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ADAPTIVE E-LEARNING: FROM THEORY TO PRACTICE

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Abstract

The theory of adaptive e-learning – the principles of which were published in a monograph (Kostolányová, 2012) – is being developed at the Pedagogical Faculty of the University of Ostrava. However, the verification of the theory in pedagogical practice required much further work, both research and routine. This paper presents the results of several years' work of researchers, particularly the development of the adaptive LMS, the proposition and implementation of an expert system for the management of the Virtual Teacher, realized pedagogical experiments concerning the system and further development of the theory.

Keywords

adaptive education, individualized education, adaptive LMS

Theory of adaptive e-learning

By adaptation of education, we mean the changes in the teaching of the same curriculum that are carried out in a different manner to suit the needs of every student. As far as full-time study in a classroom is concerned, the consistent individualization of education is virtually impossible, particularly due to time constraints. Not even an experienced teacher who is able to adapt the instruction to the needs of every student can afford to use this method. The ideal way is to use the e-learning methods, i.e. ICT tools, as long as we do not use the Internet solely for the presentation of study materials and multimedia, but we "teach" it to adapt education – to automatically individualize it according to what kind of student it is teaching.

The presented scheme of automatic individualization helped solve a number of partial problems. The problems were published in (Šarmanová, Kostolányová, 2010) while the resulting theory of adaptive education (TAE) was published in (Kostolányová, 2012). And since it is an original theory and the following chapters are directly linked to it, we will introduce its basic principles.

Student and their individuality

In order for the program that manages individualized education to be able to manage it in an individualized manner, it needs to know a number of information about the student concerning their learning style (LS). A large number of theoretical pedagogues and psychologists deal with the LS theory. Those defined several characteristics – students' qualities – that influence LS. An extensive analysis helped define a tuple of mutually independent characteristics that determine the student's LS. They were published in (Kostolányová, Šarmanová, Takács, 2009). The following are the characteristics and the 14 values:

- Sensory preference of perception (verbal, visual, auditive, kinaesthetic) = 4 values
- Social aspect (the student prefers to learn on their own, in pair, in a group) = 1 value
- Affective aspects (motivation to study – inner, outer) = 1 value
- Learning tactics, including:
    - Orderliness (the student studies systematically sequentially or non-systematically randomly) = 1,
    - Way of processing information (theoretical derivation, experimenting) = 2,
    - Technique of processing information (detailed – from bottom to top, holistic – from top to bottom) = 2,
    - Approach to study (in-depth, strategic, surface) = 1,
- Degree of self-regulation, the ability to self-manage the study process = 1,
- Success rate, talent for a studied course = 1.

Each of the mentioned qualities is rated on a scale <0,100> or <-100,100> (for motivation, approach and self-regulation). The program obtains the initial values of students' qualities through a questionnaire. Because the values obtained in this way may not be absolutely accurate or may change over time, the program system contains an "adaptive loop" for LS. The loop analyzes the data that monitor every student's education process in detail, evaluates the agreement between the student's behavior and their current characteristics and adjusts the data according to reality (if need be).

Structuralization of study material

The second important element that influences the quality of education is a study material. We will not pay attention to the factual correctness and didactic quality of the material, which we – for the time being – leave to the author. Moreover, those qualities are dealt with in further research.

As far as adaptability is concerned, there is another question: What form does the study material need to have in order for it to be adaptable to every current student's LS?

One way, chosen by the majority of experts dealing with LS, is to create a different variant of the study material for every type of student (often named). As far as 2-3 qualities with two poles (does – does not have quality) are concerned, there is a reasonable amount of variants. However,

as far as the greater number of characteristics is concerned, there would be an unbearable amount of variants (our 14 characteristics with only 2 values of every quality would have 2^{14} = 16,384 types).

We chose another way. The characteristics, which require the curriculum to be formulated in a different manner, will come in variants. It is 4 **sensory variants** (which require the use of various "active" words in text or different types of multimedia) and the success rate (which requires the instruction to have different levels of detail or extent). 3 levels of the so-called **depth of instruction** were chosen. Overall, there are 4x3=12 variants of instruction.

