

RIGA TECHNICAL UNIVERSITY
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**THE RESEARCH AND IMPLEMENTATION
OF PERSONALIZED STUDY PLANNING AS A COMPONENT
OF PEDAGOGICAL MODULE**

Summary of Doctoral Thesis

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CONFIRMATION

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.

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Date:

The doctoral thesis is written in Latvian and includes introduction, 4 sections, conclusions, bibliography, 22 appendixes, 92 figures and 8 tables in the main text, 195 pages. The bibliography contains 173 references.

TABLE OF CONTENTS

Introduction	5
1. Computer assisted learning instruments and intelligent tutoring systems.....	11
1.1. The Evolution of Tutoring Systems.....	12
1.2. The Architectures of Intelligent Tutoring Systems	13
1.3. Characteristics of the pedagogical module	15
1.4. Summary and Conclusions	16
2. Intelligent tutoring systems for the development of study plan and study courses	16
2.1. Intelligent Tutoring Systems for the Implementation of Study Courses	16
2.2. Intelligent Tutoring Systems for the Design of Personalized Study Plans.....	18
2.3. The Joint Analysis of the Reviewed Tutoring Systems Used in Implementation of Study Courses and Study Plans	20
2.4. Summary and Conclusions	22
3. Framework of personalized study planning for the implementation of a study system's pedagogical module	22
3.1. Framework of Personalized Study Planning.....	22
3.1.1. Description of the Structure of the Study Plan	24
3.1.2. Description the Structure of a Study Course	24
3.1.3. Concept Map of the Course Topics	25
3.1.4. Graph of Learning Objects	26
3.2. Analysis of the Structure of Graphs.....	27
3.3. Algorithms of Graph Visualization	30
3.4. Summary and Conclusions	30
4. Implementation of a personalized study planning system	31
4.1. Prototype of a Personalized Study Planning System	31
4.1.1. Data Input Tool <i>SPS.DataManager</i>	32
4.1.2. Tool for Personalized Study Planning <i>SPS.StudentStudyprogramBuilder</i>	33
4.1.3. Individualizētu studiju plānošanas sistēmas prototipa aprobācijas scenāriji....	36
4.2. Implementation of Rank Calculation in the personalized Study Planning System SPS	37
4.3. The Opportunities of Integration of Personalized Study Planning Systems with Other Tutoring Systems	39
4.4. Summary and Conclusions	40
The main results and conclusions.....	42
Bibliography	44

INTRODUCTION

Many people are striving for better higher education, improvement of their qualifications or wishing to upgrade their knowledge. Not all who want to learn something have the possibility to attend the institutions of higher education and acquire knowledge when choosing any form of studies. There are different study forms such as full-time, evening, part-time, and distance learning or e-studies. The most popular type of studies in Latvia is full-time studies [1], but not everybody can adapt one's daily plans with the schedule of the full-time studies. More and more widely there are used different systems for the organization of studies based on information and communication technologies (ICT) out of which the most perfect are intelligent tutoring systems [2, 3]. They allow to adapt the studies for the learner thus making the studies more available.

The Topicality of the Theme

Within the framework of the research there is carried out the analysis of the education planning documents in Latvia and European Commission. As Finland's educational system is recognized as the best in the world according to the research of educational company “Pearson” [4], it is useful to analyse the Finland's documents of planning. According to analysed documents it can be concluded that there is mentioned not only the importance of the education for the society but also its availability and the application of technologies. As the third priority in „Sustainable development strategy of Latvia till 2030” [5] there is mentioned change of paradigm in education the aim of which is to create one of the best educational systems in European Union and to become one of the leaders in adult education. As one of the directions of development in this third priority is mentioned qualitative and available lifelong education and as two of several activities for achievement of the goal are mentioned e-school and the use of information technologies, and lifelong learning.

In the report of European Union (EU) of 2011 it is invited to promote that in teaching and knowledge acquisition there are accepted student-oriented approaches taking into account their needs as well as it is invited to foster varied study forms including effective use of ICT [6].

In the EU report of 2013 it is defined to optimize ICT based learning and accessibility to qualitative, open educational resources, for example, supporting ICT based learning and assessment practice, promoting the transparency of rights and duties of the digital content users and designers, and helping educational and tutoring institutions to adapt to the spread of open educational resources especially regarding the quality assurance and supervision [7].

One more middle term document of political planning related to improvement of the quality of education and the use of ICT in education in Latvia is the implementation of the program “The Education Quality of Information and Communication Technologies” for the period 2007–2013 [8] where it is said that purposeful use of ICT is one of the topical instruments for improvement of education quality. One of the program's sub-objectives is “to

use information and communication technologies in studying process, developing electronic study materials, improving the content of education program, offering and using different services for promotion of education quality.”

Finland's Ministry of Education and Culture in planing document for 2012 as one of the priorities for improvement of education content mentions the development of learning environment using ICT. In its turn as necessary changes in professional further education, the document mentions the necessity to satisfy the needs of different learners, the use of different learning environment and ICT [9]. Consequently also in Finland's planning document there is emphasized the necessity to satisfy the different needs of learners' education and the development of learning environment using ICT.

As the demand towards education will grow in the future the reviewed planning documents suggest the conclusion that learners need to be ensured greater variety of study forms and more individualistic learning in order satisfy the necessity for new competences and skills. Full-time study forms not always correspond to the learner's demands because he/she has individual demands and interests for learning as well as skills, background knowledge, learning style, and besides the learner very often studies in parallel with work. The use of ICT has great importance in the study process which offers electronic study materials. ICT can be used as additional tools in organization of the lecture, development of study materials, knowledge assessment, communication, etc. ICT allows to make the study process more attractive and more interesting as well as more adequate to the demands of the 21st century [10]. The application of ICT in the studies and in the storage of electronic materials is ensured by computerized learning systems which offer to the learner to study in the environment that does not depend on time and location. However, it should be remarked that computerized learning systems do not ensure individual approach. Hence there is need for such learning system that implements personalized learning and it starts with the development of individual study plan according to learner's desires and need. Personalized learning can be implemented in two ways: either the teacher individually collaborates with the learner or there is developed intelligent tutoring system.

The Aim of the Doctoral Thesis

The aim of the Doctoral Thesis is to offer the framework of personalized study planning so that the learner could not only construct his/her own individual learning scenario, but also determine the most important courses, themes and concepts corresponding to them as well as implement the framework in practice as a prototype of personalized study planning and carry out its testing.

The Objectives

To achieve the aim of the Doctoral Thesis the following objectives have been set:

- to analyse the evolution of the development of the learning systems;

- to accomplish the analysis of architecture and pedagogical modules of intelligent tutoring systems (ITS) in order to clarify their components;
- to opportunities the existing personalized study planning systems in order to clarify their possibilities and drawbacks;
- to develop the personalized study planning framework as a component of ITS pedagogical module, which allows to create the study plan, define the structure of the study course, create the concept map of the course topics and choose learning objects for each topic;
- to test the opportunities of structure modelling approach for defining the importance of courses, topics, and concepts in personalized study planning, and define the most important courses, topics and concepts;
- to develop the prototype of personalized study planning system, and accomplish the test of its operation.

Object of the Research

The research object of the Doctoral Thesis is intelligent tutoring systems.

