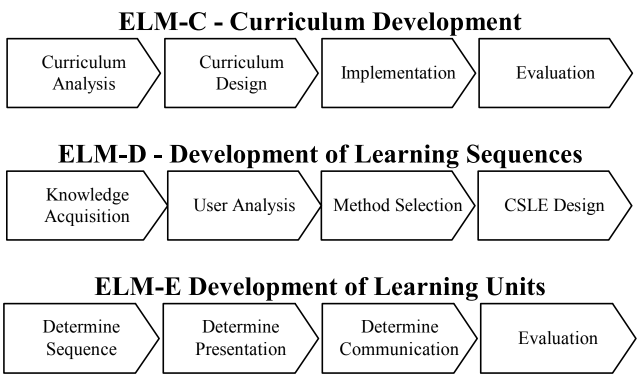

Figure 2: Main Process of the Essen Learning Model

The Essen Learning development model leads to certain design principles. These principles provide a guideline for authors and teachers in order to plan, design, and implement Computer Supported Learning Environments efficiently.

2.2 Architecture of ELM

The development process supported by ELM is based on an architecture of Computer Supported Learning Environments (CSLEs), derived from the Learning Technology Systems Architecture (LTSA) (Adelsberger et al. 1998). Figure 3 shows the components of the ELM architecture.

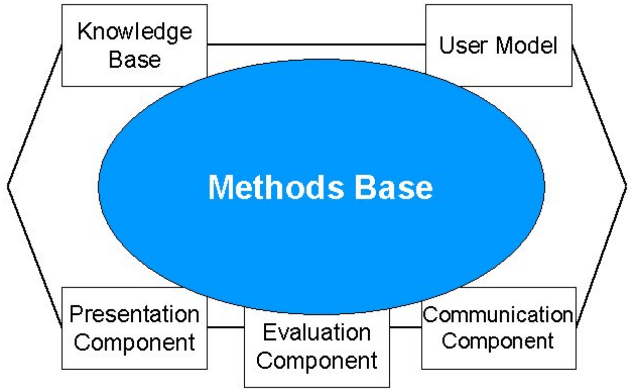

Figure 3: Essen Learning Model Architecture

The Methods Base contains different didactical methods and concepts to select a method. The author can use these concepts for teaching all kinds of learning contents. The *learning contents* and *learning objectives* are part of the Knowledge Base used by the Computer Supported Learning Environment. The User Model contains *attributes*, *characteristics,* and *knowledge of a user*. Ideally, the knowledge is represented adequately, in accordance with the User Model, e.g., learning style, etc.

3 DESIGN PRINCIPLES

In this section, we present general design principles (GDPs) for designing and developing Computer Supported Learning Environments.

GDP 1: *Successful course design depends on the quality of the following components*:

- *Knowledge Base,*
- *User Model,*
- *Methods Base,*
- *Communication Component,*
- *Presentation Component,* and
- *Evaluation Component.*

The quality of a learning environment depends on a variety of aspects. The combination of didactical, technological, and domain expertise is crucial for designing successful learning environments. Therefore, each of the components mentioned above must follow certain principles in order to meet the requirements and to increase the performance of the learners.

Following the Essen Learning Model, the design principles concerning the *knowledge base*, *user model*, *and methods base* should be applied when planning a learning sequence (e.g., a course on simulation). The principles concerning the communication, presentation, and evaluation components should be applied when planning certain learning units (e.g., a unit on simulation studies).

> **GDP 2:** *A careful analysis of the learning setting is needed. This includes the environment of the institution in which a course is held, the IT-infrastructure, educational parameters, and potential users.*

A course must be adapted or specifically designed for a certain setting. Therefore, it is necessary to analyze the learning situation carefully. E.g., the IT-knowledge of the users is a crucial parameter for the design of a learning environment. It is obvious that a group of www-inexperienced users will not be able to succeed in a web-based course.

The attributes contained in the Knowledge Base and the User Model offer the author a selection of teaching methods by means of a rule-based mechanism. The *learning objectives*, and the *user characteristics* are the important attributes concerning the development of a Computer Supported Learning Environment.