Other characteristics are being dealt with in a different manner. First of all, we use a classic division of the course curriculum into chapters or units. Gradually, the unit contains new information and new terms. We named the unit of such information (for instance 1 new term) a **frame**.

By analyzing in which the variants of study materials should differ with respect to different values of students' other qualities we came to a conclusion that they differ mainly in sequence and the choice of particular parts within the frame. For instance, a theoretically equipped successful student would prefer the following sequence: theory, explanation, examples and examination; an unmotivated and less successful student will need motivational examples, more detailed explanation, theory, examination and motivational compliment. The "rules" for adaptation, i.e. how to choose and organize particular parts of the study material according to the student's LS, can be formulated in a similar manner. Those considerations led to the division of every frame into parts, called **layers**. The following layers were defined: instructional (theoretical, semantic, fixation, solved examples and practical examples), test (theoretical questions, tasks and practical tasks) and special (motivational, navigational, formulation of goals, literature). The layers turned out to be in agreement with didactic principles, Gagné's theory of the education process and other pedagogical-psychological principles.

The result of all the considerations is the division of the education process into units and frames; frames processed in sensory and depth variants with every variant being divided into layers.

Virtual teacher

We named the program, which manages individualized education, the Virtual Teacher (VT). The program is designed to create an optimal version of the study material from the author study material structured into frames, variants and layers for the current student defined by their LS characteristics. The entire process is divided into 2 phases.

In the first phase, the VT defines the so-called optimal learning style (OLS) of the current student. It means that it compiles a theoretically optimal selection and sequence of every frame's layers valid for any study material. However, the actual study material does not have to contain all the variants and layers for every frame (see the end of Paragraph 1.2).

That is why there is the second phase of the VT, which is realized for every current frame one more time: based on the student's OLS it defines the so-called actual learning style (ALS) where the frame adaptation is adjusted to a real frame. Possible missing variants or layers are replaced by the closest ones or omitted entirely.

Both phases are managed by a series of expert rules representing the author/teacher choice of the suitable variant. The form of the rules is very important. One possibility is to define the selection and sequence of layers rule (for phase 1) for every type of student, i.e. for their tuple of qualities. However, this would make the abovementioned problem of an enormous number of LS types an expert's concern instead of author's.

Therefore, a more general solution was proposed: instead of the "complex" rules the "elemental" rules were defined which react to every quality (or a pair of qualities) and its value (the degree of the quality) separately. There is a lower number of such rules, they are simple, easy to understand and easily formulated. The rules determine which variants should be selected and which layers and in which sequence should be presented to the student.

For the entire tuple of qualities and with the use of a proper algorithm, the VT then compiles the mentioned OLS out of a set of relevant rules. When creating the ALS, other rules determine when the missing variants or layers should be replaced or omitted entirely.

Expert rules materialize "pedagogic experience, knowledge and skills" in the management of individualized education. However, it cannot be expected that the currently defined expert rules will be optimal for all types of students. Moreover, different teachers will have different opinions concerning their formulation. Therefore, the system of rules is designed (and realized, see Paragraph 2.4) in a way so that it could be easily user modified or replaced without having to change a program. Every pedagogue – expert – can set and verify their own theory of the management of adaptive education. This possibility has already been used in pedagogical experiments (see Chapter 3).

Realization of adaptive education through adaptive LMS

The proposed detailed theory of adaptive education needed to be verified in practice. As there was no LMS which would be able to use the expert rules to create the optimal version of a study material for a particular LS from a detailed study material, it was necessary to create such LMS. In 2010-2012, students and teachers of VŠB-Technical University of Ostrava (Drápela, 2013; Takács, 2014) and the University of Ostrava collaborated on the development of such system, which was realized as the LMS Barborka 4 (versions 1-3 contained only partial solutions of adaptivity). The research was supported by two projects ESF OP VK. The system is still being developed; new functions and rules are being added.

