E-LEARNING USABILITY: A LEARNER-ADAPTED APPROACH BASED ON THE EVALUATION OF LEARNER’S PREFERENCES

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Abstract: E-learning usability is a goal of the user - centred e-learning design. Its achievement depends on the determination of the requirements, characteristics and preferences of the users of an e-learning system or environment (learner, teacher and administrator of an educational process). This paper presents different aspects of e-learning usability. One of them requires an evaluation of learner’s preferences that determines the individual learning style of a learner. The results of this evaluation are necessary for learner modeling. The learner model has to influence the teacher activity in process of producing learning resources in harmony with the learning style of the learner. It is obviously that the determination of learner’ preferences is an element of the adaptation technique that ensures the development of an adaptive e-learning environment.

The creation of an adaptive e-learning environment depends on the technique of learner’s preferences evaluation. This paper presents an approach to evaluation of human’s preferences. The mathematical formulation of this approach serves for basis of tool development. A usage of this tool in the evaluation of learner’s preferences is illustrated.

Key words: E-learning Usability, Adaptive E-learning Environment, Utility Function, Evaluation, User Centred Design

INTRODUCTION

E-learning is an implementation of a teaching-learning (education) process in a computer-based environment. There are two main approaches to e-learning development, which result in different usages of computers in education. The first approach uses a process-oriented design model in the development of an e-learning system. In this case the computer technologies are used to support teacher activities i.e. carrying out the teaching process. This approach coincides with the teacher’s viewpoint about e-learning. The second approach bases on the service-oriented design model. According to it, the computer technologies are necessary for the realization of an e-learning environment that provides different forms of learning interactions. This aspect of e-learning development presents the viewpoint of an active learner with respect to the way of using computer technologies.

The evolution of process-oriented e-learning systems requires an
increasing of their capacity. They have to support a richer set of teacher activities that have to be in harmony with learner’s preferences. We distinguish three steps in the development of process-oriented e-learning systems:

- E-learning systems that ensure a teacher activity – knowledge delivery (blended learning);
- Learning management systems;
- Adaptive Web-based educational systems.

The conception of blended learning conceives of the idea that the teaching is a process of transferring knowledge (Singh, H., Reed, Ch., 2001). This kind of learning considers the education as a process of knowledge delivery. The e-learning systems that realize this idea support only one teacher activity - knowledge delivering. There are different methods of knowledge delivering that are in line with the different forms of learning (delivery options):

- Offline and online learning;
- Self-paced and live learning;
- Formal and informal learning;
- Structured and unstructured learning.

All these forms of learning are implemented by transfer procedures (delivery formats). Some of them are synchronous physical formats, synchronous online formats, self-paced asynchronous formats and etc. The e-learning systems that ensure simultaneously different delivery modes realize the conception of blended learning.

The learning management systems (LMS) cover various teaching, learning and administrative functions (Pasini, http://www.isal.cmu.edu/). They support the following teaching functions: authoring, classroom management, knowledge management, certification and training, personalization, mentoring, video conferencing and discussion boards. Generally speaking, LMS support a school administrator and teachers to achieve his educational objectives and ensure variety of learning resources.

The Adaptive Web-Based Educational Systems (AWBES) are the third step in the evolution of the process-oriented e-learning systems (Aroyo, L., Dicheva, D., 2004). They attempt to employ the Web technologies in order to achieve improved adaptation and flexibility for single or group users - administrators, teachers, instructors and learners. Furthermore, such educational systems apply new methods and types of courseware compliant with the Semantic Web vision. This promising class AWBES forms the basis of the emerging Educational Semantic Web. Their realization guarantees the achievement of interoperability among various education systems.
In service-oriented e-learning systems, the teachers are a side of an education system that supplies the learners with learning resources. From the viewpoint of a learner this side is a learning environment, in which one or more learners work. The learning environment is a factor of successful performance of a learning process. It ensures learning objects and services necessary for the learning process. The service-oriented e-learning system supports the learning environment (e-learning environment) that is considered as a virtual computer system, with which the learners interact (Kay, J., 2001). In this way, the e-learning environment is presented by a single entity that is in bidirectional connection with learners.

The second section considers the usability aspect of e-learning design. The third section describes elements of our adaptation model that ensures an adaptive e-learning environment. According to this model, the learning resources are adapted to learner’s preferences. The next section presents an approach to evaluation of learner’s preferences. The fifth section gives an example of learner modeling and determination of the preferences of a concrete learner about the form of learner assessment.

