RIGA TECHNICAL UNIVERSITY

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MODELS FOR ADAPTIVE COMPUTER-BASED LEARNING MANAGEMENT

Doctoral thesis summary

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RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
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DOCTORAL THESIS
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AT RIGA TECHNICAL UNIVERSITY

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APPROVAL

I confirm that I have developed this thesis submitted for the doctoral degree at Riga Technical University. This thesis has not been submitted for the doctoral degree in any other university.

Jekaterina Bule ……………………………. (Signature)

Date: ………………………

The doctoral thesis is written in Latvian and includes introduction, 5 sections, conclusions, bibliography, 7 appendixes, 43 figures and 33 tables in the main text, 197 pages. The bibliography contains 182 references.

ANNOTATION

Doctoral thesis is devoted to the computer-assisted learning and teaching systems researches and analysis, as well as development of general principles of such systems designing and implementation considering student model and adaptive learning organization methods.

The main attention is paid to the following problems: research of computer-assisted learning and teaching systems and adaptive methods; considering learning process analysis defining a set of models that is necessary to ensure adaptive dialogue between student and teaching system; development of teaching material model, taking into account learning objects re-using possibilities; forming programming engineer expert model; constructing a student model, which allows organization of adaptivity on various levels; research of adaptivity and adaptability problem; adaptive e-learning algorithm implementation; development of adaptive e-course and evaluation of it’s usage efficiency.

CONTENT

1. GENERAL THESIS DESCRIPTION

1.1. Thesis topicality

Nowadays due to the development of new technologies and directions in all of the industries preparing high qualified specialists, professional re-orientation and other education ways are the most actual problems. Educated people are required all over Europe and world. That is one of the main reasons why learning significance is growing. As well considering the contemporary situation at the labor market it is essential to proceed to the newer ways of learning organization, which gives a possibility to improve knowledge and skills acquiring using modern technologies. Due to this situation such learning types as distance learning, life long learning, e-learning and others are becoming more and more popular.

Lately many higher education institutions develop and widely use computer-assisted learning and teaching systems that allow optimizing of various learning organization strategies. One of the most important e-learning advantages is possibility to gain knowledge and skills at any time in any place with the connection to the global network.

While developing e-courses it is important to consider a problem of learning process organization. The efficiency of a course acquiring depends on that. Computer-assisted learning system should act as tutor regarding many factors.

To implement effective computer-aided course it is essential to focus on the material structure, which will allow better perception of information. Therefore it is necessary to develop management tools of learning modules that could be used as within one topic (e.g., defining of concepts sequence) as within a whole course (topics sequence, information and knowledge control).

During the research of more than 150 systems it was defined that student background knowledge level, psychological characteristics and other factors that influence the result are not considered. One of the most important requirements to e-learning courses is adaptivity. Adjusting could be ensured by using different tools and possibilities for information representation, taking into account student background knowledge and skills level vary amount of a teaching material, its difficulty and content. Therefore the main topic of the thesis is e-learning course implementation considering student characteristics and adaptivity principles.

Various organizations all over the world work on the researches of computer-assisted learning problem and e-learning systems development. Here should be mentioned Distance education center at Riga Technical University,; Latvian distance learning center; Interlabs

Research institute; International Forum of Educational Technology & Society; Association for Advancement of Computing in Education; International Research and Training center; Kaunas Regional Distance Education Study Centre; IT-STUDY.ru and others.

Different computer-assisted learning problems, challenges and solutions are being discussed at yearly conferences: IEEE ICALT (*www.ieee.org*), ED-MEDIA (*www.aace.org/conf/edmedia/*), IASTED CATE and WEB (*www.iasted.org*), IADIS e-Learning (*www.elearning-conf.org*), ICCMS (*www.iccms.org/index.htm*), SITE (*site.aace.org/conf*), IMCL (*www.imcl-conference.org/*) and many more.

The research of existing e-courses showed that the problem of e-learning system management hasn't been enough studied, but it is of a great significance for course development and implanting process. Therefore doctoral thesis describes the subject teaching management proposition considering modern technologies and standards.

1.2. Goal and tasks of the Doctoral thesis

The goal of the Doctoral thesis is to develop methods and models, which will allow ensuring of adaptivity and adaptability principles in e-course learning, considering the research results of learning and teaching process, student models, adaptive methods and models, that are used in computer-assisted learning systems (CALS).

To achieve the goal it is necessary to fulfill the following tasks:

- research computer-assisted learning systems and adaptation methods used in such kind of system;
- on the basis of teaching process analysis define set of models, that is necessary for ensuring of adaptive dialogue between student and system, as well as models interconnections;
- develop teaching material model for course learning, considering re-using feature of learning objects;
- according to the research results of existing knowledge models, form expert model for programming engineer;
- regarding the results of student models used in modern CALS, implement student model that allows ensuring adaptivity on different levels;
- research problem of adaptivity and adaptability in CALS and according ti gained results construct teaching algorithm that performs both features;

- implement adaptive e-learning course, include it into teaching process and evaluate efficiency.

1.3. Research methodology, scientific novelty, thesis practical significance

Research field: computer systems that are used for adaptive teaching and learning.

Research subject: adaptive computer-assisted teaching and learning systems models and methods.

Research methodology: expert evaluation and methods of mathematical statistics.

Scientific novelty. The newly results are as follows:

- offered learning material representing format that is based on hypertext mathematical notation, as well the structures of re-usable learning objects designated for knowledge acquisition and forming skills;
- developed student model that allows individual approach to each student, considering characteristics influencing learning process;
- implemented adaptive teaching algorithm based on subject and student models.

Thesis practical significance.

Student model and adaptive teaching algorithm developed and described in the thesis can be useful while designing and implementing computer-assisted learning systems, for they give a possibility to ensure individualized process organization for everyone during teaching and learning of e-course and therefore to improve efficiency of teaching. Implemented e-learning courses are included into the teaching process at Riga Technical University (RTU). E-course „Study HTML from zero" is included into the virtual library of department of Virtual European Computer Sciences.

1.4. Doctoral thesis structure

Doctoral thesis consists of five chapters and conclusions. The first chapter (Introduction) describes the thesis topicality, formulates goal and tasks of the work.

The second chapter researches computer-assisted teaching process, shows the existing computer-assisted teaching and learning systems classification after several criteria, examines computer-assisted teaching model.

The third chapter includes the research results of the models of computer-assisted teaching systems: indicated models interconnections, revised subject model representation ways, developed learning objects models, formed expert model for programming engineer, given student model classification and descriptions, as well as developed student model for adaptive learning.

The forth chapter is dedicated to researching of e-courses teaching methods, it shows e-course teaching main principles, described the problems concerning organization of adaptivity and adaptability, depicts adaptive e-course teaching algorithm based on the student model.

The fifth chapter contemplates adaptive e-learning courses development and their including into teaching process, as well as represents the results of efficiency evaluation, using two mathematical statistics methods and considering students questionnaires.

Doctoral thesis includes: 197 pages of text, 43 figures, 33 tables and 182 bibliographical resources.

2. CONTENT OF THE DOCTORAL THESIS

2.1. Computer-assisted teaching process

Computer-assisted learning is “a teaching way that being organized via accordingly programmed computer, computer system or computer network, which provides a learner necessary information, controls knowledge and skills, evaluates control results and offer recommendations for process improvement”.

Nowadays computer-assisted learning systems (CALS) are being used in many educational institutions as well as they are available freely in Internet. During the thesis development there were researched 150 CALS and they were classified according to 4 criteria: functional purpose, feedback organization, user categories number, e-course adaptive learning ensuring.

Corresponding to functional purpose all the systems can be divided into 7 groups:

1) testing programs;
2) encyclopedias and dictionaries;
3) edutainment systems;
4) universal teaching and learning systems;
5) specialized teaching and learning systems;
6) network universities and colleges;
7) virtual worlds.

The researching results show that the most popular still are testing programs (42%) and rather often can be found and used encyclopedias and dictionaries, including explanatory (20%).

To organize feedback the following possibilities are used:

- e-mail;
- chat, forums, debates;
- videoconferences;
- virtual classes.

E-mail and chats (forums, debates) are the most common ways for feedback ensuring – 55% and 42% accordingly. Videoconferences and even more virtual classes have more difficult realization and need additional resources and/or hardware and software therefore these options are not so widely used.

The main CALS user categories are student, tutor, learning material author, administrator and operator. All the categories have their own functions, but mostly in nowadays systems there are just two or three classes: student and tutor, who combines all the possibilities of tutor, learning material author, administrator and operator. Some of systems (about 56%) provided separate access for tutor, but administrator and operator were consolidated.

During the CALS research it was stated that generality of them don't provide learning process adaptivity to a student (38%). Most frequently learning is organized in linear sequence without any consideration of student work with an e-course (27%), some systems support tree structure (14%) or recurrent information representation (15%), not giving any explanations and/or examples (Fig. 2.1.).