LMS purpose and structure

This adaptive LMS is not primarily intended for collective education (it does not contain the needed functions of the Tutor module concerning tests, tasks, etc.) but it is used as a research tool by academic scholars and Ph.D. students at the Pedagogical Faculty of the University of Ostrava.

The entire LMS is divided into the following modules: Student (identification of students and a questionnaire for their initial characteristics + the instruction), Author (storing and modification of study materials), Expert (algorithms of the Virtual Teacher, an expert system

for the rules of the VU, a system for the data analysis), Tutor (organization of education, submission of tasks, realization of tests, etc.), Admin (system administration). As far as adaptivity is concerned, the Student, Author and Expert modules are important.

Author module and creation of study materials

As has already been mentioned, it is the author who decides about the factual content of a study material. However, an adjustment of the study material to the requirements for the structuring of a workbook into frames, variants and layers requires the author to become acquainted with the TAV, the methodology of the processing of variants and the meaning of types of layers.

In order for the frames to be adaptable (so a different sequence of their layers could be used), the layers should be self-supporting. It means that the entire frame needs to provide quality instruction even when a different sequence of layers is used. For instance, the student-experimentalist prefers the following sequence: practical example, explanation and theory. On the other hand, the student-theoretician prefers theory to come first followed by explanation and practical examples.

As far as the sensory variants are concerned, the author needs to become acquainted with the recommended formulations for different sensory types of students. And because the author often belongs to one of the types, their language is influenced by that type. As a result, they need to learn to express the same sentences in a different language for different sensory variants. For instance, for the auditive student the author should use "auditive" words such as "let's listen to", "let's discuss", "the sentence goes…", etc., for the visual student "visual" words such as "we can see that…", "let me show you…", "varied", etc. The author should follow the similar pattern when addressing the other sensory types.

As far as the depth of the instruction is concerned, the author needs to imagine they are instructing the average student. To this, the author needs to add something for the above-average student so they do not become bored and for the slower student they need to make the instruction more detailed and adjust its pace.

The storing and modification of the finished study material in the LMS can be done for every individual layer separately. In order for the VT system to be able to distinguish between the many variants and "know" which layers belongs to which variant and frame, parts of the study material need to contain the so-called metadata in which the system information about the structure of the study material is stored. That is another difficult task for the author.

The author usually does not create the study material in the LMS but in the text editor, multimedia are created with the use of various SW tools and the author makes notes about their placement in the text. The author saves the unit or the course to the LMS only after it has been completed. In order for the author not to lose track of the entire structure, a "form" in MS Word was designed with pre-filled boxes for metadata and containing the entire structure of the frame. As a result, the author can comfortably structure their text and does not lose track of variants and layers. The author either uses the pre-filled metadata or makes a note (usually with only one symbol) in the form. The author (or an assistant) then saves the finished study material with metadata in the LMS.

We must stress that the author does not have to deal with when a particular variant, selection or the sequence of layers is used during the actual education process. In contrast to programmed education (which is still frequently used in adaptive systems), The VT deals with this issue. The "programming" of the education process is automated not only for the average student but also according to the student's LS.

Student module and instruction

The Student module is use friendly. After the first log-in the student is asked to fill out a questionnaire from which the initial characteristics for their LS are determined. The questionnaire was compiled by a psychologist (Novotný, 2010).

Afterwards, the student chooses the course and unit after which they are being presented with a series of frames in the sequence of layers adapted by the VT according to their LS. The student (as it is usual in e-learning) chooses their own pace of education. However, the student does not have to follow the variants and the sequence of layers offered to them by the VT. At any time the student can choose another existing neighboring variant of instruction (of another sense or depth) or move on to another frame in the unit.

Test layers, theoretical questions and tasks included in the frames constitute the smallest "adaptive loop" of the entire education process. When the student answers incorrectly they are provided with a four-stage help, which should help them always come to the correct answer. This is the way the continuous control of the students' understanding of the partial paragraphs' (frames) content works.