Subject of the Research

The research subject of the Doctoral Thesis is personalized study planning approach, the analysis of its framework structure defining the important elements, and the opportunity of implementation of the developed solution.

Research Methods

In the theoretical part of the Doctoral Thesis the scientific methods used are the analysis of literature, graph theory, and structure modelling, and in the development of the practical part there are used programming engineering methods.

The scientific novelty of the Thesis is following:

- developed and described the approach of implementation of the component of pedagogical module of intelligent tutoring system based on the set of four graphs united into one system;
- developed and described framework of personalized study planning, which can be used in universities for personalized study planning in usual form of learning, after learner has participated in mobility program, after recognition of the achieved study results in previous education or professional experience, after intake of other study program or resumption of studies, as well as in lifelong education constructing training courses based on modules;
- substantiated the usefulness of exploiting structure modelling method for the analysis of three graphs of personalized study planning framework — study plan, study courses, and concept maps, which support the development of study plan and implementation of changes, and there is offered new solution of value calculations of structural significance of nodes.

Practical Significance of the Research

The practical significance of the research is related to the developed framework of personalized study planning which is suggested to be used in order to:

- create the study plan in the form of graph offering the following variants construction of:
 - the study plan;
 - learning modules for lifelong learning courses;
 - the study plan after learner's participation in mobility program;
 - the study plan after the recognition of achieved study results during the previous studies or professional experience [11, 12];
 - the study plan after learner's in take from another university or another study program;
- describe structures of study courses in the form of graph;
- create concept maps of course topics;
- define learning objects for the course topics.

The application of the developed prototype of personalized study planning system has been piloted using four scenarios, and five experts have got acquainted with its operation.

The Theses for the Defence:

- pedagogical module of ITS needs personalized study planning;
- it is possible to use integrated approach for implication of personalized studies that includes development of study plan, structure of study course, concept map, and choice of learning objects corresponding to topics and concepts;
- the graph is visual and therefore appropriate instrument for description of personalized study planning structure, as well as of sequence of courses and topics, and it is possible to ensure the choice of more appropriate type of graph design;
- depending on the demand of construction of the study plan and the necessity which is determined by study opportunities, there can be chosen appropriate application for personalized study planning;
- it is possible to apply methods of structure modelling in order to determine the significance of elements in the structures of study plan, courses and concepts, that allows to make decisions on changes in them to both the learner and the administrative employee as well as allows to identify definitely be learned courses, topics and concepts;
- it is possible to create personalized study scenario that allows learners to make well-considered decisions on study personalization not only at the university but also studying in different periods lifelong based on formation of personalized study plan, mastering the topics of courses, mastering concepts and the choice of learning objects.

The Approbation of the Doctoral Thesis

The main results of the Doctoral Thesis have been presented in six international scientific conferences:

- Rollande, R. Using graph for tutor module construction of intelligent tutoring system. 4th International Conference: Information Society and Modern Business, The Role of Regional Centers in Business Development, May 14–16, 2009, Ventspils, Latvia.
- Rollande, R. Using graph for tutor module construction of intelligent tutoring system for individual learning. Riga Technical university 50th International scientific conference, October 14–16, 2009, Riga, Latvia.
- Grundspenkis, J., Rollande, R. Graph based framework for personalization of education process realized by the tutoring module of intelligent tutoring system. International Conference: Perspectives in Business Informatics Research, 2nd International Workshop on Intelligent Educational Systems and Technology-enhanced Learning (INTEL-EDU 2011), October 6–8, 2011, Riga, Latvia.
- Rollande, R., Grundspenkis, J. Representation of study program as a part of graph based framework for tutoring module of intelligent tutoring system. The Second International Conference on Digital Information Processing and Communications (ICDIPC 2012), July 10–12, 2012, Klaipeda, Lithuania.
- Rollande, R., Grundspenkis, J. Graph based framework and its implemented prototype for personalized study planning. The Second International Conference on E-Learning and E-Technologies in Education (ICEEE2013), September 23–25, 2013, Lodz, Poland.
- Rollande, R., Grundspenkis, J., Mislevics, A. The use of structural modelling methods for analysis of personalized study planning. IEEE Technically Co-Sponsored Science and Information Conference 2014, August 27–29, 2014, London, UK.

The results of the research carried out within the framework of the Doctoral Thesis have been reflected in six publications in international scientific editions:

- Rollande, R. Using graph for tutor module construction of intelligent tutoring system. Proceedings of the 4th International Conference „Information Society and Modern Business, The Role of Regional Centers in Business Development”, ISBN 978-9984-648-12-5, pp. 39–48, 2010, Ventspils, Latvia.
- Grundspenkis, J., Rollande, R. Graph based framework for personalization of education process realized by the tutoring module of intelligent tutoring system. Proceeding of the International Conference „Perspectives in Business Informatics Research”, 2nd International Workshop on Intelligent Educational Systems and Technology-enhanced Learning (INTEL-EDU 2011), ISBN 978-9984-30-197-6, pp. 216–225, 2011, Riga, Latvia.

- Rollande, R., Grundspenkis, J. Representation of study program as a part of graph based framework for tutoring module of intelligent tutoring system. Proceedings of the Second International Conference on Digital Information Processing and Communications (ICDIPC 2012), ISBN: 978-1-4673-1106-9, pp. 108–113, Klaipeda, Lithuania. Citation indexed: Scopus, IEEE Xplore, Google Scholar, ISI Proceedings.
- Rollande, R., Grundspenkis, J. Graph based framework and its implemented prototype for personalized study planning. Proceedings of the Second International Conference on E-Learning and E-Technologies in Education (ICEEE2013), ISBN: 978-1-4673-5093-8, pp. 137–142, 2013, Lodz, Poland. Citation indexed: Scopus, IEEE Xplore, Google Scholar.
- Rollande, R., Grundspenkis, J., Mislevics, A. The use of structural modelling methods for analysis of personalized study planning. IEEE Technically Co-Sponsored Science and Information Conference 2014 (SAI), ISBN: 978-0-9893193-1-7, pp. 921–926, 2014, London, UK. Citation indexed: Scopus, IEEE Xplore.
- Rollande, R., Grundspenkis, J., Mislevics, A. New Approach of Using Structural Modelling for Personalized Study Planning, Article Published in International Journal of Advanced Computer Science and Applications (IJACSA), Special Issue on Extended Papers from Science and Information Conference 2014, pp. 104–113, 2014. Citation indexed: Directory of Open Access Journals (DOAJ), Ex Libris, Serials Solutions, Index Copernicus (IC), Google Scholar, Microsoft Academic Search, GetCITED, CiteSeerx, ArXiv, EBSCOhost, WorldCat, Bielefeld University Library, Ulrichsweb™.

The Structure of the Thesis

The Doctoral Thesis consists of an introduction, 4 chapters, the description of the results and conclusions, and a list of literature.

The introduction substantiates the topicality of the research, defines the aim and objectives of the thesis, enumerates the scientific methods applied in the Doctoral Thesis, describes the scientific novelty and the practical significance of the obtained results as well as characterizes the approbation of the thesis.

The first chapter of the Doctoral Thesis is dedicated to the development of tutoring systems from the historical aspect. There is examined the architecture of intelligent tutoring systems and its pedagogical module.