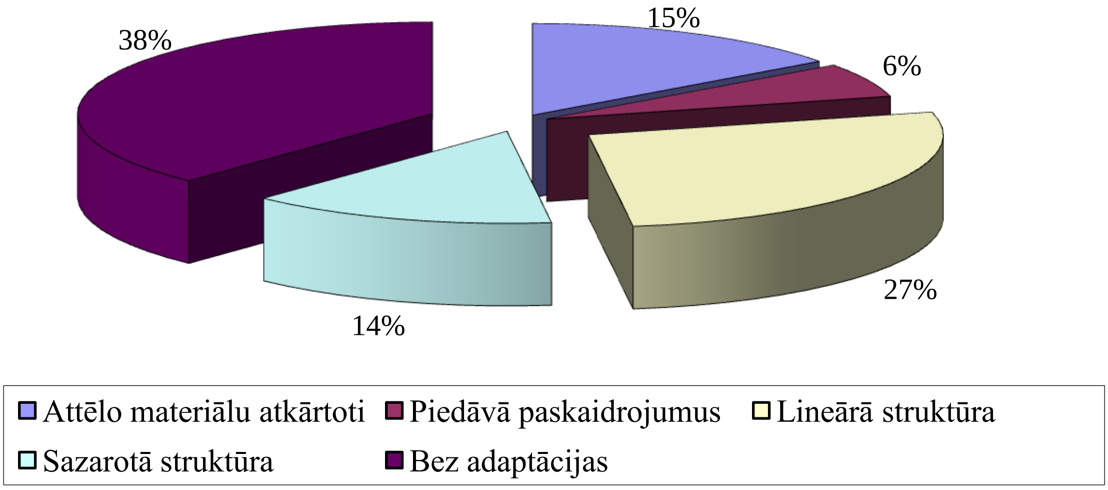


Figure 2.1. E-course learning organization

Teaching process is influenced by various factors – both outside (environment, where student works, additional information, goals, etc.) and inside (system information, implemented algorithms and methods, other system resources).

Many scientists to describe teaching process reposed on Professor L. Rastrigin model, which is the most detailed computer-assisted teaching process description with the use of a student model (Fig. 2.2.).

- Before learning student is in state S_1. After getting and acquisition of a teaching material T student state becoming S_2. While being in that state student is being offered a task or a question J to define whether information is obtained or not. After fulfilling a task his/her state is S_3. After each set of these steps a student model is being changed.
- Former of teaching information applies to a teaching algorithm that determines what exactly information T to give a student from Knowledge and databases.

- Question and tasks former generates tasks J for topic acquisition control considering student work with a course till task fulfillment moment, as well as other information from a student model.
- Database includes general information on users (students, tutors, etc.), existing courses and so on.
- Knowledge base keeps a set of models (course model, topic model, dialogues scenario, knowledge/expert model, student model). It can be expanded from outside information resources I.
- Teaching algorithm consists of two parts – answer analyzer and management module. Considering afore defined goals M, environment states AV, as well inside R_2 and outside R_1 resources, algorithm passes essential information to Teaching information former and Question and task former. Answer analyzer processes as given answer to a task or question (or set of questions) as student activity during information obtaining. After processing results management module defines, what to do next.

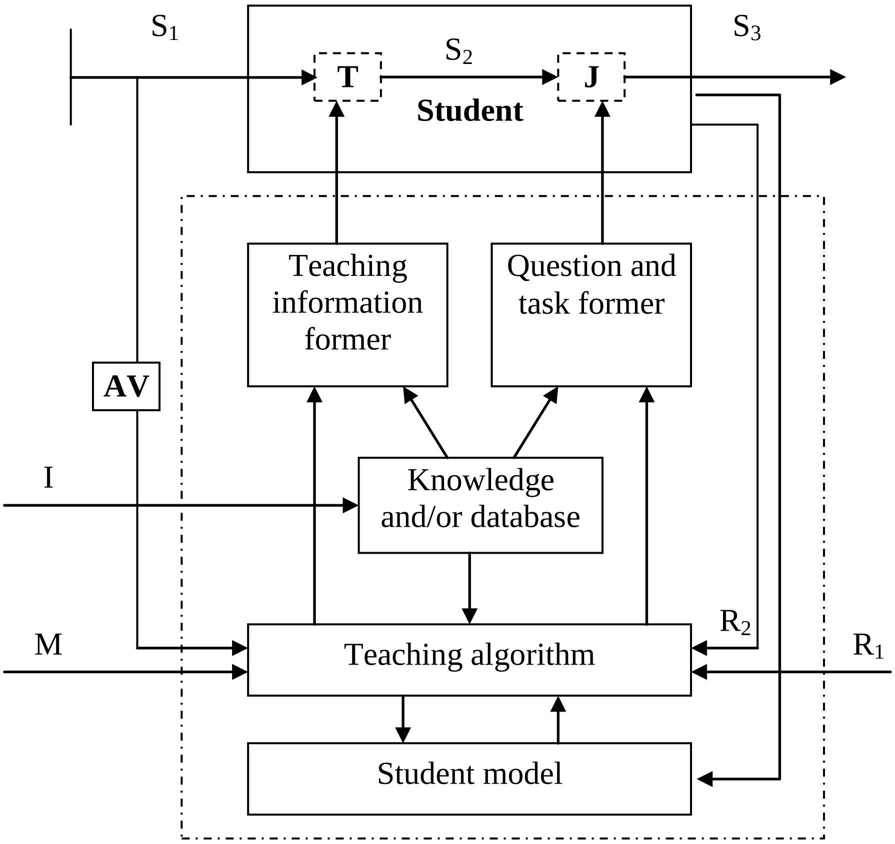


Figure 2.2. Teaching process model

As it can be seen teaching process based on several model. The main model is a student model.

2.2. Models in computer-assisted teaching systems

2.2.1. Course model

Course model can be regarded as teaching process fundamental, for it defines “what to teach?” which is one of the main didactics questions. It includes all theoretical information and knowledge control tasks that are planned while teaching a definite course.

During a development of a course model it is necessary to consider the goal indicators that can be divided into two groups: quantitative and qualitative. Quantitative indicators include teaching material acquisition level, acquisition computerization degree and realization. And qualitative are teaching material difficulty and complexity.

Course consists of several topics, which are interconnected. All the connections have weight that shows a topic acquisition level, i.e., the detailing of knowledge of a topic. Thus, course model is oriented graph with weighed edges G (V, S). Graph vertices represent learning objects (LO) and edges are connections between them (Fig. 2.3.). Edges can be one of four types:

s_1 – to obtain current LO general knowledge on previous is essential;

s_2 – while working with current LO many appealing to previous are possible;

s_3 – to acquire current LO special knowledge on previous objects is necessary;

s_4 – for current LO gaining and using information for practical reasons good knowledge of previous objects is essential.

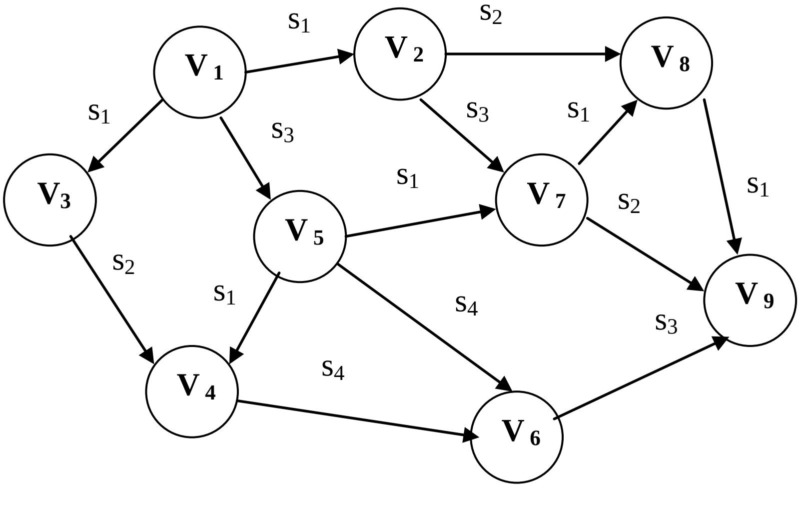


Figure 2.3. Course model graph model

Learning object (LO) can be represented on two levels: macro (topic, chapter) and micro (teaching information quant). LO is any digital resource that can be re-used for teaching and learning assistance.

The main requirements for developing a micro level learning object are as follows:

- they are small teaching material quanta lasting 2 – 15 minutes;
- they are complete, which means that they can be used separately, ensuring the re-usage possibility;
- can be combined in one group (e.g., in topic, course chapter);
- described with metadata (each LO is described so it can be found easily).

Learning objects can be divided into two groups: learning object information (LOI) and learning object task (LOT).

Thus, using Becus notation

<LO> :: = <LOI> | <LOT>.

LO information is used for teaching information acquisition and can include various information types that define detailing degree of descriptions:

- MAIN – short (general) information on concept;
- EXM – MAIN explaining example;
- EXP – detailed explanation on a concept;
- EXP2 – more detailed and complete explanation of a concept;
- EXP3 – detailed explanation of an example.