Besides the instructional units, the author can also use tests containing only test layers, which are usually placed in between the units. The author or the guarantor of the course decides about the number of tests (usually there are several mid-term tests and one final test). The tests constitute the middle "adaptive loop" of the entire education process, which controls the students' understanding and learning of the larger wholes of the course.

Besides the actual instruction, which is carried out in the described manner and managed by the VT, the student can also choose from 3 other modes: usually the introductory mode 1 guides the student through the unit presenting them only with instructional layers, without continuous examination. This is usually followed by mode 2.

Mode 3, which displays only test layers, is intended for final revision. If the student answers correctly, they can proceed to the following question. If, however, the student answers incorrectly, they can use the abovementioned help that refers to the particular instructional layer or the entire solution which is described in the so-called HELP layer.

Mode 4, which is intended for self-testing, contains the final test. The student answers the questions and solves the tasks as in a real test, i.e. without any help and within the specified time limit. At the end of the test the student receives the result. The student can take the self-test any number of times until they are sufficiently prepared for the real exam.

The last two modes are designed and discussed in the dissertation (Prextová, 2014).

The student's every "mouse click" in every mode is recorded in the education process protocol. The analysis of the protocol can reveal interesting facts about the student, the study material or the rules for the management of instruction (see Paragraph 2.6).

Virtual teacher: expert management

The Expert module is the main research tool of adaptive education. Besides the functions of the management of education itself, it also has other functions.

The Expert module unique expert system with the database of expert rules and algorithms for their use represents a brand new approach to the management of education (Takács, 2014).

According to the TAV theoretical proposition, the database contains expert pedagogical-psychological rules used to create the OLS and ALS of the current student.

The database of rules is structured into several groups according to the educational content: generally valid – basic pedagogical principles; for a group of courses – e.g. field of study, subject; for a group of frames – e.g. unit, particular frame; for a group of students – e.g. classroom; for a particular student. Another way of the division of rules is according to the mode of education – first reading, instruction, revision, self-testing.

Moreover, the author can also select only some of the rules and set their own rules in any group's frame. They can do so by using the LMS without having to consult the programmer. This enables researches from the field of adaptive education to set their own rules and conduct their own experiments when verifying the optimal procedure for different types of students and courses.

The rules are of the IF – THEN type, presumptions are the characteristics of the student's LS, consequences represent the choice of sensory variant of the frame and recommended selection of depth and the sequence of layers. As has already been mentioned, the rules are elemental and contain only 1-2 characteristics in the presumption. That is why it is necessary to choose all the relevant rules coinciding in presumptions with the LS characteristics when creating the OLS. The specially designed OLS inference algorithm, which compiles the sequence of the recommended steps (frames) of the OLS, is used on selected rules. The step is described as follows:

(layer_type, layer_sequence, layer_depth.)

The ALS algorithm modifies (if need be) the OLS sequence according to the offered layers of the current frame. If any of the theoretically defined layers does not exist because the author did not include it, the algorithm tries to find the closest layer or omits it entirely. This algorithm is also controlled by expert rules.

The setting of the rules for education has already been used in the dissertation (see Chapter 3).

Modeling of virtual teacher's expert decision making

It was necessary to verify the realized expert VT system, particularly the correctness of the formulation of rules and the realization of inference algorithms for both the OLS and ALS. The verification had two phases: (1) OLS for every type of student needed to be created (as has been

mentioned above, there is a large number of such theoretical techniques); it needed to be verified that the created sequence of layers follows the expert's concept; (2) ALS for every type of student including every possibility of missing author layers needed to be created; it needed to be verified that the created sequence of layers follows the expert's concept.

There are two reasons why all the verifications could not take place in the actual instruction. Firstly, there are thousands of student types, which makes it impossible to find all of the theoretically defined types for the experiments. Moreover, every type should be verified on more than one person. Secondly, it is impossible to create an adaptable course in all possible variants of missing layers as there are dozens of combinations.