E-LEARNING USABILITY

E-learning design as each one design process has two aspects that originate a constructive design approach and an approach to harmonization with the user(s). The constructive aspect of e-learning design is presented by the process-oriented and service-oriented design models. E-learning design is a constructive task that organizes the components of a computer-based environment in conformance with these models. In process-oriented e-learning design the computer technology is used for the purposes of a teacher/school administrator. The service-oriented e-learning systems guarantee the framework of an e-learning environment that supplies learners with learning resources (Fig. 1.). The development of an e-learning environment has to ensure not only learning objects, but the realization of different didactical methods: constructivist learning, collaborative learning, problem-based learning and etc.

The learning resources perform a dual role: they are products of instructor activities and elements of a learner-instructor interface. This interface meets the needs of the learner(s) during the educational process. The learning resources have to ensure all possible types of interaction between a learner and a teacher in an e-learning environment. These interactions present e-learning activities that include all learner and teacher activities. The learning resources are a consequence of the educational activities that support the implementation of different instructional strategies.
(Mehlenbacher, B., 2002): the identification, evaluation and integration of a variety of information; collaboration, discussion and communication of ideas; participating in simulated experience, apprenticeships and cognitive partnership; the examination of learners. At the same time, the learning resources support the following learner activities:

- Accessing information – learners identify instructional materials relevant to their educational objectives and access them;
- Scanning information – learners search for particular headings, information items or instructions related to their problem representation;
- Understanding information;
- Transferring information during a discussion, exercises, etc.

Fig. 1 E-learning design

The harmonization of e-learning with its users is an objective of the user-centered design. The latter is closely linked with the concept of usability, which comes from the field of Human Factors (also known as Ergonomics). Human Factors is a form of engineering, which puts the human at the centre of design rather than machines and equipments. The user-centered design takes as its basic premise the view that product development should be driven from user requirements and preferences rather than from technological capabilities. Hence, the constructive aspect of e-learning
design presents a system-oriented approach to design. According to the system theory e-learning can be a system, if its parts interact with one another to form an aggregate unified system. In this system the human being is considered as a user and the computer implements a computer-based application system. The integration of these two heterogeneous parts requires the harmonization of their relationships. An approach to achievement of this goal is the creation of user-adapted e-learning systems.

Usability is about producing products and systems that are easy to use and suitable for consuming by individual users. Usability engineering and user-centered design help designers to ensure that their product and system will meet the needs of the users for whom it is intended. This approach requires modeling and identification of the users that will use a service or product. The factors of user modeling are product characteristics.

The usability characterizes the interaction between a person and a computer-based system and its products. For the clear determination, the concept of usability is broken down into the following measurable elements: effectiveness (the ability to achieve specific goals and perform certain tasks in the environment), efficiency (in terms of used resources and time for task support), usefulness (should do anything that we expect to do and serve a purpose), users’ satisfaction (including encouraging users) and learnability (the ease and speed with which users can comprehend how to use a product in order to learn effectively and retain the skills and knowledge).

We share the view that e-learning usability has two main aspects: the usability of e-learning systems and the efficiency of computer-based teaching process that produces “learner fit” learning resources. When it is considered the e-learning system usability the focus is on the assessment of the effectiveness and efficiency of the computer technologies that are implemented for supporting of teacher/administrator tasks (Storey, M. A., et al., 2002). This assessment usually bases on usability tests, field studies and heuristic evaluation (Miller, M. J. http://www.learningcircuits.org). At the other hand, the efficiency of a teaching process determines the usability of the e-learning environment that is closely connected with the effectiveness learning process.

This paper presents an approach to the production of usable e-learning resources that have to ensure effective learner activities, i.e. a usable learner-instructor interface in order to achieve their mutual educational goal. Since the usable interface is guaranteed by adaptive interactions, we suggest achievement of e-learning usability by the production of learning resources that fit best the learner. It is a part of the development of an adaptive e-learning environment that depends on the used adaptation technique...
The latter is determined by the answers of the following questions: what would be adapted, how it is to be adapted and what is the condition it is to be adapted to. We propose technique to adapt learning resources, which are a component of the learning environment, to the main characteristics and preferences of their users - learners. The realization of this approach is connected to a relatively new direction of research on the crossroads of user modeling and user-centered design of computer-based systems (Winograd 1995, Brusilovski 2001).

ELEMENTS OF THE USED ADAPTATION TECHNIQUE

The usability of e-learning resources can be viewed from both sides of education - teachers and learners. They work together for achievement of one and the same educational goal. From teacher’s point of view usability is grounded on designing reusable learning materials, which could be reused in different context, based on constructive learning theory and applying variety of pedagogical approaches and instructional scenarios in order to achieve declared educational goal. From student’s point of view, usability means to be available such learning resources and services allowing them to find this ones that fit with learner’s goal, knowledge and preferences. Therefore usable learner-teacher interface has to be:

• Useful – to help achieving predefined educational goal through providing appropriate learning materials and conditions;
• Effective – to allow easily performing of all learning activities in a quick and proficient manner;
• Adaptable – to allow variety paths in the process of knowledge acquisition and checking, i.e. some kind of personalisation;
• Encouraging – allowing users to perform their best.