Thus, according to Becus notation LOI is as follows:

<LOI> ::= <MAIN> | <MAIN> <EXM> | <MAIN> <EXP> | <MAIN> <EXM> <EXP3> | <MAIN> <EXP> <EXM> | <MAIN> <EXP> <EXP2> | <MAIN> <EXP> <EXP2> <EXM> | <MAIN><EXP> <EXM> <EXP3> | MAIN> <EXP> <EXP2> <EXM> <EXP3>.

MAIN LOI is one of the following four types: Definition, Structure, Example, Rule. Object type depends on information that is included on a concept. LOI structure is shown in Figure 2.4.

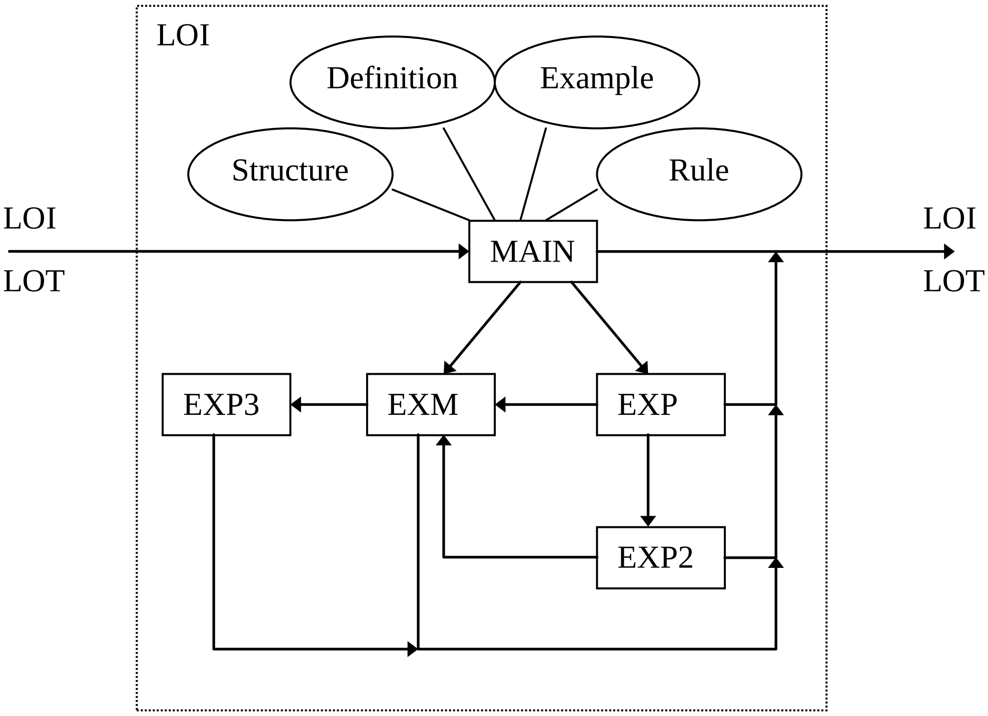


Figure 2.4. LOI structure

LO task is used to obtain essential skills fulfilling some task or answering a question. It consists of two main parts: task or question (TASK) and comment (COMMENT). In it's turn, task text can consist of two (or more) parts as well: general task/question (G_TASK) and individually generated fulfillment conditions and rules (I_TASK). Comment can be of different types:

- RIGHT – correctness comment (correct, wrong, not precisely);
- SHORT – short explanation;
- FULL – detailed explanation.

Thus, with the Becus notation LOT is as follows:

<LOT> :: = <TASK> | <TASK> <COMMENT>,

<TASK> ::= <G_TASK> | <G_TASK><I_TASK>,

<COMMENT> :: = <RIGHT> | <RIGHT> <SHORT> | <RIGHT> <FULL> |

<RIGHT> <SHORT> <FULL>.

Task (TASK) type accords to MAIN LOI type, which is predecessor for current question. LOT stricter is shown in Figure 2.5.

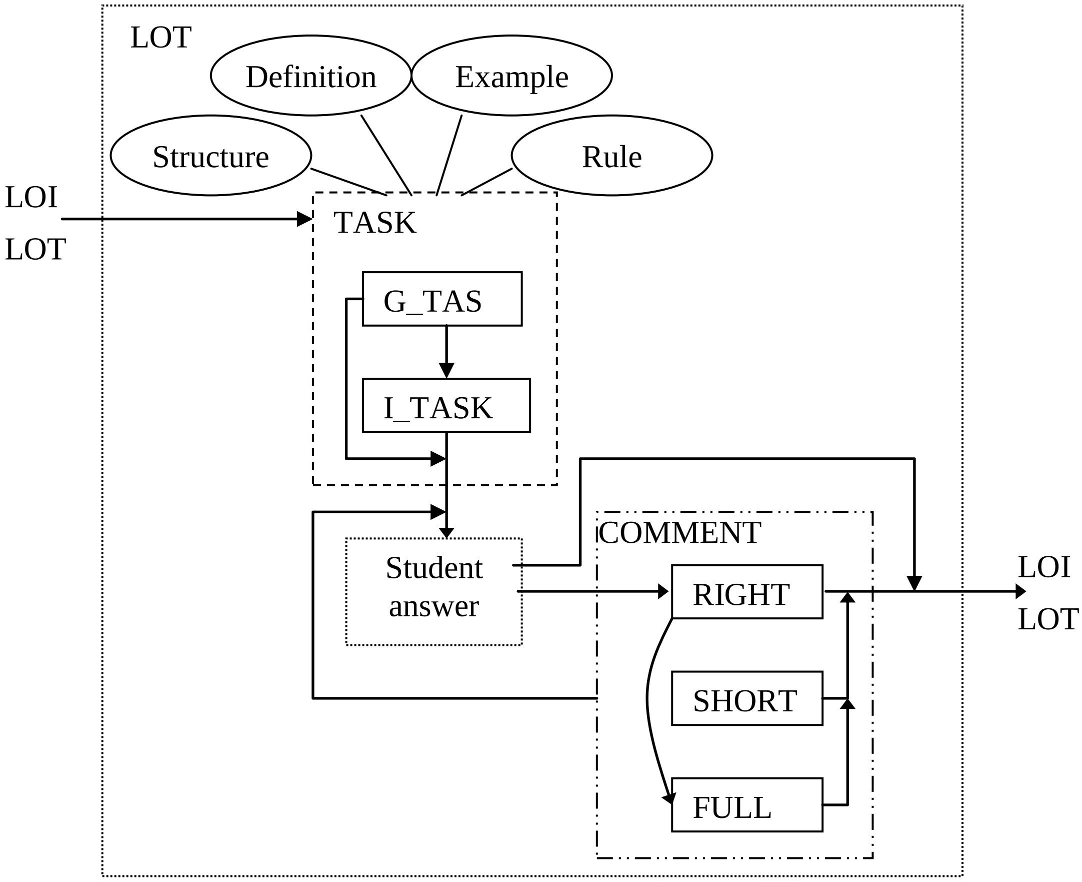


Figure 2.5. LOT structure

Both LO information and LO task can be afore developed (before starting a course), combined in a structure and included into computer-assisted teaching system Knowledge base (KB). As well it is possible to generate them during a learning process according to other models that are included in KB.

Considering the offered structures of LOs learning material model can be represented more clearly by using hypertext mathematical notation:

$$MV = (T, I, S, Q),$$

where T – subject thesaurus, which shows all the possible relationships among learning objects;

I – hypertext informational component that includes contents of all LOs $I = \bigcup_i I_i$;

S – vocabulary of all the LOs (alphabetical or chronological);

Q – main topics being covered by learning objects.

To describe each LO relationships with others it is necessary to define LO thesaurus:

$$t_{loi} = \{lo_i, A_{loi}\},$$

where lo_i – learning object being reviewed;

$$A_{loi} = \{R_1(lo_{11}, lo_{12}, ..., lo_{1a}), R_p(lo_{p1}, lo_{p2}, ..., lo_{pb})\},$$

where p – the number of relationships for current learning object;

a – LO number with R_1 relationship with the current;

b – LO number with R_p relationship with the current.

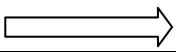
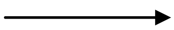
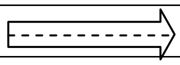
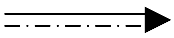
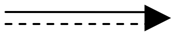
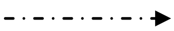
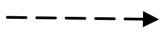
General thesaurus structure includes the thesauruses of all the learning objects (n – number of LOs in a course):

$$T = \{t_1, t_2, ..., t_n\} = \{lo_1, lo_2, ..., lo_n, A_{lo1}, A_{lo2}, ..., A_{lon}\}.$$

Graphically model thesaurus can be represented as a network with the vertexes defining learning objects and edges – relationships among them determining a bond type as well. Relationships types for learning material model are shown in Table 2.1.