As a result, a tool for debugging of rules and algorithms of the VT (Kostolányová, 2013) was proposed, realized and integrated in the Expert in the LMS 4 Barborka, which made it available to other researchers.

The tool for modeling of the expert rules and algorithms of the Virtual Teacher makes it possible to include the support model – a fictitious study material that marks the layers included in the material, and to set a tuple of characteristics of a fictitious student. The support can be easily set through a graph that visualizes its structure while the student characteristics are entered into a simple form.

After the mentioned information has been entered, the system performs a complete calculation for adaptive education, i.e. the calculation of the OLS and ALS sequences. The set expert rules and both VT algorithms will be used. The result is visualized into a proposed graph which contains all sensory and depth variants with all types of layers. Different senses are displayed in different colors while the layers are vertically divided into the following groups: introductory, instructional, test and literature.

The calculated sequence of the ALS is not represented by trios; instead, in the pattern, every trio is represented by a black dot in the selected layer and variant. The dots are connected by line segments so the entire sequence has a form of a transparent graph. As a result, the expert can easily verify whether or not the calculated ALS coincides with how they think the instruction should be adapted. When only some of the students' qualities are entered and the instruction is comprised of more resulting ALSs, they are all displayed in one graph. This way it is possible to debug several LS types at the same time and verify whether or not the study material is consistent in key parameters.

The presented tool was used for debugging of all basic generally accepted rules and both algorithms. It led to discovering and correcting of several errors both in the rules and in the inference algorithms. The current version of the VT conforms to the requirements of the experts who designed the rules.

Course of instruction protocol analysis

It has already been mentioned that the entire education process of every student is being recorded: every mouse click, every move to the next layer, every time the student deviates from the recommended educational sequence, the student's every answer, etc. Extensive data are

gathered which, when analyzed, may provide feedback on the education process. The instruction analysis has three main parts.

The first analysis is the effectiveness of instruction from the point of view of the correctness of author study materials (Dvořáčková, Šarmanová, 2011). It is evaluation of the course study material based on the monitoring of a number of actually completed educational processes. Not only opinions and feelings of students from the evaluation questionnaire are being analyzed, but also their real behavior during the education process. The analyses assume that the characteristics of all students are correctly set and the educational rules are correctly formulated. It is aimed at specifying the parts of the study material that are either unsuccessful in general, or for particular types of students.

The second type of analysis assumes the already debugged study materials and examines the correctness of the adaptation of the study material for particular students. In other words, it verifies the correctness of the currently registered student characteristics. If the student often chooses other than the recommended variants, it means that they are not satisfied with the preset ones and that the error may be in the incorrectly set "commands" of the VT, i.e. in the incorrectly registered characteristics. If the same behavior of the student occurs in more than one course, the system can automatically modify their characteristics and further monitor their behavior during the instruction. The student's characteristics can change with their LS gradually changing. When some of the student's characteristics are incorrect (e.g. surface approach), such changes are appropriate and the VT rules should lead to them. Such analyses are being conducted.

The third type of analysis examines the correctness of the preset expert rules of the VT. These are the most demanding analyses, which are also currently being developed. They should result in the debugging of all study materials and the correctly set current qualities of students. Afterwards, it needs to be determined when the majority of students are not satisfied with which rules or when the rules do not lead to the improvement of students' LS.

Further research concerning theory of adaptive education

The TAV published in 2012 contained the defined basic principles of the adaptation of study materials depending on the LS of particular students. A number of other pedagogical-psychological and implementation problems concerning the theory were defined during the realization of the principles in the LMS, their verification, pedagogical experiments and theoretical discussions of the entire group of researchers. We will present the ones that have already been solved.

Adaptive testing theory

The theory of adaptive testing was a natural extension of the theory of adaptive education. The basic education mode contains test layers of three types: theoretical questions, application tasks and practical tasks. They are used as immediate feedback and are used particularly for the student as they help them determine whether or not they have mastered particular parts of the studied curriculum.