Usually usability of some product is evaluated a posterior. They test already created product if it satisfies some heuristics or tests (Miller, M. J., http://www.learningcircuits.org). We assert that this approach isn’t appropriate in case of the learning process implementation. If one discovers at the end of some learning course that it is not usable, i.e. learners couldn’t perform their tasks and assignments successfully, it will be total waste of time and will discourage learners from attending courses. This situation can be avoided if the teachers ensure the achievement of e-learning usability through a priory identification of the learners. The necessary information about student’s characteristics could be derived from inquiry (Mehlenbacher, (Paramythis, A., S., http://www.fim.uni-linz.ac.at/Publication/Paramythis/Adaptive_Learning_Environment_eLearning_Standards))
user modelling, teacher’s previous experience, pedagogy theory and practice.

In our work we use elements of user modelling which involves inferring unobservable information about the user from observable information about him/her, e.g. his/her actions or utterances. The user modeling techniques can be classified by type of modeling method, by approach to model creation and by modeling objectives. There are two types of user modeling methods: empirical methods and reasoning-based (theoretic) methods. The empirical user modeling techniques use both explicit and implicit user model acquisition to determine the user’s characteristics or attributes (Zukerman and Litman, 2001). The reasoning-based methods realize substantiated subjective user modeling that makes user models through concepts. The classification of modeling techniques in correspondence with the modeling objectives depends on the type of user models that the corresponding technique creates. The classification of the user models depends on the following aspects:

- Models of direct and indirect users;
- Models of user’s characteristics, background, knowledge, preferences, interests and individual traits;
- Stereotypical user model or updating user model.

The direct user model represents a user who interacts with an application system and determines its output (system products). This model concerns the creation of an adaptive user-computer dialogue and guarantees adaptive control of the system. The model of an indirect user helps the creation of usable system products. The stereotypical model is a result of a modelling approach that qualifies the behaviour or preferences of a group of users in certain circumstances as similar and they are represented by a fixed (constant) user model. The updating user model bases on a preliminary user model that is update in accordance with the actual user behaviour. In many cases, we are not interested in user modelling in any general sense, but only in correspondence with the purposes for which user models are formed. For this reason, there are different models for the representation of user’s characteristics, preferences (attributes), interests or background.

Taking into consideration the usability research, we can summarize the main learners’ characteristics as follows:

- Literacy – computer, domain knowledge;
- Cognitive abilities – educational level, knowledge background, testing ability;
- Personal abilities and preferences:
preferable learning style - deductive, inductive, sequential, reflective;
preferable content presentation – explanatory, expository, descriptive, argumentative;
self passing – pace and course of learning activities - tasks, assessments, tests, exams.

According to the proposed adaptation technique the e-learning usability is achieved by producing adaptive learning resources (what would be adapted). They have to ensure flexibility and comfort to learners, content understanding, operational performances as well as they enhance the learning process and the users’ satisfaction. This goal is achieved by gradually adapting pedagogical approaches, content granularity and functionality (how it is to be adapted) to the level of competence and interests of the users i.e. the preferences of a group of users (what is the condition it is to be adapted to). Other benefit is that adapted learning resources are useful for a heterogeneous group of users.

Matching the learner’s characteristics and preferences with pedagogical strategies and applied educational approaches and tools is at the core of the e-learning usability achievement.

MATHEMATICAL FORMULATIONS AND METHODS

The estimation of the preferences of a group of learners bases on a mathematical approach that concerns the utility theory (Barbera, S., Hammond, P., Seidl, C., 2001). The group preferences are reflected by the preferences of a teacher (decision-maker – DM) for the way of carrying out an educational process. They have to be in harmony with the preferences of learners which the teacher observes during his work. By means of the mathematical approach presented below we describe and evaluate the preferences of indirect users of an e-learning system - learners. The modelling technique that bases on stochastic algorithms for assessment of expert utilities and values on the basis of the expressed preferences is a reasoning-based technique for modeling of learner’s preferences. It creates one-dimensional models. This technique is used for creation of a stereotypical model of learner’s preferences for the form and style of an examination. The learner (user) modeling uses the teacher’s opinion about learners’ preferences. It is a result of his experience.