Table 2.1.

Graphical relationship representation

Nr.	Graphical notation	Description
R_1		Kind-Type (e.g., LOI-MAIN, LOI-EXP)
R_2		Type-Kind
R_3		Part-Whole (concept-topic, LOT-test)
R_4		Whole-Part
R_5		Process-Metaprocess (test-exam)
R_6		Metaprocess-Process
R_7		Consequence-Reason (the first level LOs relationships that defines curriculum sequence)
R_8		Reason-Consequence
R_9		Equality (LOs that describes the same concept with different technologies)

Constructing an e-learning course model it is necessary to consider several questions: how many LOs are in the course (both LOI and LOT); will there be tests, exam or other control works; what kind of relationships are among all these units.

The thesaurus forming step-by-step is shown for the following example:

1. e-course consists of 17 learning objects, where 9 are LOI and 8 LOT;
2. there are 2 tests (PD) designated for controlling course parts acquisition. As well the exam (EKS) on all the topics is planned at the end of the course;

3. all of the LOI levels are included – LOI-MAIN, LOI-EXP, LOI-EXM, and for representing information various multimedia is used (text, audio and graphics);
4. the path through subject model depends on student current activity, background knowledge and other characteristics;
5. relationships for each LO are as follows:
    a. $A_{LOI1} = \{R_1(LOI_2, LOI_3), R_8(LOI_2, LOI_3, LOI_6), R_9(LOI_4, LOI_5)\}$
    b. $A_{LOI2} = A_{LOI3} = \{R_1(LOI_1), R_7(LOI_6), R_8(LOI_1)\}$
    c. $A_{LOI4} = A_{LOI5} = \{R_1(LOI_2, LOI_3), R_8(LOI_2, LOI_3, LOI_6)\}$
    d. $A_{LOI6} = \{R_8(PD_1, LOI_7)\}$
    e. $A_{LOI7} = \{R_4(LOI_8), R_8(PD_2), R_9(LOI_8, LOI_9)\}$
    f. $A_{LOI8} = A_{LOI9} = \{R_8(PD_2)\}$
    g. $A_{LOT1} = \{R_3(PD_1), R_9(LOT_4, LOT_5)\}$
    h. $A_{LOT2} = \{R_3(PD_1), R_8(LOT_3)\}$
    i. $A_{LOT3} = \{R_3(PD_1)\}$
    j. $A_{LOT4} = A_{LOT5} = \{R_9(LOT_1)\}$
    k. $A_{LOT6} = A_{LOT7} = A_{LOT8} = \{R_3(PD_2)\}$
    l. $A_{PD1} = \{R_4(LOT_1, LOT_2, LOT_3), R_6(EKS), R_7(LOI_6), R_8(LOI_7)\}$
    m. $A_{PD2} = \{R_4(LOT_6, LOT_7, LOT_8), R_6(EKS)\}$
    n. $A_{EKS} = \{R_5(PD_1, PD_2)\}$
6. the whole thesaurus for e-course is as follows:

    $T = \{LOI_1, LOI_2, LOI_3, LOI_4, LOI_5, LOI_6, LOI_7, LOI_8, LOI_9, LOT_1, LOT_2, LOT_3, LOT_4, LOT_5, LOT_6, LOT_7, LOT_8, PD_1, PD_2, EKS, R_1(LOI_2, LOI_3), R_8(LOI_2, LOI_3, LOI_6), R_9(LOI_4, LOI_5), R_1(LOI_1), R_7(LOI_6), R_8(LOI_1), R_1(LOI_2, LOI_3), R_8(LOI_2, LOI_3, LOI_6), R_8(PD_1, LOI_7), R_4(LOI_8), R_8(PD_2), R_9(LOI_8, LOI_9), R_8(PD_2), R_3(PD_1), R_9(LOT_4, LOT_5), R_3(PD_1), R_8(LOT_3), R_3(PD_1), R_9(LOT_1), R_3(PD_2), R_4(LOT_1, LOT_2, LOT_3), R_6(EKS), R_7(LOI_6), R_8(LOI_7), R_4(LOT_6, LOT_7, LOT_8), R_6(EKS), R_5(PD_1, PD_2)\}$

Graphical representation of the developed thesaurus is shown in Figure 2.6.

Relationships among objects are binary therefore are hanging if model reviewing direction changes that allows defining an orientation of thesaurus processing.

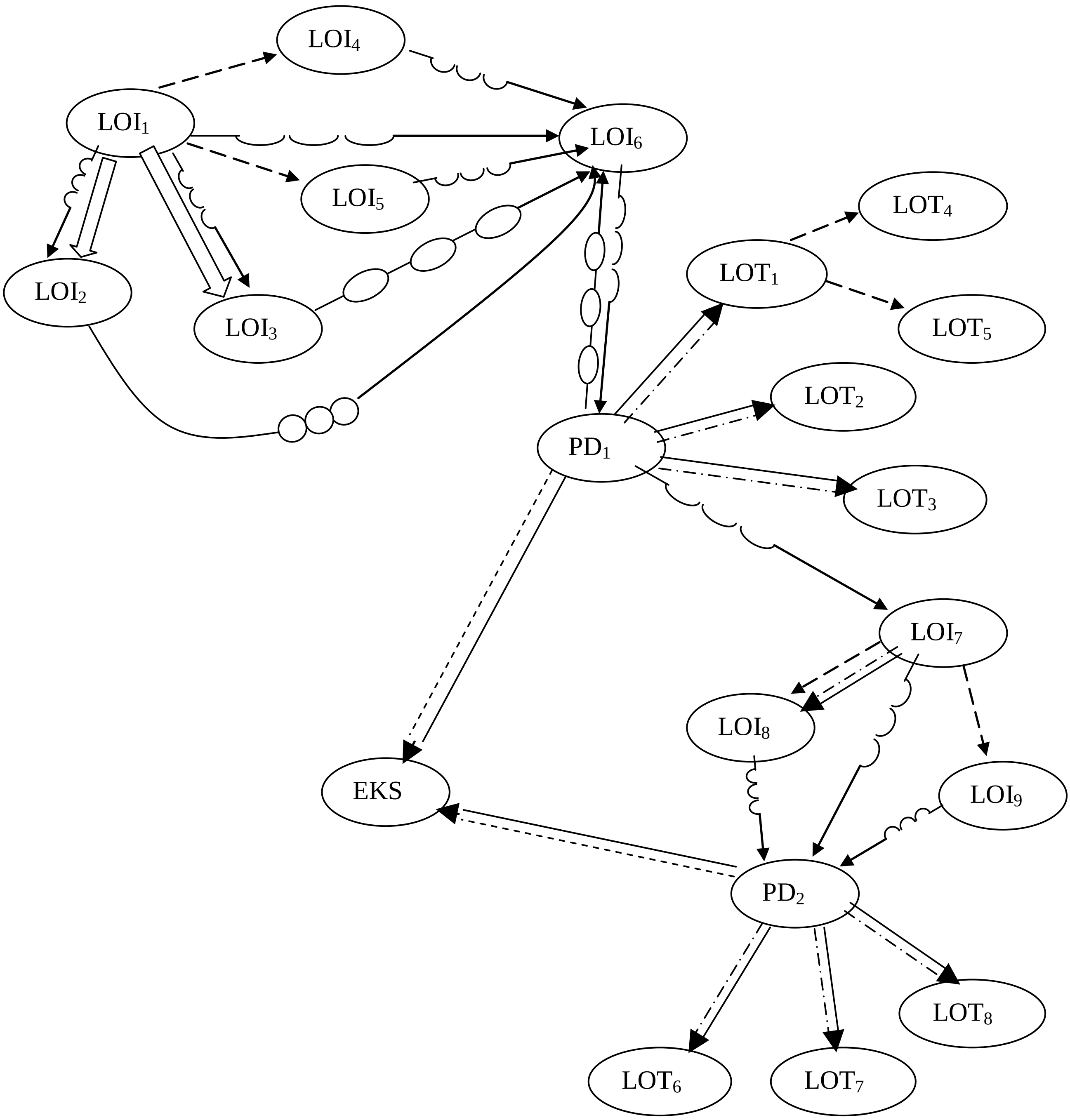


Figure 2.6. Subject model thesaurus

2.2.2. Expert model

Expert model represents course teaching goals. It means that this model shows what student should know and be able to do after definite course acquisition.

Expert model is static and is being compared with student model at the end of learning. It means that student gained result is compared with according expert model parts. Thus, expert model should include information about knowledge and skills as well as professional and psychological characteristics that a specialist should have:

$$M_{eks} = \{Z, IP, PI\},$$

where

Z – knowledge about a course, i.e., “information that a person gained in experience, learning, etc.”. The most often way to represent it is a mark, which has to be attained for successful finishing of a course. The same way – marks can be defined for border topics (vector) or every learning object accordingly to a course graph;

IP – skills (“ability to do something that is gained after training”). Depicted the same way as knowledge on a course;

PI – psychological characteristics. Defines what psychological characteristics should have the specialist.