Finding an adequate didactical method, particularly for the highly complex domain of simulation, mainly depends on *learning objectives* and the *user group*. According to (Adelsberger et al. 2000), these two design principles are an integral part of the development of every Computer Supported Learning Environment and therefore of the Essen Learning Model.

3.1 Knowledge Base

> **GDP 3:** *The learning objectives of a course must be identified, structured, and classified.*

The textual formulation of learning objectives can only be used for an outline of a course. A more detailed analysis of those learning objectives is needed in order to prioritize the contents. Secondly, this analysis helps the teacher to find and to design an adequate didactical method.

Learning objectives allow to organize courses, to plan teaching strategies, and to evaluate testing techniques. Unless a course is defined in terms of learning objectives, a course author has no concrete means to measure student's success in learning the course material. Without any objectives at all, there is the danger of "teaching A and testing B". Using clear learning objectives, both the students and the instructor know where they are and what needs to be done (Center for Instructional Technology (CIT) 1997). Unfortunately, a variety of classifications of learning objectives are currently in use, often resulting in inconsistent classifications and terminologies. We suggest using a classification of learning objectives, containing the criteria *abstraction level*, *dimension*, and *kind of content*. Our suggestion is based on the work of (Moeller 1973), (Bloom 1973), and (Baumgartner, Payr 1994).

(Moeller 1973) distinguishes learning objectives between three different *abstraction levels* according to (United Nations Educational, Scientific and Cultural Organization (UNESCO) 2000):

1. *strategic*,
2. *general,* and
3. *specific*.

By means of this abstraction levels, a certain hierarchy concerning the learning objectives can be realized. For example, in the field of simulation, a strategic objective is the optimization of a production planing process. For this purpose, using simulation is a general objective. Finally, performing a simulation study in ARENA describes a specific learning objective.

Secondly, we use a classification of *dimensions*. Extending Bloom's classification of intellectual behavior (Bloom 1973), we distinguish between four dimensions:

- *cognitive*,
- *affective*,
- *psychomotor*, and
- *social.*

Cognitive learning is demonstrated by knowledge recall and intellectual skills, like: applying knowledge, comprehending information, analyzing and synthesizing data, etc.

Affective learning is demonstrated by behavior, indicating attitudes of awareness, interest, attention, concern, responsibility, and the ability to demonstrate those attitudinal characteristics or values, which are appropriate to the test situation and the field of study.

Psychomotor learning is demonstrated by physical skills: e.g., coordination, dexterity, strength, and speed.
The social dimension describes skills like the capacity for teamwork, solving conflict situations, the ability to assert oneself, etc.

In order to identify an adequate didactical method, it is necessary to identify the *complexity* of learning objectives. In our example we focus on the cognitive domain. Bloom identified six levels within this domain, from the simple recall or recognition of facts as the lowest level, through increasingly more complex and abstract mental levels, to the highest order, which is classified as evaluation:

1. *knowledge*,
2. *comprehension*,
3. *application*,
4. *analysis*,
5. *synthesis*, and
6. *evaluation*.

The third approach is the classification concerning the *kind of learning content*, according to (Baumgartner, Payr 1994):

1. *learning facts and rules* (remember, receive)
2. *rules, procedures* (apply, imitate)
3. *problem solving* (decide, select)
4. *gestalt perception*, *pattern recognition* (explore, understand)
5. *complex situation* (invent, master, cooperate).

The first level describes learning environments whose main purpose is to present and transfer contents (verbal, multimedia). The main activity of the user (interaction) is to navigate among pieces of information. The second level typically consists of exercises and tests. The learner acquires and tests procedural knowledge. On the next level, the learner is asked to deal with more complex situations by planning his own procedures. The goal of the fourth level is to perceive and holistically understand processes with their causes and effects, and to discover common characteristics and pattern in various "cases" (Baumgartner, Payr 1998). The experience of complex situations, e.g., in simulation games, offers the student the opportunity to increase his thinking flexibility, according to Kolb's learning cycle (Geuting 1989).

Determination of learning objectives. Taking into account the criteria of classifying learning objectives (e.g., *abstraction level, dimension, complexity*, *and learning content*), we specified learning objectives for our simulation course (Table 1).