The second chapter of the Doctoral Thesis deals with existing intelligent tutoring systems for the development of plans and study courses.

The third chapter of the Doctoral Thesis includes the main theoretical results: personalized study planning framework as a pedagogical module component of the intelligent tutoring system which is based on mutually connected set of four graphs. This chapter also describes the structure modelling approach for the analysis of the personalized study planning

framework structure, the algorithms of graph visualization, the functions of personalized study planning framework, and the architecture of data basis.

The fourth chapter of the Doctoral Thesis discusses the prototype of personalized study planning system, which allows construct personalized study plan, define the structure of the study course, describe the learning objects of the topics as well analyses the significance of the study plan, study courses, and the elements of the concept map using the structure modelling approach. This chapter describes the approbation scenarios of the prototype of the personalized study planning system, and integration opportunities of personalized study planning system with other tutoring systems.

The results and the conclusions of the Doctoral Thesis are summarized at the end of the thesis.

1. COMPUTER ASSISTED LEARNING INSTRUMENTS AND INTELLIGENT TUTORING SYSTEMS

In the Informative report of the Ministry of Economics of the Republic of Latvia about medium and long term forecasts on labour market it is stated that the demand of workforce with higher education in nature sciences, mathematics, and information technologies as well as in engineering sciences, manufacturing, and construction will exceed the supply even in 2020 and in 2030 [13]. In order to attract students to these technologies capacious industries it is possible to make redistribution of the budget places, however, that will not completely solve the problem because these fields have large numbers of expelled students. Consequently students need personalized approach in order to help the learners to integrate into the study programs compensating the missing knowledge. To personalize the learning process there can be applied individual collaboration of the learner and the lecturer or intelligent tutoring systems.

Learning can be implemented with physical presence of the lecturer or without the lecturer's presence. Considering the fast tendencies of development of the modern technologies, the learning process has to be made more attractive corresponding to modern learner's perception, technologies should be more involved in the study process. ICT encouraged the development of technologies supported learning. In the process of technologies supported learning there are applied ICT to support teaching and learning, and the lifelong development of the competence [14]. However, none of the technologies can replace the lecturer completely in the study process. To make the study process more flexible, wholesome, effective, individual, attractive, and interesting for the learner, without losing the effect of lecturer's presence in study process, the solution is ITS [2, 15, 3, 16, 17].

ITS advantages in comparison with traditional forms of studies and technologies supported learning are:

- it is possible to apply additional methods in different forms of studies in order to make the process of learning more attractive for the learner;

- during the study process there is ensured individual collaboration between the learner and the lecturer of the virtual learning environment [18];
- ITS adapts according to the needs of the learner [19, 20];
- each learner can study in one's own learning pace;
- the learner can choose one's own appropriate learning style [21, 22, 23, 24];
- ITS supports adaptation to the learner's needs [19, 25, 26];
- ITS automates assessment of the learner's knowledge [27, 28];
- ITS supports personalized study principles by adapting study process to each learner's level of knowledge and skills [29].

The next subchapter sets out the evolution of tutoring systems to characterize their development and their functional possibilities.

1.1. The Evolution of Tutoring Systems

The emergence of tutoring systems was advanced by the demand of personalized training which was sped up by rapid development of personal computers and other ICT. Different interpretations about the origins of the tutoring systems can be found in different sources of literature. Little confusion is observed also in the terms. The evolution of tutoring systems is characterized by: *Programmed learning* [30, 31], *Programmed instruction* [30, 32, 31], *Linear Programming* [30, 2, 32, 31], *Branching Programming* [30, 2, 32, 31], *Adaptive Programming* [30, 33, 34, 35], *Generative Programming* [30, 2, 15, 36], *Computer Assisted Instruction/Computer Assisted Learning* [2], *Intelligent Tutoring Systems* [2, 37, 38, 16].

Nowadays the more often met terms related to learning systems are Computer Assisted Learning Systems and Intelligent Tutoring Systems.

Computer Assisted Learning Systems (CALS). They are intended for the organization of studies. CALS are interactive and adapt to learner. As it is mentioned in the paper [2], considering the CALS shortages, J. A. Self in his paper [39] assured that computer assisted learning program should define who is taught, how is taught, and what is taught, and that tries to include Intelligent Tutoring Systems (ITS).

Intelligent Tutoring Systems (ITS) [2, 37, 38, 16]. The first articles about ITS appeared at the end of 1950's and the beginning of 1960's. The first authors of the ITS idea were A. Turing, Marvin Minsky, J. McCarthy and A. Newell who believed that the computer could think like a man [15]. In 1973 J. R. Hartley and D. H. Sleeman presented the initial ITS demands and agreed that ITS should process [17]:

- 1) knowledge about problem domain (expert's model);
- 2) knowledge about learner (student's model);
- 3) knowledge about learning strategy (pedagogical model).

These models are used in corresponding modules that implement ITS architecture.

In 1982 D. H. Sleeman and J. S. Brown [40] were the first to introduce the notion ITS to describe the development of tutoring systems and separate them from CALS.

When analyzing the evolution of tutoring systems and the documents of planning in the field of education, the author of the Thesis concludes that the development of tutoring systems is moving towards personalized learning process. Solutions of the issues of personalized learning can be understood looking at the principles of the structure of ITS which are described in the next subchapter.

1.2. The Architectures of Intelligent Tutoring Systems

This subchapter describes the architecture principles of ITS. As it is mentioned in the article [17], in 1973 J. R. Hartley and D. H. Seeman defined that ITS basically includes the expert's module, the student's module, and the pedagogical module.

The Expert's Module. It stores the information about learning content. The expert's module cooperates with pedagogical module in order to make decision about the output of learning content. To carry out the mentioned operations, the module stores knowledge about problem environment or the so-called expert's model.

The Student's Module. It is responsible for the adaptation of the learning method for the learner [18]. In order to make decision about the correct learning method, ITS should evaluate the learner's skills and his/her behaviour characteristics, the learning outcomes. It is very important to evaluate also the shortage of the learner's knowledge. In the student's module there should be retained the learner's cognitive condition, his/her learning abilities, aims, etc., that all together forms the knowledge about the learner or the so-called student's model.

The Pedagogical Module. The pedagogical module controls and manages the study process. It cooperates with other modules and plans learning strategies personalized for each learner [18]. The pedagogical module together with the student's module responds to the question how to teach. One of the most important tasks of the pedagogical module is consecutive planning of study plan and courses or strategic planning of studies.

Reviewing ITS architectures described by different authors, different explanation of the terms can be encountered. Within the framework of the given Doctoral Thesis the notions of model and module are explained as follows:

1) The model is a simplified description of a system or function which describes how the system operates and how it is constructed.

2) The module is a component of the system which performs different functions and cooperates with other components of the system. The model can be at the basis of the module.

Basic architecture of modern ITS still includes three modules and such architectures are called three module architectures. Analysing the literature it is concluded that there are offered architectures of different ITS. As it is mentioned in the book [41], in 1988 S. J. Derry,

L. W. Hawkes, and U. Ziegel offered **three module architecture**: tutor module, expert domain module, and student knowledge module. Whereas, in 1998 J. Siemer, and M. C. Angelides offered three module structure where as the main cooperation element of modules is the general control system [41]. Basic modules are similar to those as described in previous systems. The latest research identified and added to those three modules **the fourth module**: user interface module [2, 18, 42, 17, 43], which controls the cooperation between the learner and ITS [2]. While investigating works of different scientists there were noticed differences in four module architecture. In the paper [44] there are identified **five ITS architecture components** out of which four were described previously, and the fifth component is the expert module. The expert module is similar to expert domain module in the fact that it has to include information which should be used in order to teach. The expert module can compare the learner's knowledge to expert's knowledge and define the shortage of learner's knowledge.