Doctoral thesis shows the developed expert model for programming engineer. The formation of the model was based on the Latvian standard PS0227 consisting requirements for profession “Programming engineer” and questionnaire results. The questionnaires filled the leading Latvian companies’ specialists, who work on software systems development. The created pool consists of seven chapters with various evaluation indicators:

1) general skills for IT field specialists – 5 indicators;
2) professional skills – 30 indicators;
3) professional psychological characteristics – 7 indicators;
4) social factors – 9 indicators;
5) programming languages – 9 indicators;
6) technologies and specialized software – 10 indicators;
7) operating systems – 6 indicators.

Questionnaires processing results showed what knowledge and skills as well as psychological and social characteristics are essential nowadays for a programming engineer. The most important and the least important factors according to expert opinions are outlined in Table 2.2.

Table 2.2.

Questionnaire result

Nr.	Factors group	Factor	
		The most important	**The least important**
1.	General skills for IT field	Use text and graphics editors and other office programs	Participate in project management
2.	Professional skills	Write and debug programs	Manage co-workers team
3.	Professional psychological characteristics	Work abilities (ability to fulfill a task unaided)	Good memory
4.	Social factors	Consider principles of professional ethics	Prepare presentations and events
5.	Programming languages	C, C++, Java	Simulation language GPSS
6.	Technologies and specialized software	DBPS (Oracle, DB2, etc.)	ICE (Integrated Configuration Environment)
7.	Operating systems	MS Windows	MAC OS

2.2.3. Student model

Student model includes information about learner knowledge and skills levels, progress in working with a course, results, personal psychological characteristics and other factors. Student model is dynamical and is changing according to a student activity while working with a course.

The problem of a student modeling is still as actual nowadays as it was earlier, but nowadays there are more possibilities to solve it owing modern technologies. Many scientists and developers of computer-assisted teaching systems offer their student models that allow ensuring adaptation in various ways: Shute V., Roselli T., Grasso A., Plantamura P., Kabassi K., Virvou M., Sison R., Rikure T. and others.

During research 16 models were examined and was made their comparative analysis considering the representation way (Fig. 2.7.). Presently the most popular ways are vector and graph – 30% and 61% accordingly. The least used is genetic graph – 2%.

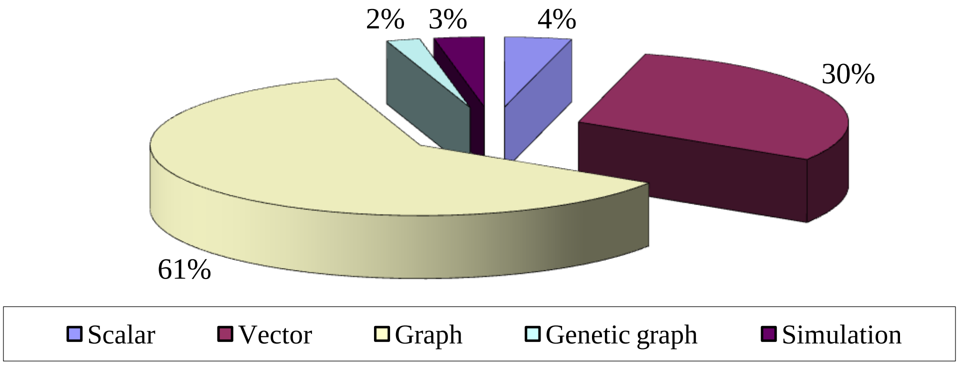


Figure 2.7. Student models types

According to a student model representation way (type) various parameters are considered (Fig. 2.8.):

1. knowledge level;
2. psychological characteristics;
3. learning speed;
4. tasks performance quality;
5. learning ability;
6. skills level;
7. teaching methods, strategy;
8. knowledge graph.

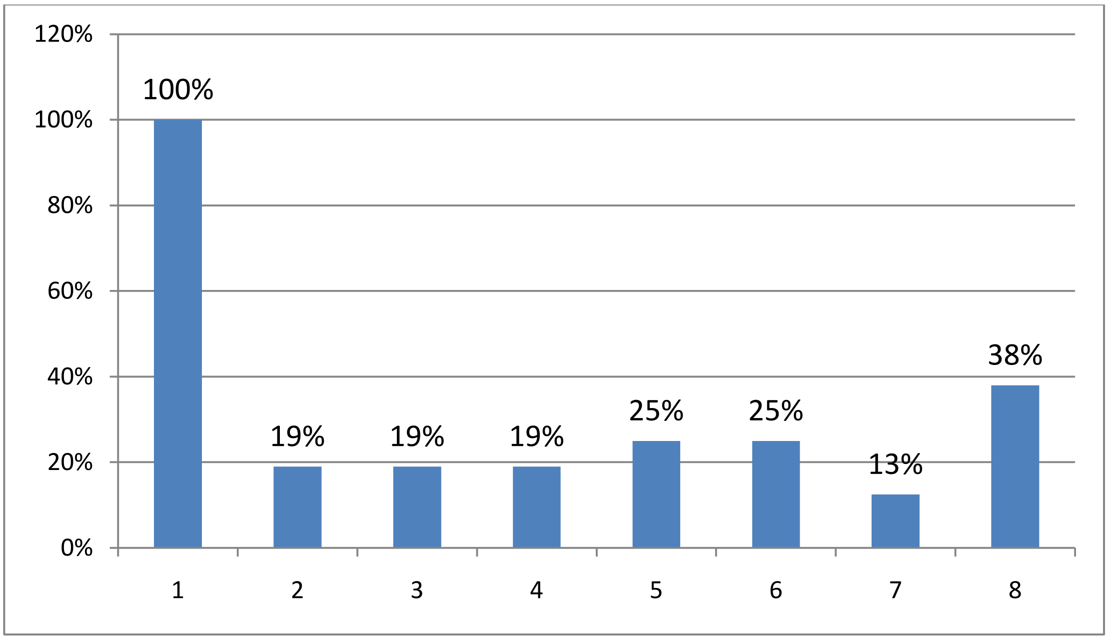


Figure 2.8. Student models parameter

All of the researched models include knowledge level. It is obvious because of one of the main teaching goals is to give a student essential knowledge on a course. Mostly it combines not just knowledge, but also skills level and is represented as a mark. But this way doesn't allow defining whether student really gained determined teaching goals. Of course, separately knowledge and skills could be derived form made tasks, but it's more useful to keep this data apart to see student levels at once. Knowledge and skills levels are important results of learning, but not the only ones that influences final outcome. The learning result is affected also by psychological characteristics and abilities, but this parameter almost is not included in any model.

The developed student model for adaptive learning consists of 6 components with 19 parameters (Tab. 2.3.). It has heterogeneous structure – at the first level it is a vector, but the next are vectors and graph. So, the first level of the student model is as follows:

$$M_{st} = \{M_{vi}, M_{am}, M_{sl}, M_{p\bar{\imath}}, M_{d}, M_{pap}\}$$

General information is vector M_{vi} = {MP, F, Spec, PS}, where MP – study program, MP = {bachelor, engineer, master, college}; F – faculty; Spec – specialty; PS – experience in working with computer, PS = {high, intermediate, low}.

Teaching method M_{am} shows, what a teaching method AM and/or teaching strategy MS should be used at the current step. This component also can be represented as a vector for method and strategy could be defined separately:

$$M_{am} = \begin{cases} AM, \\ \{AM, MS\}. \end{cases}$$

Background knowledge and skills level M_{sl} also is a vector M_{sl} = {Z, IP, Rangs}, where Z – knowledge level, IP – skills level, Rangs – rank, which depends on knowledge and skills level. Z and IP are 10-point system mark. If student starts work with a system for the first time (which means, that there are no data about him), then to define the values for these parameters afore knowledge control should be organized. After each course part acquisition data changes according to the gained results.

Psychological characteristics $M_{p\bar{\imath}}$ are represented as a vector: $M_{p\bar{\imath}}$ = {UT, O, MVeids}, where UT is one of perception types {aural, visual, tangible}; O – one of orientation types {on task, on him/herself, on collaboration}; MVeids – learning style, MS = {active, thinker, theorist, pragmatic}.

Current work with a course is a graph M_{td} (V, L), that is being made during learning process. The vertices of graph are vectors V = {MO_ID, Atk, Pask, Piem, Ātr, KD, UG, MSk, Atz}, where LO_ID is learning object, Atk – repetition (how many times student repeated the current topic); Pask – explanations (how many times used a possibility to get explanations on topic, concept, etc.); Piem – examples (how many times used a possibility to get examples for definite concept using); Ātr – speed (how long worked with current learning object); KD – number of mistakes (while performing a task, if there were allowed several tries); UG – task difficulty, UG = {low; average; high}; MSk – number of tries, that shows how many time student tried to fulfill a task; Atz – a mark for fulfilled task considering task parameters and tries and mistakes numbers.

Table 2.3.