In our course we focus on the basic methods and concepts of simulation. The students learn how to model, implement, and evaluate simulation systems for specific manufacturing problems in selected simulation languages.

3.2 User Model

GDP 4: *The learning environment must be adapted to certain user characteristics.*

In todays learning settings, courses are held for users with different experiences, background, interests, and preferences. In order to tailor a course to individual needs of a user (and to improve the learning experience), a detailed analysis of the potential user group is needed. The crucial point is to provide an individualized context. In our case, students with a business and an information systems background participate in the same course. Therefore, we provide different examples (business cases and information system cases).

User characteristics. The majority of learning environments do not use standardized specifications in order to support the exchange of materials. To overcome those weaknesses, several standardization projects have been started. The most promising approach in the field of characterizing users is the Public And Private Information specification (PAPI), which intends to be an IEEE Standard. The PAPI Learner Specification aims on portable student records, addressing privacy and security issues in a distance, distributed, and nomadic learning environment (Learning Technology Standards Committee (LSTC) 2000). It is divided in four sections:

- personal information,
- performance information,
- portfolio information, and
- preference information,

to cover the whole information of a user.

Nevertheless, this specification is still a draft and it is not foreseeable when it will become a standard, due to difficult legal and ethic discussions.

Taking into consideration the lack of a standardized user description, we decided to use the Berlin Model (BM) to bridge this gap since it is well accepted and elaborated.

The **Berlin Model** (Schulz 1965) is a didactical model concerning the analysis and construction of learning sequences. The user analysis focuses on *social / cultural*, and *anthropogenic* characteristics.

Social / cultural characteristics are described by:

- policies concerning the educational system,
- curricula, and
- public policies supporting the evolution to an information society.

Anthropogenic characteristics are:

- differences between teacher / learner,
- knowledge,
- skills,
- capabilities,
- social origin, and
- motivation.

In our approach, we generalize the Berlin Model characteristics according to noncritical attributes of the Public And Private Information draft (Table 2). Combining an existing standard for user characteristics with the upcoming standard, we support a format for the interchange, reuse, and the combination of user characteristics.

Table 1: Extract of a Learning Objectives Network

abstraction level strategic	general	specific	dimension	complexity	content
Applying the concept of simulation in the context of manufacturing enterprises			social: ▪ capacity of teamwork ▪ decision-making ability ▪ performing simulation studies in small teams	Evaluation	complex situation
	Definitions, concepts, and applications of simulation		affective	comprehension	facts & rules
		Definition of simulation	cognitive	knowledge	facts & rules
		Theory of modeling and simulation	cognitive	application	complex situation
		Fundamental Simulation concepts	cognitive	comprehension	facts & rules / procedure
	Event-driven hand simulation		affective	application	problem solving
	Simulation languages:		cognitive	comprehension	problem solving
		Concepts of simulation languages	cognitive / affective	comprehension	facts & rules / procedures
		Continuous and discrete simulation languages	cognitive	comprehension	problem solving
	Survey of selected simulation languages & systems		cognitive	analysis	gestalt perception
		GPSS	cognitive	comprehension	gestalt perception
		SLAM	cognitive	comprehension	gestalt perception
		SIMAN	cognitive	comprehension	gestalt perception
		AutoMod	cognitive	comprehension	gestalt perception
		Taylor – ED	cognitive	comprehension	gestalt perception
		eM-Plant	cognitive	comprehension	gestalt perception
	Simulation studies		cognitive / affective	evaluation	complex situation
		Problem formulation	cognitive	analysis	gestalt perception
		Solution methodology	cognitive	application	problem solving
		System and simulation specification	cognitive	synthesis	rules, procedure / problem solving
		Model formulation and construction	cognitive	synthesis	complex situation
		Verification and validation	cognitive	evaluation	problem solving
		Experimentation and analysis	cognitive	synthesis	problem solving
		Presenting and preserving the results	cognitive	application	problem solving
		Interpreting the results	cognitive / affective	evaluation	gestalt perception
		Implementation and documentation	cognitive	synthesis	problem solving
		Comparing and benchmarking of alternative system models	cognitive / affective	evaluation	gestalt perception
	Simulation with SIMAN		cognitive	application	complex situation
		Model frame	cognitive	application	procedures / problem solving
		Experimental frame	cognitive	application	procedures / problem solving
		(Primary) SIMAN blocks and elements	cognitive	application	procedures / problem solving
		Basic Interaction	cognitive	application	procedures / problem solving