Standard description of the utility function application is presented by Fig. 2. There are a variety of possible final results that are consequence of a learner activity determined by an educational objective, i.e. the activity context. A utility function U(.) assesses each of these results.
The DM judgment of these results is measured quantitatively by the following formula:

$$ U(p) = \sum_{i} P_i U(x_i), \quad p \text{ is probability distribution } \sum_{i} P_i = 1 $$

We denote with $P_i$ ($i=1+n$) subjective or objective probabilities which reflect the uncertainty of the final results. Strong mathematical formulation of the utility function is the next: Let $X$ be the set of alternatives and $P$ be a subset of the set of probability distributions over $X$. The DM’s preferences over $P$ are expressed by (1), including those over $X$. A utility function is any function $u(.)$ for which is fulfilled:

$$(p > q), \ (p, q) \in P^2 \iff (\int u(.) dp > \int u(.) dq). \quad (1)$$

The mathematical expectation of the utility $u(.)$ is a quantitative measure concerning the teacher preferences about the probability distributions over $X$. In practice the set $P$ is a set of finite probability distribution. We suppose that the singleton distributions belong to $P$, $(X \subseteq P)$. A "lottery" is called every discrete probability distribution over $X$. We mark the lottery “x with probability $\alpha$ and y with probability $(1-\alpha)$” as $<x, y, \alpha>$. There are different systems of axioms that give satisfaction conditions of utility existence. The most famous of them is the system of Von Neumann and Morgenstern’s axioms (Barbera, S., Hammond, P., Seidl, C., 2001).

We start with the assumption that any convex combination of elements of $P$ belongs to $P$: $(q, p) \in P^2 \Rightarrow (\alpha q + (1-\alpha)p) \in P$, for $\forall \alpha \in [0,1]$ (Pavlov, Y., 2005, Pavlov, Y. Ljakova, K. 2003). This condition and $(X \subseteq P)$ determine the utility function over $X$ (when this function exists) with the accuracy of an affine transformation. The most used utility assessment approach is comparisons of the kind: $(z \sim <x, y, \alpha>)$, where $(x \updownarrow z \updownarrow y)$,
α∈[0,1], (x,y,z)∈X^3. It is well known that the transitivity of "~" is breached in practice because of the so cold certainty effect and probability distortion identified by Kahneman and Tversky (Prospect Theory) (Barbera, S., Hammond, P., Seidl, C., 2001). Here is proposed a procedure which resolves some of these difficulties (Pavlov, Y., 2005):

\[ <x,y,α> (↑ or ↓ or (~ or "no answer")) z, α∈[0,1], (x,y,z)∈X^3 \]

Every comparison of this kind defines a "learning point" \( t=(x,y,z,α) \).

With probability \( D_1(x,y,z,α) \) the DM assigns the "learning point" to the set \( A_u \) or with \( D_2(x,y,z,α) \) to \( B_u \):

\[ A_u= \{ (x, y, z, α)/ (αu(x)+(1−α)u(y))>u(z) \}, \quad B_u= \{ (x, y, z, α)/ (αu(x)+(1−α)u(y))≤u(z) \}. \]

The DM answers (\( \uparrow \)⇔1; \( \downarrow \)⇔-1; \( \sim \)⇔0) are with probability and subjective uncertainty.

The main recurrent stochastic procedure in the proposed approach has the form (Pavlov, Y., 2005, Pavlov, Y., Ljakova, K., 2003):

\[
\sum_{n=1}^{\infty} Y_n^2 < +\infty, \forall Y_n \geq 0 . \tag{2}
\]

Here \((c^n,Ψ(t))\) denotes scalar product and \( D^t+ξ \) are the teacher answers (\( \uparrow \)⇔1; \( \downarrow \)⇔-1; \( \sim \)⇔0) were \( ξ \) is noise (uncertainty) in the teacher answers with mathematical expectation equal to zero. The scalar product has the form:

\[
(c^n,Ψ(t))=α(c^n,Φ(x))+(1−α)(c^n,Φ(y))−(c^n,Φ(z))=
\]

\[
αg^n(x)+(1−α)g^n(y)−g^n(z)=G^n(x,y,z,α). \tag{3}
\]

The coefficients \( c_i^n \) take part in the decomposition of \( g^n(x) \) by a chosen family of functions \( (Φ_i(x))_n \):

\[
g^n(x)=\sum_{i=1}^{N} c_i^n Φ_i(x). \]

The line above \( T = (c^n,Ψ(t)) \) means that \( \overline{T} = 1 \), if \( T > 1 \), \( \overline{T} = -1 \) if \( T < (-1) \) and \( \overline{T} = T \) if \(-1 < T < 1 \).