Student model parameters

Component	**Parameters**
General information $\mathbf{M_{vi}}$	Study program Faculty Specialty Experience in work with computers
Teaching method $\mathbf{M_{am}}$	Methods and/or strategy
Background knowledge $\mathbf{M_{sl}}$	Knowledge level Skills level Rank
Psychological characteristics $\mathbf{M_{p\bar{ı}}}$	Perception type (aural, visual, tangible) Orientation (on task, on him/herself, on collaboration) Learning style (active, thinker, theorist, pragmatic)
Current work $\mathbf{M_{d}}$	Speed Mistakes number Task difficulty Tries number Mark
Additional information $\mathbf{M_{pap}}$	Explanations Examples Search out of the system

The current work graph is being made accordingly to a course model, dialogue scenario and student work. Graph example is shown in Figure 2.7.

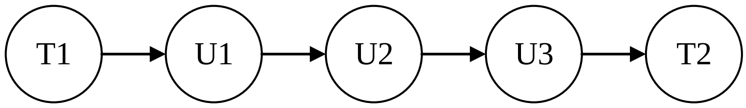


Figure 2.9. Current work with a course

Vertexes, shown in Figure 2.9., are as follows: {T1; 10; -; -; -; -}, {U1; 15; 2; average; 3; 4}, {U2; 10; 0; low; 1; 6}, {U3; 7; 0; low; 1; 8} and {T2; 15; -; -; -}. It means that a student after the first learning object T1 acquisition (time spent – 10 minutes) performed a tasks U1 with average difficulty. To fulfill the tasks student needed 15 minutes, he made 2 mistakes and answered correctly from the third time getting as a result mark 4. Considering that student couldn't make the tasks of an average difficulty he was provided with next task of low difficulty – U2, spending 10 minutes he answered from the first time with mark 6. To fixate the result he was given one more task of easy level – U3, which he performed within 7 minutes getting the mark 8. After tasks student went on to the next learning object information – T2, spending at it 15 minutes.

As it is shown in Figure 2.7., current work with a course is linear graph, because of it shows the way a student goes through course or topic model.

Additional parameters are represented as a vector M_{pap} = {Pask, Piem, Mekl}, where each element shows whether student in current session used and if yes, then how many times, additional possibilities to use detailed explanations (Pask), examples (Piem) for definite concept employment situations and search information outside of a system (Mekl).

2.3. E-course teaching adaptive methods

For effective e-course organization it is essential to ensure adaptivity and adaptability features. Adaptivity can be realized in three levels: to a user class, to a group within a class, individually to a user (student in this case). Every level uses different adaptivity ensuring methods (Tab. 2.4.).

Adaptabilty means that student will be able to change some system adjustments:

- working mode – if a course is available in different modes (learning, training, knowledge control, references) and it isn't strictly said which one is mandatory;
- topic to learn or train – when a course consists of several big topics and their prerequisite sequence is not defined;

- task difficulty level – training mode allows for everybody, knowledge control mode can be as additional parameter for tutor defined students;
- number of tries – the same as previous;
- LO for learning – according to topic model students with higher rank can be offered some explaining or examples LO's as alternative;
- audio/video/animation/presentation turning on/off – i.e., student chooses information representation way;
- comments output and detailing degree – for knowledge control and training modes.

Table 2.4.

adaptation ensuring in computer-assisted teaching systems

Adaptation level	**Adaptation methods**	**Used models**
User class	Adaptive navigation support Adaptive information presentation Example-based problem solving	User class model Student model
Group within user class	Curriculum sequencing Adaptive information presentation Adaptive navigation support	Course model Student group model Student model
Individual user (student)	Curriculum sequencing Interactive problem solving support Adaptive information presentation Adaptive navigation support Example-based problem solving	Student model

There were researched 150 computer-assisted teaching systems and it was defined that mostly adaptation is ensured for knowledge control mode determining before work student background knowledge and offering tasks of according difficulty level linearly (27%), without consideration of the performance. Some developers provide treed structure when the next task difficulty level depends on the current task accomplishment (14%). Unfortunately, there are many systems that don't ensure adaptation at all (38%). Also there are some minimal adaptation systems that offer possibility to get the same information repeatedly without any explanation and/or examples (15%). Some systems come with reaction to student activities that usually is short explanation.

Dialogue scenario ensures computer-assisted teaching and learning system adaptivity and adaptability. Scenario can be made in three ways: totally computerized dialogue development, partly computerized, afore determined.

I. Totally computerized dialogue development – curriculum author or tutor totally relies on developed algorithm, which defines what information, when and how should be presented to a student. The only thing that a person has to do is to prepare learning objects (LO, both information and tasks) – the content and all the metadata. Course teaching algorithm chooses LO from database according to information from student model.

II. Partly computerized dialogue scenario – curriculum author/tutor prepare a course (topic) teaching frame, including objects that he/she considers as important for course acquisition and mandatory for all the students. Algorithm if necessary adds scenario with appropriate objects according to student model.

III. Afore determined dialogue scenario. Curriculum author/tutor develops the full dialogue scenario. There can be made several scenarios that are planned for definite groups, specialties, knowledge and skills levels and so on. Algorithm accordingly to parameters chooses scenario. In this case adaptation is ensured on the second level (to a group with user class), as well as individual student considering his/her perception type, time for learning objects and other characteristics. Using such approach for developing dialogue scenario it is essential to remember that every student will get the same learning objects information (could be used various information representation ways, but the content is the same), but learning objects tasks could be different, if in scenario a tasks group is determined.

Using afore mentioned research results doctoral thesis describes the developed adaptation ensuring algorithm that considers all information from available models during learning process (Fig. 2.10.):

1) according to a student faculty, group, specialty, rank and other information from a course/topic model the learning objects (LO) are gotten – both information and tasks;
2) considering student background knowledge and skills level (rank) the mandatory LO’s are defined – just main, first level explanation and example, every. I.e., the detailing level is determined;
3) depending on information about whether or not student was using a possibility to get additional LO – explanation or examples (i.e., learn non-mandatory) and how

many times he/she did that in a row, the indicators for detailing degree definition are changed;

4) if a student for a current LO information (LOI) acquisition spent more or less time then it was necessary, then he gets a LO task (LOT) with a goal to check why it happened – everything is already obtained (less time) or difficulties to understand material and it is needed to offer additional information;

5) after current LOI student gets LOT's to evaluate if essential knowledge and/or skills are gained;

6) student answers influence model change – current work, overall background knowledge and skills level (rank), psychological characteristics.

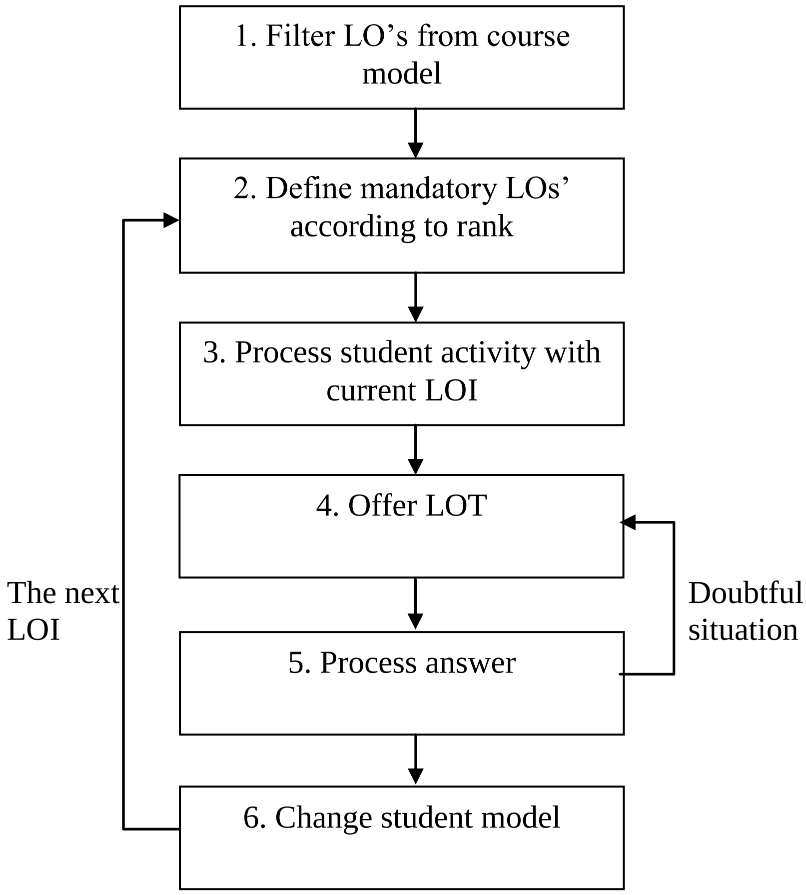


Figure 2.10. Adaptive e-learning algorithm steps

Such algorithm provides individual approach to every student accordingly to his/her work at each step. That increases the efficiency of e-course using. Algorithm is being used for e-learning at Institute of Applied Computer Systems Software Engineering Dpt.