Comparing the architectures of three, four and five modules described in this chapter it should be concluded that more suitable is the four module architecture which includes three ITS modules of basic architecture, whereas the fourth module — user interface module — is as qualitative supplement that improves the ITS architecture. The fifth module — knowledge domain module — in three and four module architectures is included in the expert module. Hence this module cannot be regarded as fundamentally new supplement.

In ITS the learner studies by solving problems [17]. The operation of the system starts with the assessment of the learner's existing knowledge that is carried out by the student's module. In accordance with the study material the system makes the decision what the learner should know, which element of the study material should be offered currently and which later, and how to achieve all that. The decision is made with the help of tutor module. It means that the system itself makes decision how to teach. Taking into account those considerations the system develops the description of the problem. ITS compares the learner's solution with the computer solution and carries out diagnosing, regarding the differences between the both solutions. The system gives feedback taking into account the fact when the last feedback was ensured, whether the learner has already received any advice, etc. After creating the feedback the program refreshes the information about the learner's skills (inputs the information about what the learner has mastered and what has not) in the student module and increases the parameters of the study progress. The refreshment of parameters is carried out by the student module. Further on the cycle repeats with the generation of a new problem [17].

ITS operational model is more effective than CALS operation model because it stores information about the learner and how to teach him/ her, and therefore it is more suitable for the learner's individual needs.

Nowadays ITS develops more and more rapidly. That demands the use of new solutions among which at present prevails the use of the agents and multiagents' approach in ITS [45, 46, 38, 47, 48, 49, 29]. Each of ITS modules, which form the 3, 4 or 5 module architecture,

can be implemented by agents or the set of agents [29]. Each function of the module can be described as agent. Systems may include several agents, and such a system is called multiagents system [45]. Such system consisting of several agents is easier to develop than system as one entirety. Moreover agents in the system can be simply added, deleted or changed. Therefore recently there are created many ITS based on agents. In the doctoral thesis author use IKAS (Intelligent knowledge assessment system) system in which there is implemented the intelligent agents' approach. IKAS is the knowledge assessment system based on concept maps that evaluates the learner's knowledge comparing his/ her constructed concept map with that created by the lecturer [48]. IKAS is more described in subchapter 4.3.1.

In all architectures of ITS there is included pedagogical module that has to ensure study planning (including also personalization). Hence personalized study planning is the component of pedagogical module of ITS. In order to implement that it is necessary to investigate the pedagogical module.

1.3. Characteristics of the pedagogical module

ITS pedagogical module has to answer the question how to teach and has to allow to plan studies personalized for each learner's needs. The characteristics of the operation of the pedagogical module:

- The control over all **study plan** in order to select and arrange consecutively the study courses [44, 50]. The description of the study program is stored in problem domain module [51].
- The **topic** output to the learner. The system adapts the topic individually to each learner's needs [16, 52, 53]. Topics are stored in problem domain module [51].
- **Output of the study content.** The study content of each topic can be divided into smaller units (concepts) [51], representing it a several forms (presentations, audio, video, etc.) [53] and sequence [54, 55]. Automated choice of the form of the study content is related to the student's learning style [21]. In its turn the sequence of the output of study content depends on study content described in problem domain module and on student's background knowledge that is stored in the student's module.
- The choice of the **learning strategy**. The learning strategy defines the way how the study aims will be reached, in what way the topics will be output, how knowledge will be assessed, and how the study process will be supervised.
- **The generation of the problem.** After the choice of the topic there has to be generated the problem which the learner has to solve [16].
- **The feedback.** The system has to determine what kind of feedback the learner needs [16, 51].

- Learner's **knowledge evaluation**. The learner's knowledge is evaluated according to study aims, and the evaluation is stored in the student's module. Depending on the results of the learner's knowledge evaluation there can be done changed in mastering the course [51].

The pedagogical module supports personalization, and the level of its implementation depends on to what extent the learner itself has the possibility to participate in studies.

1.4. Summary and Conclusions

The main conclusions are:

- Analyzing the evolution of tutoring systems and the planning documents of the field of education it is concluded that the development of tutoring systems are moving towards the personalized study process.
- As a result of literature review it is concluded that nowadays in ITS there is used exactly four module architecture. Although there is offered also ITS architecture of three and five modules, nevertheless the basic functions of ITS do not change.
- It is concluded that in order to ensure personalized study process, there has to be used pedagogical module where it has to be described study planning for personalized learner's needs, starting with creation of the study plan and ending with the choice of learning objects.

Accomplishing the source analysis connected with the theme of the thesis it is concluded that in the pedagogical module of ITS planning and personalization are not ensured in an integrated way including the structuring of the study plan, the framework of study course, the course content on the concept level, and the choice of learning objects.

2. INTELLIGENT TUTORING SYSTEMS FOR THE DEVELOPMENT OF STUDY PLAN AND STUDY COURSES

The analysis of planning documents of education field states the necessity of tutoring system that offers personalized approach to the learner. The analysis of tutoring system evolution concludes that the development of tutoring systems moves towards personalized learning. The analysis of ITS architecture clarifies that it includes pedagogical module. In the doctoral thesis there has been put forth the thesis that pedagogical module needs personalized study planning. The given chapter discusses the existing personalized study planning systems in order to state their possibilities and drawbacks.

2.1. Intelligent Tutoring Systems for the Implementation of Study Courses

This subchapter assesses four the most often quoted ITS which implement the development of the study courses.

1. The authors of the sources [18, 56, 57, 58] describe the developed ITS, which ensures adaptive learning environment, offering to the learners personalized studies. The task of study process personalization the authors solve using the ITS structure with four components: the problem domain module, the student's module, the pedagogical module, and the interface module. The problem domain module [56, 18] stores the information about study course structure in the form of the tree, and the mutual relationship among study topics is stored in the graph of course topic dependence. The student's module [18] includes the description of the student's profile and the learner's situation. Depending on the data of the student's profile in the pedagogical module the topic planner searches the topic dependence graph to choose the most acceptable topic sequence individually for each learner; the component of the learning material selection chooses the most suitable set of materials according to topic planner suggestion for each learner corresponding to the selected topic from the repository; the result analyst summarizes and analyzes the learners' results and plans how to improve them.

In this system the learner cannot create the study plan and choose the training scenario by him-/herself because the system itself adapts the studies according to the learner's abilities.

2. The system of curriculum and course development CREAM (*Curriculum REpresentation and Acquisition Model*), which based on the learner's abilities, study objectives, and pedagogical resources supports the reach of study objectives, generates study courses and shows the study content. CREAM includes three models [38, 59, 60, 61]: capability model (CREAM-C), study objective model (CREAM-O), and didactic resource model (CREAM-R). Capability according to the authors [59, 60] is “a unit of knowledge that is stored in person's long-term memory, which allows him/her to achieve success implementing physical, intellectual and professional activities”. These three models are united in the module of curriculum knowledge transfer net (CKTN). In subsequent articles [38, 60] the authors name it the curriculum pedagogical module.