We know from pedagogical experience that the long-term memorization of the acquired knowledge is even more important than the immediate knowledge. Separate tests during the course of instruction (covering larger units of the curriculum) or at the end of the course are used for this purpose. The students should have a tool at their disposal that would help them verify their knowledge before the actual examination. Besides the possible sensory variant of the formulation of questions, there should also be a tool that would offer the students the possibility of both self-testing and the immediate help when they are having trouble with the curriculum.

This issue is being dealt with in (Prextová, 2014). The theory of adaptive testing has been formulated and two other modes of education have been proposed: repetition with consultation and self-testing.

Adaptive testing consists in the adaptive presentation of questions and tasks of different difficulty levels to the student. When the student answers correctly, they are presented with more difficult tasks. All tasks are of the minimal recommended level of knowledge. The tasks (theoretical and application) are organized into a "matrix", vertically according to several levels of difficulty, horizontally browsing through the curriculum of the tested course.

The student deals (horizontally) with all tasks of a unit or a course. Every student works on a particular level which is determined according to their reactions. At the end of the test, it is determined at which level the student answered the most questions, i.e. at which level of knowledge (and a grade) they currently are.

When the student answers incorrectly, they are offered the mentioned 4-stage help. The first time the student answers incorrectly, they are only notified about the incorrectness of their answer in order for them to be able to correct any possible typing errors or slight incomprehension. The second time the student answers incorrectly, they are offered simple help. The third time the student answers incorrectly, they are pointed to the exact part of the study material so they can once more go through the particular section related to the tested theory or the solved tasks. If the student still answers incorrectly, the complete solving process is displayed to them, which they then only copy.

The so-called equivalent questions are another way of expanding adaptive education and the testing process. In order to prevent the student from being presented with the same questions during their way through the course in the repetition and self-testing modes, the author can enter a group of questions instead of only one question (in the metadata, such questions are in a group). This way, if the student answers any of the questions correctly at the first try, the next time they go through the course they are not offered the same question but one of the equivalent questions. The equivalent questions differ in the formulation of facts, numerical values in mathematics or physics, the use of different sentences to test the same grammar in languages, etc.

Therefore, there are individual records of every student's LS characteristics, but also of the entire course of instruction: which units, frames and layers they have gone through, at which of the testing layers they were successful, how many times, etc.

Foreign language instruction theory

Compared to other subjects, the instruction of foreign languages is specific. It is not based only on teaching the student, through any sense, knowledge and skills from the syllabus of the subject, but on teaching them to use all the senses in a foreign language equally well: auditive for the understanding of listening, visual for reading and writing, kinaesthetic for practice speaking, verbal for vocabulary and grammar rules.

(Horký, 2014) focuses on one of the theories. The development of skills is the basis of the instruction of foreign languages – listening, speaking, reading – and also the grammar and vocabulary. The development of language skills and knowledge requires the so-called stretching of styles, i.e. to learn how to use the subordinate styles. This theory is based on the assumption that superiority and inferiority of sensory styles could reflect the sequence and depth of the assigned study materials.

The study material makes the student go through all sensory variants, but in a different order. The student starts with the variant of their strongest sense, continues with the second strongest and ends with the weakest sense. The basic principle of this method lies in the fact that the information acquired in previous steps makes each further step easier for the student.

Since at the time of the experiment the expert rules did not contain rules for the change of the sequence of frames, they needed to be added. That marked the first time the new rules were used in a special research.

Instruction supported by semantic network

Another way of improving the possibilities of the LMS is supporting the instruction by the semantic network. The semantic network is a graph of the nodes-edges type where the node represents the term and the edge in between the nodes represents the relations between the terms. In reality, there are various types of relations between terms.

The semantic network (SNT) in the LMS 4 Barborka (Šeptáková, Šarmanová, 2014) is defined for the terms defined in the study material, particularly in the theoretical layer. The terms are highlighted by the author of the study material, who can also add synonyms of the term. The edges represent the relation of the following types: **predecessor** (term defined earlier and appearing in the definition of the current term), **successor** (term defined later whose definition contains the current term), **occurred before** (the term occurred in the study material before being defined), **occurred after** (the term occurred in the study material after being defined).