2.4. E-courses development and efficiency

There was developed e-learning course “Software implementation” for the doctoral thesis. This e-course includes two types of learning objects – information LOI and tasks LOT (Tab. 2.5.).

Table 2.5.

Learning objects of e-course “Software implementation”

Nr.	**Type**	**Number**
1	*LOI*	*15*
	main	6
	exm	4
	exp	5
2	*LOT*	*19*
	Total	*34*

LOI describes the course concepts, examples, etc. The main LOI metadata that is necessary for adaptive learning is as follows:

- kind (MAIN – mandatory LOI, EXM – example, EXP – explanation). According to adaptive learning algorithm EXM and EXP can be optional for students with better rank or mandatory as the MAIN. The developed course has just three levels for examples and explanations, so if a student rank is 1 then EXM and EXP are optional, for rank 2, then the first level EXM and EXP are mandatory and all other are optional, for rank 3 all of them are mandatory;
- minimal time for LOI acquisition;
- maximal time;
- type (definition, example, structure, rule);
- specialty.

As to LOT, they are used to evaluate student knowledge and skills level on topic and on a course overall, i.e., border and final control. LOT metadata is:

- kind (multiple choice, word, number);
- significance;
- difficulty;

- time (if time is 0, then there is no limitations for LOT performing);
- number of tries (if LOT can be used in training mode, then number of allowed tries should be defined, for knowledge control it's 1);
- mode (training and/or knowledge control);
- goal (what's being tested – knowledge or skills).

For e-course learning organization partly computerized dialogue scenario development was used, i.e., all the LOI's were included in the frame, but for LOT's just questions and tasks groups were defined, and LOT is taken randomly form that group.

This e-course and six more are included into teaching process for subjects "Software engineering" (SE) and "Software metrology and planning models" (SMPM). To evaluate their efficiency the experiment was performed.

The goal of the experiment – to study efficiency of subjects SE and SMPM, including into teaching process e-courses. During comparative experiment in ingenuous circumstances the scientific hypothesis was evaluated: adaptive e-course including increases the efficiency of teaching process, motivation of students and decreases learning time (thanks to external work) in comparison with non-adaptive e-courses.

Experiment conditions.

Experiment was performed from 2004 till 2008 in 28 student groups, who learnt at study program "Computer systems". 373 students participated in it – the 3rd year bachelor and 1 year master program. Two strategies were used for including e-courses into teaching process:

- as optional tool. Students could choose to use or not adaptive e-course. This option was exploited by 54% of students;
- as teaching process part, when definite topics are presented in the e-course and students can get information from them (not during traditional lectures). In this case it's also was optional and was used by 72% of students.

During acquisition afore mentioned subjects students have to fulfill seven practical tasks of equivalent difficulty. Six of them are laboratory works and one course work for forming essential skills. As well at the end of a course they have to take an exam to evaluate knowledge and skills level.

Therefore evening experiment conditions are as follows: subject program (curriculum), control tests, laboratory works, course work and exam; control works timetable; classes' timetable and tutor. As to changeable conditions then they are student list (group) and subject teaching method (with adaptive e-course or not).

Experiment methodology.

One of the main parameter that shows acquisition level is a mark. In this case the mark of exam (describes knowledge on a subject) and marks for practical works (define skills in appropriate area) were considered. Therefore to evaluate e-courses using efficiency the following criteria were chosen:

1) exam mark;
2) practical work mark (course work).

E-course using results according to chose criteria are shown in Table 2.6., where Group A students who used adaptive e-courses and Group B didn't (used e-courses that don't support adaptive algorithm).

Table 2.6.

E-courses using results

Criteria / Year	1		2	
	Group A	**Group B**	**Group A**	**Group B**
2005	6.56	4.7	7.4	4.63
2006	7.124	5.21	7.38	4
2007	6.0	5.05	6.97	5.75
2008	6.15	5.42	7	4
Total	6.46	5.1	7.18	4.6

It can be concluded form Table 2.5., that adaptive e-courses including into teaching process improves results. To evaluate the efficiency more precisely mathematical statistics methods were used. And students background knowledge form other professional subjects was considered as well.

Evaluation of e-learning course applying with Student t-criteria.

Considering that marks are discrete values the student t-criteria for comparing two averages was used. The algorithm is as follows:

1. Define X (Y), that corresponds to the Group A (B) results according to every criteria;
2. Calculate average for every group;
3. Calculate selection dispersion $S_X^2 = \frac{\sum_{i=1}^{n_1}(X_i - X_V)^2}{n_1 - 1}$ and $S_Y^2 = \frac{\sum_{i=1}^{n_2}(Y_i - Y_V)^2}{n_2 - 1}$
4. Calculate empirical critical statistics value

$$\left|t_{emp}\right| = \frac{\left|X_V - Y_V\right|}{\sqrt{\frac{(n_1 - 1) * S_X^2 + (n_2 - 1) * S_Y^2}{n_1 + n_2 - 2}}} * \sqrt{\frac{n_1 * n_2}{n_1 + n_2}}$$

5. Define critical value $t_{kr}(\alpha, n_1 + n_2 - 2)$ for appropriate significance level α and given freedom degree number $r = n_1 + n_2 - 2$.
6. Compare t_{emp} and t_{kr}. If $t_{emp} \geq t_{kr}$, then difference between average values is vital for given significance level.

Taking into account that students of the groups are with different background knowledge and skills level for evaluation a mark increment was used:

$X_{ij} = M_{ij} - M_{ijp}$, $Y_{il} = N_{il} - N_{ilp}$,

where

X_{ij} (Y_{il}) – j-th (l-th) student i-th criteria increment in Group A (B);

M_{ij} (N_{il}) – j-th (l-th) student average i-th criteria value in Group A (B);

M_{ijp} (N_{ilp}) – j-th (l-th) student average i-th criteria value in specialty appropriate subjects in Group A (B);

i – number of criteria and i = 1, ..., ks, where ks – total amount of criteria (here 2);

j (l) – student number and in Group A (B) j = 1, ..., n_1, (l = 1, ..., n_2), where n_1 (n_2) is total students amount;

p – subject number and p = 1, ..., ps, where ps is total subjects amount.

It is needed to evaluate the hypothesis H_0: $X_V = Y_V$ with concurring H_1: $X_V > Y_V$. If the result of the seventh step of the algorithm is positive, i.e., $t_{emp} > t_{kr}$, then H_1 is true.

Value t_{emp} with true H_0 is divided according to Student rule with $r = n_1 + n_2 - 2$ freedom degrees. In this case the right critical range is being taken. Relevance level is presumed α=0.05 and therefore t_{kr} for r = 213 is equal to 1.64. Experiment data processing results are shown in Table 2.6.

Evaluation of e-learning course applying with Laplas function.

If independent selections size is big (more than 30), then selections average values are distributed approximately normally, but selection dispersions are satisfactory good general dispersion values and can be considered as approximately known.

In this case for hypothesis H_0: $X_V = Y_V$ evaluation criteria choose random value:

$$Z = \frac{\overline{X} - \overline{Y}}{\sqrt{\frac{S_X^2}{n} + \frac{S_Y^2}{m}}},$$

where $\overline{X}$ and $\overline{Y}$ are average values of students marks from Groups A and B accordingly;

n = 93, m = 120 – students number in Group A and Group B;

S^2_X and S^2_Y – selection dispersions for Groups A and B,

$$S_X^2 = \frac{\sum_{i=1}^{n_1}(X_i - X_V)^2}{n_1 - 1}, S_Y^2 = \frac{\sum_{i=1}^{n_2}(Y_i - Y_V)^2}{n_2 - 1}.$$

Concurring hypothesis is the same as in previous case – H_1: $X_V > Y_V$, therefore the right critical range is studied. Relevance level is taken α=0.05, then critical point is

$$\Phi(t_{kr}) = \frac{1 - 2\alpha}{2} = 0{,}45.$$

According to Laplas function table t_{kr} = 1,64. Experiment data processing results are shown in Table 2.7.

Table 2.7.

Experiment results

Criteria	**X_V – Y_V**	S_X^2	S_Y^2	**t_{emp} (Z)**
Student t-criteria				
1	0.4	1.08	1.02	2.84
2	1.11	13.6	23.5	1.83
Laplas function				
1	0.4	1.08	1.02	2.88
2	1.11	13.6	23.5	1.85

Therefore according to the Table 2.6., it can be seen, that for all criteria t_{emp} is bigger than t_{kr}, which means $H_1$is taken as true and proves adaptive e-course including in the teaching process positive influence on the results – the outcome for Group A students are better with relevance level 0.05.

As well for both criteria Z > t_{kr} makes H_1: $X_V > Y_V$ true, i.e., selections average values differs significantly. Thus, adaptive e-course using notably improves results with relevance level 0.05.