The tool allows automatically generate the curriculum and courses. The process of course building starts with the definition of objectives or capabilities, and the search of corresponding curriculum structure in order to get the descriptions of course objectives. The designer of the studies has to determine the knowledge that he wants to teach, has to supervise the process and has to accept or refuse the generation of the course. It is possible to change both the curriculum and the course. CREAM ignores the individual wishes for the course plan building because the course plan is generated automatically. CREAM implements individualized learning that is based on decisions about the curriculum and courses to be learned that are made by the system not by the choice done by the learner.

3. The system of the building the curriculum and courses -IDE Interpreter is the adaptive study system created by D. M. Russell in 1988 and based on planning, which automatically generates the study courses. It uses IDE (Instructional Design Environment) knowledge structure as the knowledge source for the generation of study course [62].

IDE Interpreter curriculum is shown in the same form of graph as for previous two systems. Thus once again it is proved that graph is suitable instrument to describe the course. IDE Interpreter similarly as in two previously viewed systems the curriculum is generated automatically and the learner has no possibility to plan personalized studies by him-/ herself. IDE Interpreter implements personalized learning that is based on the rules of strategy and pedagogy not the choice of the learner.

4. The system of the building the curriculum and courses — Expert CML [63] offers to perform the design of the curriculum and study courses. Its operation is described in three stages. The first stage — **development of the curriculum** — implies the whole curriculum starting with the description of general objectives of the study program up to defining lectures and modules including learning activities and evaluation methods. The second stage — **designing of the course**. The course designing stages are the following: the choice of the study program part for including it into the course and review of the course map. The course map describes the study content object: topic, subtopic or module. The course map is represented in the AND/OR type of the tree. It does not represent the way what the learner may choose for studies but the limits so that the learner could improve by choosing the study material. The system allows the user to choose the learning strategy. The third stage — **evaluation** when the learner's knowledge progress is evaluated as the result of studies. That helps the designer to assess the content if the study courses and studies by analyzing the learner's achievements.

Assessing Expert CML it is concluded that the system offers the set of tools that helps to design, implement and manage the curriculum but does not offer to the learner to build it by him-/herself. However, the system allows the learner to build the study content. After that the learner outputs the course map in the type of oriented graph. The system includes complete description of the study structure starting with general objectives and the study program, continuing with courses, topics and subtopics. Expert CML does not allow the learner to project personalized studies by him-/herself starting with curriculum and ending with the choice of learning objects. Besides none of the systems discussed previously offers to carry out structure analysis which is one of the tasks set in the given doctoral thesis.

2.2. Intelligent Tutoring Systems for the Design of Personalized Study Plans

This subchapter describes different ITS which allow to design personalized study plan.

1. The design of the study plan with the help of CEWebS (Cooperative Environment Web Services) platform which is envisaged for the visual description of the study plan using the graph [64, 65]. For the study plan visualization there are offered three levels. **The level of the study plan** describes the study plan using the graph. **The level of module** describes the study course at the level of the study plan and other courses connected directly with it. **At the**

course level the courses are described in Wiki pages and for the courses there is described the course title, type, credit points, content, methods of acquisition, methods of evaluation, and literature.

The system is meant only for the lecturers and the learners cannot work with it independently. Furthermore, the study plan described in the system cannot be changed. All learners are provided with only one learning scenario and no personalization of the study plan is possible. CEWebS describes the study plan but does not offer to describe course topics and learning objects.

2. The visualization of the study plan with CurricVis tool (Curriculum visualization) [66, 67]. Its architecture includes the study plan that is described in the form of oriented graph where the nodes denote study courses, and the curves describe the mutual relation of the courses. The graph is automatically generated based on the information existing in the knowledge database. CurricVis is meant for learners as well as for administration which is connected to the management of the study plan. CurricVis program has two basic views. **The view of the study plan** depicts the study plan courses. Visualizing the study course the learner can clearly see the routes to the preferred courses. He/she can see which courses have to be mastered first to master the preferred course. **The progress view** shows the progress diagram of the learner's mastered study courses where it is possible to obtain information about successfully mastered courses, credit points and their share from of the total credit point amount for the study plan expressed in percentage.

CurricVis tool does not have interactive graph building mode. It means that the learner choose the study courses to be learned from the study plan graph and in the progress view offered by the program follow the process of mastering the study plan, but there is not built the graph or list of his/her chosen study plan courses. CurricVis after the choice of study courses does not offer next steps of personalized studies: the selection of course topics and learning objects. Hence it does not completely satisfy all demands for the personalized study planning tool.

3. The visualization of the study plan with ViCurriAS [68] tool. The tool can be used by methodists, consultants and learners of the faculty. It allows the consultants and the learners see the course dependencies and the learner's progress of mastering the study plan. **The module of the study plan** is intended for the design and the modification of the study plan. The module allows methodists and consultants of the faculty put courses manually into the study plan, and define the range of prerequisites thus obtaining the map of the study plan. **The consultation module** allows the representative of university administration or the lecturer insert the ratings or planning information in the same graph which was created in the study plan module. The progress of mastering of the study course can be seen in the consultation module.

ViCurriAS system just like the two systems described in previous subchapters reflects the study plan in the form of graph. The system does not offer to the learner to build dynamic study plan neither shows the study course topics, concepts, and learning objects.

4. The design of the study plan using the graphs of the learning outcomes. The author [69] bases the topicality of his system on the fact that learners do not always have a clear view about the necessity of mastering one or the other course. Especially that is characteristic at the starting period of the studies when there should be mastered mathematics, physics, etc. general engineering subjects because the university learners do not see the necessity and connection of these subjects with the practical application.

One of the aims of the system design is to give learners greater but not complete freedom in designing the study plan [69]. The work with the system starts when the learner chooses the competences in accordance with his/her personal interests and objectives. Later there is determined the list of the necessary courses which is built proceeding from the learning outcomes included in the competences. The learning routes show to the learner how each course corresponds professional competences. Therefore the learner is interested to build one's own study plan which corresponds to his/her interests.

Familiarizing oneself with the opportunities offered by the system, the author of the doctoral thesis concludes that this system like all the others discussed previously only partly ensures personalized study planning and does not offer to carry out the structure analysis at all.

2.3. The Joint Analysis of the Reviewed Tutoring Systems Used in Implementation of Study Courses and Study Plans

In the study process personalization there are possible two alternatives in cooperation with the user:

- the learner him-/herself builds his/hers learning plan and determines the tutoring scenario;
- the system basing on the learner's knowledge builds appropriate study plan and tutoring scenario for him/her [64, 66, 68, 69].

In the reviewed tutoring systems for the description of the study plan and the study course structure most often there is used a graph because the graph is graphic and therefore very suitable instrument to describe the sequence of courses and topics. With changing the number of nodes increases the significance of the depiction types of the graph. None of the reviewed in this chapter systems offer flexible visualization of the graph allowing to choose the most suitable depending on the type of the graph. In order the graphs of different sizes could be described transparently, it is useful to build in several different types of graph visualization in the tutoring system.