Table 2: User Model

Type	Description	Sample Attributes
Personal	general private information, not directly related to the learner's performance	name, address, age, sex
Preference	user's preferences and characteristics	learning style, location
Performance	past, present, and future information about the user's learning performance	Timestamps, performance coding, certification
Portfolio	a collection of user's achievements and works	certificates, courses, skills

3.3 Methods Base

Based on the specifications in 3.1. and 3.2., we suggest two principles concerning the methods design process, leading to a high quality learning environment.

GDP 5: *The didactical method must be chosen carefully, based on learning objectives, learner characteristics, and teacher experiences.*

For complex learning objectives (such as gestalt perception in a simulation study), "traditional" methods like face-to-face lectures will lead to insufficient learning results. Hence, we use a rule base to suggest promising methods for classes of learning objectives. In the case of our simulation course, we found that a combination of face-to-face and distance learning phases would be helpful for the learners. Furthermore, we made the experience that a single method does not fit for the variety of learning objectives. Therefore, we chose different methods for different phases of the course.

GDP 6: *The quality of a course must be evaluated continuously.*

Considering the rapidly changing developments in the field of Information and Communication Technology in general and specifically in simulation, continuous quality assurance must be part of the design process. The actuality of a course, and the design of the components mentioned above must be evaluated internally by students and teachers and by an external advisory board. In the future, we expect international quality standards for courses on different educational levels.

4 DESIGN AND IMPLEMENTATION OF AN EXPLORATIVE LEARNING ENVIRONMENT

The principles mentioned in Section 3 shall be applied in the general design process of learning sequences (respectively courses). We developed and implemented the learning sequences for a web-based simulation course, based on the specified learning objectives and the provided user characteristics.

Firstly, we describe the learning settings of our course. In the next paragraph we formulate more specific design principles (SDPs) for the design of explorative learning environments, derived from our experiences with explorative learning environments.

An important design issue is the selection of a didactical method. As already mentioned, this selection process is rule based in ELM, depending on learning objectives, contents, and user characteristics. We transformed the general objectives, e.g., event-driven hand simulation, in learning sequences / phases. For each phase, we chose the learning objectives with the highest priority. The teaching methods selection is based on these priority objectives according to the general learning objectives and its corresponding specific objectives (Table 3).

Table 3: Extract of the Didactical Methods Selection

phase	priority objectives	Teaching method
Definitions, concepts, and applications of simulation	• *dimension*: cognitive • *complexity*: knowledge • *content*: facts & rules	• (computer-supported) face-to-face (lectures)
Simulation studies	• *dimension*: cognitive, social • *complexity*: evaluation • *content*: complex situation	1. face-to-face 2. case study 3. computer-supported simulation game
SIMAN	• *dimension*: cognitive • *complexity*: application • *content*: gestalt recognition	• tutorial • web-based explorative learning environment

Following the design principles for explorative learning environments, we implemented our departments web-based simulation course on four levels:

- lectures
- case study / simulation game
- tutorial (programming laboratory)
- explorative web-based learning environment.

This solution offers the opportunity of face-to-face and distance learning phases of the course, including collaborative aspects.

The students can tailor the CSLE to their preferences, e.g., individual learning pace, preferred learning method, and preferred presentation format.

Combining the distance learning phase with the tutorial into a synchronous and asynchronous sequence, offers the possibility to take social aspects into account, e.g., communication with other participants and the tutor.

SDP 1: *Learners shall be able to freely operate in the learning environment.*

Using explorative learning environments significantly changes the typical role of a teacher. The user himself is responsible for the success of the learning process. He should be able to navigate within the environment and to explore certain problems. The teacher can only moderate and guide the process. This rather unusual teaching method is new for most students to avoid irritation, the teacher has to make students aware of this immediately at the beginning of the course. In our case, this was provided in a face-to-face session. During the distance learning phases, the users were supported by each other and by the teacher when they needed suggestions for the continuation of the learning process.