3. DOCTORAL THESIS RESULTS

The goal of the doctoral thesis was to research and to develop adaptive computer-assisted teaching methods considering modern computer technologies possibilities and student model. The thesis describes computer-assisted teaching process and its organization using various models.

The main results of the doctoral thesis are as follows:

1. Researched and classified according to 4 criteria 150 computer-assisted learning systems. The results showed that adaptation mostly is not ensured (38%) or recurrent LO representation is provided (15%). As computer-assisted learning process model the modified professor L. Rastrigin model for complex system management was considered.
2. Analyzed models that are used to organize CAT: subject (teaching material) model, expert (knowledge and skills) model and student model. Models interconnection is described in details.
3. Researched course model developing process, quality and quantitative characteristics and representing ways. As well examined re-usable learning objects constructing principles and offered learning object information and learning object task structures. Proposed course model describing way by using hypertext mathematical notation, which includes all the learning objects and their relationships.
4. Offered expert (knowledge) model. This model can be considered as a goal of a course teaching, for it represents what knowledge and skills as well psychological characteristics should have student after finishing. According to organized questionnaire of Latvian experts the most important general skill in IT field is to use text and graphics editors and other office programs, the main professional skill – to code and debug programs, professional psychological characteristic – working ability, social factor – to follow the principles of the professional ethics, language knowledge – C, C++ and Java, knowledge of technologies and specialized software – DBMS, operating systems – MS Windows.
5. Researched student models and their parameters, given models classification according to the types, accomplished comparative analysis based on the type (the most popular is vector – 30% and graph – 61%) and parameters (the most models includes knowledge level – 42%, and also knowledge graph is rather popular – 16%). The thesis offers student model for adaptive learning, which includes five components with 19

parameters: general information, background knowledge and skills level, current work with e-course, teaching method, psychological.

6. Described developed adaptive teaching algorithm considering student model data. Explored adaptability feature that allows students changing various e-course learning parameters – commenting, tasks difficulty, number of tries, choosing of learning objects, and representation of information.
7. Shown e-learning course development, results of including it into teaching process and efficiency evaluation, using methods of mathematical statistics and students' questionnaire.

The main doctoral thesis result is proposed models, on the basis of which the adaptive and adaptable teaching and learning can be organized. Models set consists of student model that includes all the information about a student; course model containing the re0usable learning objects with theoretical information and practical tasks/questions as well showing relationships among them; knowledge/expert model representing goals of a course teaching.

4. THE RESULTS APPROBATION

The doctoral thesis was presented at the seminar of the International Research and Training Center for Information Technologies and Systems National Academy of Science of Ukraine and Ministry of Education and Science of Ukraine. As the result the recommendation for the thesis defense was received.

4.1. Reporting at the conferences

1. Advanced Learning technologies and Applications ALTA'03. Kaunas, Lithuania. September 11 – 12, 2003
2. Advances in Databases and Information Systems: 13th East-European Conference, ADBIS 2009. Riga, Latvia. 7 – 9 September, 2009
3. E-learning conference'06 Computer Science Education. Coimbra, Portugal. September 7-8, 2006
4. IADIS International Conference e-Learning 2007. Lisabon, Portugal. July 6-8, 2007
5. IADIS International Conference Mobile Learning 2005. Qawra, Malta. June 28 - 30, 2005
6. IASTED International Conference on Computers and Advanced Technology in Education. Rhodes, Greece. June 30 – July 2, 2003
7. International Conference "Knowledge Society Challenges for E-Learning". Kaunas, Lithuania. May 26-27, 2005
8. International Workshop Telematics and Life-Long Learning TLLL-2001. Kiev, Ukraine. October 15 – 17, 2001
9. RTU 42. International scientific conference. Riga, Latvia. October 11 – 13, 2001
10. International Inter-higher School Scientific and Educational Conference "Actual problems of Education". Riga, Latvia. February 24-25, 2005
11. International Inter-higher School Scientific and Educational Conference "Actual problems of Education". Riga, Latvia. February 23-24, 2006
12. The 10th IASTED International Conference on Computers and Advanced Technology in Education. Beijing, China. October 8-10, 2007
13. The 11th IASTED International Conference on Computers and Advanced Technology in Education. Crete, Greece. September 29 - October 1, 2008.

14. The 11th international conference on information systems development (Methods & Tools. Theory & Practice) ISD 2002. Doctoral Consortium. Riga, Latvia. September 12 – 14, 2002
15. The 18th International Conference on Systems for Automation of Engineering and Research SAER-2004. Varna, Bulgaria. September 24 – 26, 2004
16. The 3rd IEEE International Conference on Advanced Learning Technologies ICALT'03. Athens, Greece. July 9 – 11, 2003
17. The 6th International Conference on Advanced Learning Technologies (ICALT 2006). Kerkrade, Netherlands. July 5-7, 2006
18. The 8th IASTED International Conference on Computers And Advanced Technology In Education. Oranjestad, Aruba. August 29 - 31, 2005
19. The 8th IEEE International Conference on Advanced Learning Technologies (ICALT 2008). Santander, Cantabria, Spain. July 1-5, 2008.
20. The First International Conference "Information Technologies in Education for All" (ITEA - 2006). Kiev, Ukraine. May 29 – 31, 2006.
21. VII International Scientific Conference "Innovative technologies in pedagogic of higher education" - Yekaterinburg, Russia. October 11-13, 2010
22. World Conference in Educational Multimedia, Hypermedia & Telecommunications ED-MEDIA. Lugano, Switzerland. June 21 – 26, 2004
23. X Scientific-methodical conference Telematika'2003. St-Petersburg, Russia. April 14 – 17, 2003
24. II international conference "Quality strategy in national economy and education", Varna, Bulgaria, June 2-9, 2006
25. Education and virtuality - 2001. Proceedings of the 5th international conference. - Kharkov-Yalta, Ukraine, September 19 – 21, 2001

4.2. Publications

1. Boule C., Zaiceva L. Learning objects for mobile learning // Proceedings of IADIS International Conference Mobile Learning 2005 Qawra, Malta 28-30 June 2005, p. 189 - 193
2. Bule J. Adaptivity in computer-assisted teaching systems based on student model // Proceedings of II international conference "Quality strategy in national economy and education", Vol. 2 - Varna, Bulgaria, June 2 - 9, 2006, p. 204 - 207 (in Russian)

3. Bule J. Adaptive Computer-aided Teaching Methods based on Student Model // Proceedings of First International Conference “Information Technologies in Education for All” (ITEA - 2006), Ukraine, IRTC - Kiev 2006. – p. 221 – 230
4. Bule J. Adaptive E-Learning Courses at Riga Technical University Software Engineering Department // Proceedings of Advances in Databases and Information Systems: 13th East-European Conference, ADBIS 2009. Riga, Latvia. 7 – 9 September, 2009. pp. 238-245.
5. Bule J. Internet Technologies Applying in Learning. // RTU scientific proceedings. Series 5, vol. 8. 2001, - pp. 150-156. (in Latvian)
6. Bule J. Problems of learning course management. // Proceeding of 43rd student scientific-technical conference. - Riga: RTU, 2002, - pp. 31. (in Latvian)
7. Bule J. Management of teaching course using multimedia and web technologies. // ISD 2002. Eleventh international conference on information systems development (Methods & Tools. Theory & Practice). Doctoral Consortium Proceedings. Riga: RTU, 2002, - pp. 6.-14.
8. Bule J. Overview of student models for computer-based teaching systems. // Educational Technology & Society 6(4) 2003 ISSN 1436-4522 (in Russian)
9. Bule J. Comparative analysis of student models. // Proceedings of X Scientific-methodical conference Telematika'2003. Tom 2. Section D, E. - Sankt-Petersburg, 2003, - s. 364 - 366. (in Russian)
10. Bule J. The e-Learning Course: „Software Implementation" Development // Proceedings of the 11th IASTED International Conference on Computers and Advanced Technology in Education. Crete, Greece. September 29 - October 1, 2008, - pp. 126 - 129.
11. Bule J., Zaiceva L. Expert Model Development in E-Learning Systems // Proceedings of the 10th IASTED International Conference on Computers and Advanced Technology in Education. Beijing, China. October 8-10, 2007, - pp. 81 - 84.
12. Bule J., Zaiceva L. Multimedia in Education // Telematics and Life-Long Learning. Proceedings of the International Workshop. TLLL-2001. October 15-17, 2001, Kyiv, Ukraine: IRTC UNESCO, IEEE Learning Technology Task, Force 2001, - p. 51 - 53 (V.Glushkov Cybernetics Institute of Ukraine Science Academy)
13. Bule J., Zaiceva L. Development of learning courses based on multimedia // Education and virtuality - 2001. Proceedings of the 5th international conference. - Kharkov-Yalta, 2001, - pp. 145 - 152

14. Bule J., Zaitseva L. Computer-based learning process organization. – Proceedings of International Conference “Knowledge Society Challenges for E-Learning”. Kaunas, Lithuania. 26-27 May 2005. 185 - 189 pp.
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