Necessity to have personalized study plan is not only for those learners who want to build their own study plan according to their wishes and objectives but also in such cases when the learner has been on exchange program in another university or wants to continue studies after in take from other study program, or wants to start studies after recognition of the learning outcomes achieved during the previous education or professional experience to credit points. Also in the institutions which implement lifelong education programs it is essential to allow the learners to build personalized study plan which corresponds to the objectives of their professional or personal improvement. It should be noted that such possibilities are not offered by any of the reviewed systems.

One of the problems the learner may encounter when building one's own personalized study plan is that he/she does not know which courses to include in it and which course has greater importance in achievement of the goals of the study program. In order to help the learner to make decision about the courses that should be included into the study plan it is necessary to carry out the analysis of the study plan structure to identify the most significant courses.

As the existing personalized study planning systems do not ensure the learner with building personalized study plans and courses within the framework of one system, it is necessary to complete the pedagogical module which supports personalized learning allowing the learner to build appropriate for his/her own needs study plan, view the topics of the study course and choose the sequence of the mastering the study course, get acquainted with the relation of concepts and choose learning objects of the topics. From the carried out analysis of the learning system architecture derives the following demands for the new architecture:

- develop a united system which allows to personalize the study process beginning with the design of study plan to its acquisition;
- describe the study plan, study courses, topics, concepts, and learning objects;
- include the opportunity for the learner to personalize the study process allowing to develop the individual study plan, set the sequence of course acquisition, frame the concept map, and choose the learning objects for acquisition of topics and concepts;
- the structure of study plan, study courses, concepts and learning objects display in the graph mode;
- define the range of prerequisites and restrictions for the study courses and course topics;
- offer the building of the study plan for the lifelong education courses;
- ensure the building of the study plan taking into account that the learner may participate in the mobility program or study after in take from the other study program or after the acknowledgment of credit points;
- offer several visualization modes for the graphs of study plan, study course, concepts and learning objects;
- include the defining of the node significance in graphs.

2.4. Summary and Conclusions

The main conclusions are the following:

- The existing at the moment tutoring systems ensure the building of study plan and course sequence but personalized study planning should be understood more widely and therefore it is necessary to add personalization of concepts and learning objects.
- It is necessary to improve the pedagogical module of the system of personalized study implementation including there the analysis of study plans, courses, and concepts in order to define the most significant elements (courses, topics, and concepts).
- Improvement is required for the pedagogical module which supports personalized learning allowing the learner to build appropriate for his/her needs study plan, view the topics of the study courses and choose the sequence of acquisition of the study course, introduce oneself to the relations among notions and choose learning objects of the topics.
- The pedagogical module of the personalized study implementation system has to support the approach that allows the learner to plan personalized studies not only at the university but also learning during different periods through all the life.
- The viewed ITS confirm the use of graph for the study plan description as appropriate tool for the study plan description.

As a result there are set the demands for new architecture which pedagogical module allows not only build the study plan but also describes the structure of the study course, the concept map of the course topics, and the graph of learning objects of the topics.

3. FRAMEWORK OF PERSONALIZED STUDY PLANNING FOR THE IMPLEMENTATION OF A STUDY SYSTEM'S PEDAGOGICAL MODULE

3.1. Framework of Personalized Study Planning

In order to implement personalized study planning from the point of developing a study plan to choosing the study subjects, the Doctoral Thesis contains a personalized study planning framework, which is in line with such set of graphs [70]:

- 1) Graph $G_1(V_1, Q_1)$, which allows to develop a personalized study plan;
- 2) Graph $G_2(V_2, Q_2)$, which allows to determine the sequence of acquiring study courses;
- 3) Graph $G_3(V_3, Q_3)$, which allows to present the content of topics, each of which is presented as a set of concepts;
- 4) Graph $G_4(V_4, Q_4)$, which describes learning objects corresponding to each topic or concept.

The graphs of personalized study planning framework are related. Each next graph results from the previous one. The steps of constructing a framework of personalized study planning:

- Step 1 — at first, the graph G_1 is designed and the name of the study program, which is the root node of the G_1 , is defined;
- Step 2 — in the next level, the years of study — the direct successors of the root node — are defined;
- Step 3 — next, each of the years receives 2 nodes of successors — spring semester and fall semester;
- Step 4 — in the next level of the graph G_1 , each semester defines successor nodes, which conform to the title of the part of the study program;
- Step 5 — each part of the study program as a successor node defines the titles of the corresponding study courses;
- Step 6 — titles of the study programs need to describe other course titles, that are prerequisites for acquiring these courses;
- Step 7 — the graph G_2 is designed and the title of the study program as well as its CP (credit point) value, which is one of the root nodes of the graph G_2 , are developed. The number of G_2 graphs conforms to the number of course titles described in G_1 ;
- Step 8 — successor nodes — numbers of lessons — are defined for the study course nodes (these numbers correspond with the CP value of these courses, in Ventspils University College one CP is equal to 8 classes, one class lasts 2 academic hours);
- Step 9 — each class in the next graph level receives the next successor nodes — titles of topics to be acquired in certain classes;
- Step 10 — each topic receives predecessors, that are presented by predecessor nodes and show the titles of prerequisite topics;
- Step 11 — topics are chosen and concepts, corresponding to the graph G_3 , are defined, thereby the number of G_3 graphs is equal to the number of topics;
- Step 12 — the concepts are related by links and the semantics of the links are defined;
- Step 13 — topic titles are chosen from the graph G_2 or concept titles from the graph G_3 , which is the root node of the graph G_4 . The number of G_4 graphs corresponds to the number of topics in G_2 or the number of concepts in G_3 ;
- Step 14 — in the next level, the root node of G_4 receives titles of learning objects as successor nodes;
- Step 15 — according to the titles of each learning object, learning objects are defined.

Such a comprehensive framework of a study process graph as developed in this Doctoral Thesis cannot be found in any of the reviewed sources of literature. Therefore, it is considered as one of the scientific innovations of the research. In the next four subchapters each of the graphs and their roles in the planning of personalized studies are described in detail.

3.1.1. Description of the Structure of the Study Plan

The graph $G_1 (V_1, Q_1)$ is AND/OR graph for the building of a personalized study plan, where V_1 is a set of nodes that presents the hierarchy of the study plan. The graph shown in Figure 3.1 shows a general structure of building a personalized study plan, the structure of the Ventspils University College (VUC) Bachelor study program “Computer Sciences” is shown here: <http://1drv.ms/1n77tX7>. It consists of 94 nodes and 93 links.