SDP 2: *The learning environment must be adapted to the users context.*

To ease the handling of the learning environment, we provided applications, which were familiar to the users. This leads to an easier understanding of the basic concepts of simulation. In a second phase, new contexts were provided, so the users can abstract and therefore understand more complex contents.

SDP 3: *The communication structure of a course must be adapted individually.*

In the presented approach, we followed the scaffolding approach. In the first phase, the user was provided with problem solving and navigational skills. In this phase, the tutorial effort was higher than in a traditional course. Later in the course, the tutoring effort was decreased, increasing the student's responsibility. The evaluation of the course showed that the communication needs have to be adapted during the course, based on the students progress.

SDP 4: *The presentation of the contents shall be adapted to the users preferences.*

Learners prefer different presentation formats (e.g., graphics, animations, videos). We provided a variety of learning materials in different formats, offering a choice for the learner. It is obvious that even well elaborated multimedia presentations might not help certain learning styles. Therefore, it is necessary to provide different perspectives on the learning content.

SDP 5: *The performance of a student shall be measured by individualized assessments.*

The variety of learning objectives in a simulation course leads to a complex testing structure. Simple tests do not reflect the learning performance of the students. Therefore, we chose a combination of "traditional" assessments, problem solving tests, and discussions.

This explorative learning environment (Figure 4 and Figure 5) significantly increases the motivation and the learning performance of the participants.

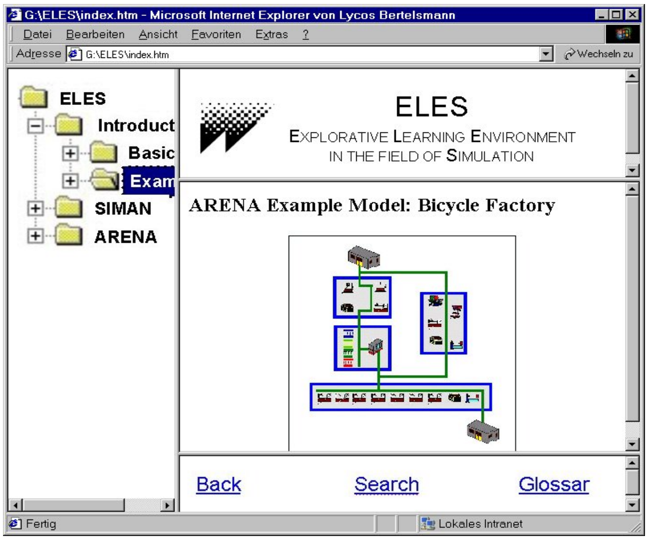

Figure 4: Web-Based Learning Environment

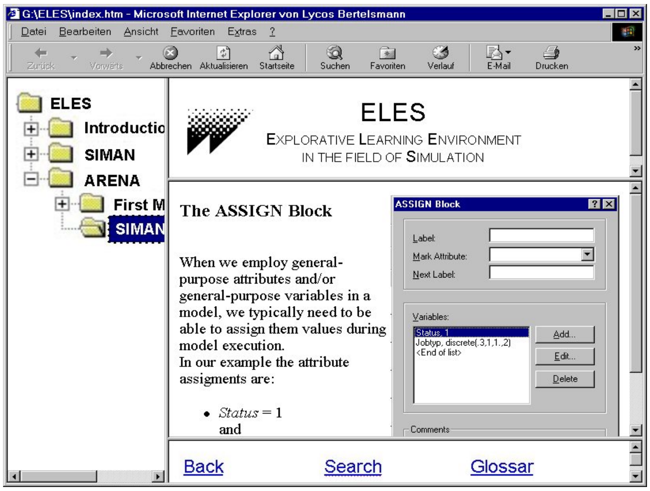

Figure 5: Web-Based Learning Environment

5 CONCLUSION

We described the importance of using a multilevel-development model supporting the development process for Computer Supported Learning Environments. We presented six general design principles a described how to utilize them teaching the highly complex domain of simulation.

In this paper we focused on identifying learning objectives and determining user characteristics, which both highly influence the decision of an adequate teaching method.

The web-based learning environment ELES is a first implementation of this approach and strictly follows the design principles presented in this paper.

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