It is known that under the procedure (2) conditions specified above the next integral converges to the (min):

\[
J_{Q}(G^n(x,y,z,α)) = \inf_{x} \int_{D^n(t)} \left( \overline{y} - D'(t) \right) dF \rightarrow a \left( \int_{D^n(t)} \left( \overline{y} - D'(t) \right) dF \right). \tag{4}
\]
Here p.p. denotes “almost sure” and s(t) denotes s(t)=αs(x)+(1-α)s(y)-s(z). After some calculations the following make the convergence clear:

\[
\inf \int_{s(t)}^{y} (\int_{s(t)}^{y} D'(t) \, dy \, dF) \geq \lim_{n \to \infty} \frac{1}{2} \int (G^{s}(t) - D'(t))^{2} \, dF \geq 0
\]  

(5)

Taking into account the convergence and the structure of the function \( G^{s}(x,y,z,\alpha) \) (3) it is assumed that \( g^{n}(x) \) is approximation of the empirical utility if \( (n) \) is sufficiently great. The “learning points” are posed with the use of a pseudo-random Sobol’s sequences.

**EVALUATION OF LEARNERS PREFERENCES WITH RESPECT TO EXAM FORM**

The estimation of the preferences of a group of learners is performed by a decision support system for estimation of individual’s utility functions developed on the basis of the presented mathematical formulations and methods in an environment that consists of Visual Studio, Visual Basic 6.0. The final calculations and graphics are performed in the MATLAB environment.

The objective of this example is the evaluation of the learners’ preferences for the form and style of the exam. This estimation bases on the teacher’s opinion of these preferences that is a result of his experience. The examination (A) - form concerns the way of knowledge expression by a learner: test or free expression. The examination (B) - style regards learner’s exam: oral and written. The possible criteria for the estimation of the preferences of learners which satisfaction is the objective of the teacher during an examination are the followings: (A) “% test in relation to the entire examination material” (0% to 100%) – illustrated in Fig. 3 and Fig. 4; (B) “% time for written exam in relation to the whole time that is necessary for this exam” (0% to 100%) - illustrated in Fig. 5 and Fig. 6.

The number of teacher answers is 64 for the Fig.3 and Fig. 4. It is sufficient only for the first approximation. The seesaw lines in Fig. 4 and Fig. 6 recognize correctly more than 95% of the teacher answers. Fig. 5 and Fig. 6 are constructed by 1024 “learning points”. The utility dependence on probability can be assessed directly with the proposed procedure (2). For this purpose we search for an approximation of the kind \( u(x, \alpha), \alpha \in [0,1], x \in X \) following Kahneman and Tversky. The utility functions \( u(x, \alpha) \) are shown on Fig. 3 and Fig. 5. The explicit formula of the utility \( u(.) \) has the form

\[
u(x) = \int_{0}^{1} u(x, \alpha) \, d\alpha.
\]
Since the teacher accepts that the factors (A) and (B) are mutual independent in relation to “utility”, the utility function has the following expression:

\[ U(a,b) = K_1 f_1(a) + K_2 f_2(b) + (1 - K_1 - K_2)(f_1(a) f_2(b)), \]

where \( a, b \in [0,100]\% \).
The determination of the coefficients $K_1$ and $K_2$ depends on the determination of $f_1(.)$ and $f_2(.)$. This utility function is presented by the Fig. 7 and Fig. 8. The figure 8 illustrates the lines of identical preferences that show a way for partition the group of learners in subgroups in accordance with their identical preferences. We can determine to which subgroup belongs a learner through the construction of his $f_1(.)$ and $f_2(.)$. They are a source for the determination of $a_{\text{max}}$ and $b_{\text{max}}$ and $U(a_{\text{max}},b_{\text{max}})$ that shows the position of the learner in the space presented by Fig. 8, i.e. the subgroup to which the learner belongs.
CONCLUSIONS AND FUTURE WORK

The fundamental challenge facing today's learning professionals is the satisfaction of the needs and preferences of individual learners or group of them. A one-size-fits-all approach does not work well enough. That is why teachers have to provide customized learning experiences for targeted groups.

We present a technology of the evaluation of learners’ preferences that helps the creation of adaptive e-learning environment. The presented mathematical method allows practical use of expert information about complex system and problems, which is difficult to use in another way. This approach is used in our research for learner modelling with respect to the form of examination. It is also applicable to evaluation of other learners’ preferences, since the presented evaluation technology is developed for
estimation of human’s preferences. The learner is a user determined in education setting. The user is a human in the computing environment.

REFERENCES


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**Publication e-learning III and the knowledge society**

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