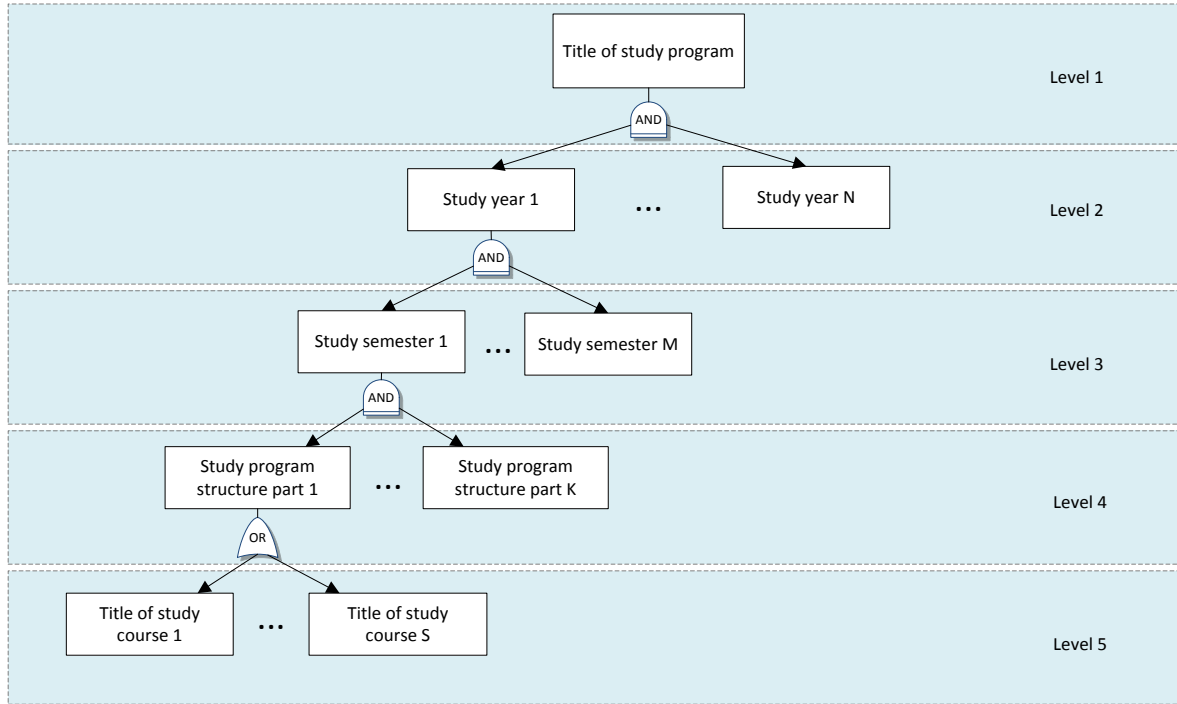


Figure 3.1 The conceptual structure of a study plan

The graph structure can be changed by adding additional prerequisite links between the courses. It allows to develop the study plan correctly (available at: <http://1drv.ms/1qncvzI>). The 5th level of the graph $G_1 (V_1, Q_1)$ contains depending courses, to whom the sequence of implementation is significant, and independent courses, that do not require any background knowledge. The learner can personalize his/her study plan by choosing courses from the parts B and C of the study program.

The graph $G_1 (V_1, Q_1)$ has been defined the following cases of use:

- The building of a study plan;
- The building of learning modules for lifelong learning courses;
- The building of a study plan after the learner's participation in a mobility program;
- The building of a study plan after the recognition of credit points [71, 11];
- The building of a study plan after in take from another university or study program.

3.1.2. Description the Structure of a Study Course

The next graph $G_2 (V_2, Q_2)$ describes the structure of a study course. This graph is built after the graph $G_1 (V_1, Q_1)$ of the study plan is ready. The lower level of the $G_1 (V_1, Q_1)$

structure consists of the study plan courses, and this is the end of the graph's structure, whereas the graph $G_2(V_2, Q_2)$ shows the structure of each study course. Consequently, if the lower part of the graph $G_1(V_1, Q_1)$ presents, e.g. 60 courses, also 60 graphs $G_2(V_2, Q_2)$ are needed. The full graph of the study course “Object-oriented Modelling” (in abrev.— OOM) can be found here: <http://1drv.ms/1t0fBM1>. The root node of $G_2(V_2, Q_2)$ includes the title of the course and its value in credit points. As successors, the classes are represented in the 2nd level according to the number of CPs, one class is equal to 2 academic hours¹. The 3rd level of the graph shows the study course topics, which can be supplemented by characteristics determining the level of acquisition. For this reason, Blooms Taxonomy is used [72, 73, 74]. Acquisition levels that have been added to the study course topics in the 3rd level of the graph are available at: <http://1drv.ms/1t0fBM1>.

In order for the learner to choose the sequence of acquiring topics, each of the topics needs to define predecessors thereby describing the prerequisite topics of each topic. The topic correlation of the VUC Bachelor study program “Computer Sciences” course “Object-oriented Modelling” is available at: <http://1drv.ms/1qncYlp>.

3.1.3. Concept Map of the Course Topics

Continuing with the personalized study planning, in the next step each topic of the study course graph $G_2(V_2, Q_2)$ is taken and presented with a concept map (CM) [75].

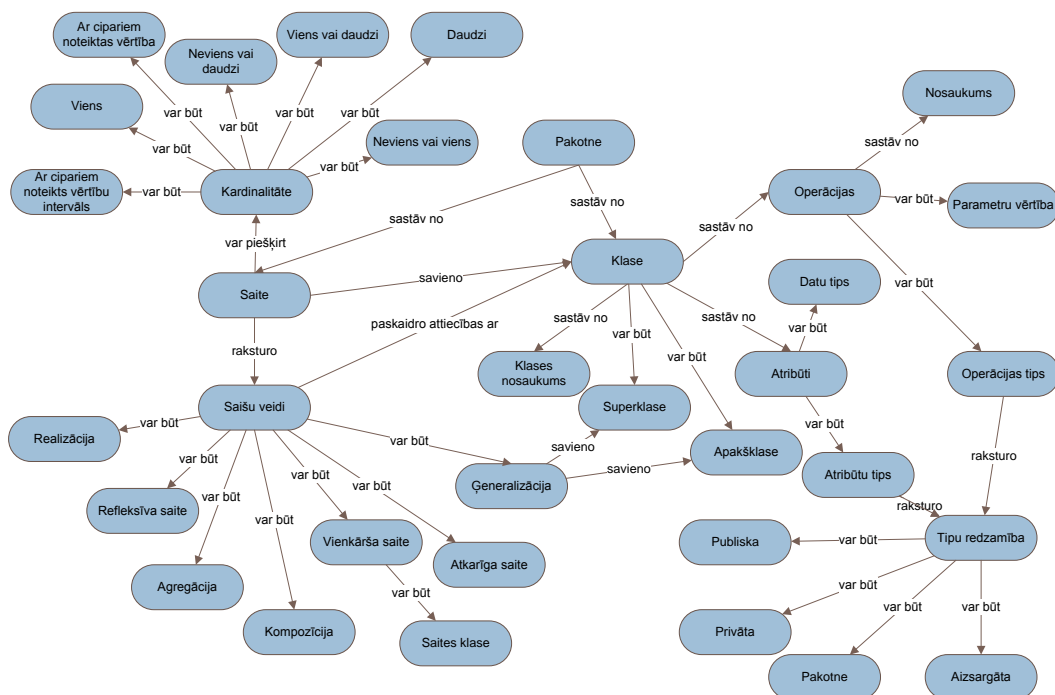


Figure 3.2 A concept map for the topic “Components of class diagrams”

Concept maps were introduced in 1972 by J. D. Novak [76]. A concept map is the presentation of knowledge in the form of a graph [77]. Graph $G_3(V_3, Q_3)$ is used for

¹ Academic hour – a unit of study time (duration – 45 minutes) [8].

representing the concepts and their correlation. It includes a set of un-empty nodes V_3 representing concepts, and a set of un-empty links Q_3 representing the relation between concepts. The relation between concepts is described by the semantics of the links. A concept describes an event or an object. Two or more correlated concepts form a sentence [76].