After the study material has been added to the LMS, the corresponding SNT can be created automatically without the author's interference.

The SNT is important for both the student and the author of the study material.

The author is provided with the evaluation of the study material on the basis of which they can then modify or update the study material and its variants before it is presented to the students. It generates a list of errors and highlights possible errors resulting from didactic principles, e.g. the use of undefined terms, defining terms with no further use, etc. Moreover, the SNT also automatically generates an explanatory dictionary of the course.

The SNT is intended particularly for the student. When the student studies the curriculum step by step as it is described in the textbook, situations may arise when they need to revise earlier terms which are related to the new curriculum. The SNT enables them to find both the definitions of the terms and the additional information without their having to "browse through" the study material. When the student asks a typical question "What is it good for?", the SNT immediately shows them both the theory related to the new term and how it can be applied in practical situations, e.g. when solving a task, etc. The SNT helps the student to develop the structure of terms and their context in their memory. When revising the curriculum before an exam, the SNT improves the student's orientation in the terminology. Visualization of a network of terms is better for remembering than plain text.

The use of an interdisciplinary SNT will make it easier for both the authors and the students to compare the definitions of terms, or alert the authors about possible discrepancies. The students are often not aware that the same term has the same meaning in various subjects and is only being discussed from another point of view, which results in them learning such terms again, overloading their memory and not understanding the relations between subjects. Therefore, the use of the interdisciplinary SNT will enable the students to see the same terms from a different perspective, which will improve their understanding of reality. Examples of such terms are: vector (mathematics, physics, programming), system (virtually everywhere), etc. The interdisciplinary use of SNT reveals the unnecessary duplicities in the instruction or possible discrepancies in definitions or their interpretation.

Pedagogical experiments with adaptive education

In 2013-2015, various experiments concerning the adaptive LMS were conducted, all of them related to dissertations of the students studying in the "ICT in Education" study program. They all drew on the theories described in Chapter 3 and led either to the extension of the expert rules or to the addition of new functions to the LMS.

The **foreign language instruction** theory, which uses all 4 of student's senses added to the LS characteristics in the order of decreasing significance, was verified on the sample of 200 students from the Silesian University in Karviná (Horký, 2014). On the basis of a questionnaire, the students were assigned the characteristics of their individual LS.

The main hypothesis was divided into several smaller partial hypotheses. A series of pedagogical experiments confirmed that the students who are taught a foreign language in the adaptive system are statistically more successful in mastering it than the students that are taught a foreign language in a non-adaptive system.

Also the theory of adaptive testing was verified in a pedagogical experiment on the sample of 53 students from a primary school in Ostrava-Poruba (Prextová, 2014). On the basis of a questionnaire, the students were assigned the characteristics of their individual LS.

A 6-unit mathematics curriculum including the revision for final examination in the 9th grade was created for the use in the instruction. A pretest, individual study in adaptive e-learning and a posttest revealed that the proposed algorithm for the repetition with consultation mode and

the proposed adaptive rules contribute to the improvement of students' knowledge and skills. The improvement is noticeable especially among the weaker students.

Further experiments using the SNT and the evaluation of instruction protocol by the analysis of instruction are being conducted in the 2015 fall semester.

Conclusion

In conclusion, we can say that:

- The formulated theory of adaptive education was incorporated in the new type LMS including all described possibilities of automatic adaptation of the study material according to the individual characteristics of the student's learning style;
- The theory has been expanded in several ways: by the theory of adaptive testing, the theory of the use of all senses during the instruction (in the order of decreasing significance), the use of the semantic network of terms for better orientation of the student and the author in the structure of terms; further theories are being developed;
- The abovementioned theories have been verified by pedagogical experiments.

New topics have been appearing during the research and development of individual adaptive e-learning education, which will be used not only as topics of dissertations. A permanent team of researchers, especially from the Department of Information and Communication Technologies at the Pedagogical Faculty of the University of Ostrava has been systematically working on them.

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