Concept maps can be helpful in the study process and when evaluating knowledge [78, 76]. If concept maps are used for showing the structure of the course topic, the learner perceives the training as “conceptually more transparent” [76]. Not all learners identify the most significant concepts successfully, but a concept map helps to acquire them. Study courses that include remembering lots of facts, dates, names, equations etc. can become boring for the learners, while the use of concept maps allows them to control the course and acquire it successfully [76].

The graph G_3 , shown as a concept map, can be oriented or non-oriented. Figure 3.2 shows an example concept map of the graph’s G_2 topic “Components of class diagrams”.

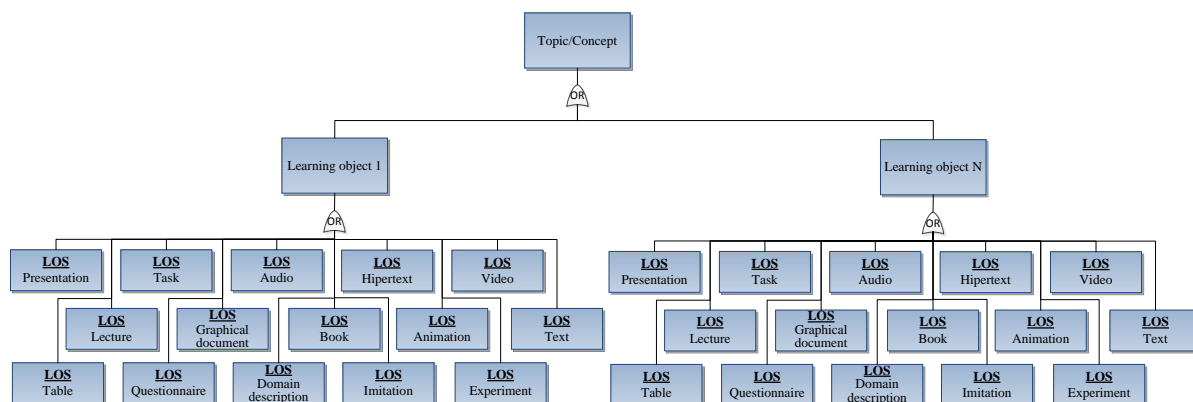
Since the concepts of the graph G_3 (V_3 , Q_3) are connected with the topics of the course structure graph G_2 (V_2 , Q_2), learners can personalize the way of acquiring knowledge about the specific concept.

3.1.4. Graph of Learning Objects

The fourth graph G_4 (V_4 , Q_4) of the framework of personalized study planning describes the objects of topics and concepts, that are available for acquiring knowledge. A learning object is the central element of training systems. The learning object can be repeatedly used together with other learning objects by using different combinations of them and thereby creating the training content. It has been stated that [79]: learning objects are entities that include information on the study content; these can be digital or non-digital; in order to manage learning objects, study content management systems are used; these can be used once or more times; one and the same learning object can be used in different courses; learning object can make the training process faster, more flexible and more effective; they need to be modular, mutually compatible and distributable (combined in several ways), and they should easily integrate in different courses.

The graph G_4 (Figure 3.3) allows the learner to choose different learning objects, thereby respecting the individuality and the different level of knowledge, as well as the way of perceiving knowledge of each learner. The choice of learning objects depends on the way how the learner studies or his/her learning style which is a set of cognitive, emotional, characteristic and physiologic factors, and determines how the learner perceives the learning environment and cooperates with it [81]. Several authors offer models of learning styles, but one of the models used most often [82, 83, 84] is the learning style model by R. M. Felder and L. K. Silverman [21]. They defined 8 learning styles [85, 86]. In order to define a learning style, R. M. Felder and B. A. Soloman have developed a questionnaire available on the

Internet [87], where anyone can define the learning style most suitable for him/her just by answering 44 questions. In order to help the learners to choose study subjects according to their learning style, the lecturer needs to describe the learning objects and classify them according to the learning style classifier. Then, the learner can choose learning objects according to his/her learning style.



Apzīmējums:
LOS – Learning object style

Figure 3.3 Graph of the topics' possible learning objects

Since the study plan and the structure of study courses are subject to change, it is important to analyse them. The structural analysis allows the change-makers to make reasonable decisions on the changes to be made in the structure. The structural analysis of graphs has been described in the next subchapter.

3.2. Analysis of the Structure of Graphs

The analysis of the structure of graphs has been described in several sources of literature [88, 89, 90]. The author of this Doctoral Thesis chose to use the following approach of structure analysis — structural modelling — in her research, since it allows to determine the significance of elements, which is the main difference in comparison with other methods. Structural modelling is a branch of topological modelling, based on computer construction and analysis, the development of a knowledge basis and usage of inference procedures [88]. It began to develop in the middle 1970s and the development of it was possible due to the significant contribution of 13 researchers from the Riga Technical University [88]. It has been created for the mathematical modelling of technical systems with physically various elements in conditions of imperfect information [91]. Structural modelling investigates the relations between structural elements, the significance of elements in the functioning of the system as well as evaluates the effect of excluding elements [91].

The use of structural modelling approach for structural analysis of study plans, study courses and concept maps is a new application of it.

In order to choose the suitable method of structural modelling, the type of the graph's relation mode needs to be analysed. In structural modelling, the concepts of unilaterally and

strongly related structures are used [88]. The graphs G_1 , G_2 and G_3 described in the Doctoral Thesis belong to the unilaterally related structures. In structural modelling, qualitative and quantitative structural analysis can be distinguished [88]. Qualitative analysis defines the significance of the graph's nodes thereby showing how significant the node is in the overall structure. In the quantitative analysis, the distance between elements that is used in the theory of graphs is used. In this Doctoral Thesis the qualitative analysis of the structure will be used. In order to conduct the qualitative analysis for a unilaterally related structure, it is necessary to calculate the ranks of the nodes [88]. There are several methods of calculating ranks [88]. In order to carry out a complete analysis of the graphs G_1 , G_2 and G_3 , three methods of calculating ranks have been chosen:

- using the nodes' local grade R_{LG}^1 ;
- using the number of routes, that comprises the given node R_{CE}^1 ;
- using the number of nodes to be reached R_{CE}^2 .

After the rank values are known, the values of nodes' structural significance are calculated according to the previously obtained rank values. When calculating the values of nodes' structural significance, two ranks are usually used: the rank of numbers of routes in the graph and that of the numbers of vertices to be reached [88], while the author of the Doctoral Thesis suggests to add also the third rank to this calculation — the rank that is calculated after the nodes' local grade. If the nodes are ranged after their local grades, the direct link is analysed, but the indirect link, which is important in difficult systems, is ignored. [88]. Thereby, the local analysis of the difficult system's local grades is not actual. Still, it is different from the personalized study planning system, where calculating the rank after the local grades of nodes is essential when it is necessary to analyse the local information of each study course, topic or concept.

The structural analysis of each graph G_1 , G_2 and G_3 is made, in order to reach specific goals that allow to formulate the recommendations given below. The identification of the more significant nodes in the study plan that are described by the graph $G_1(V_1, Q_1)$ is important:

- in order to make decision on proposed changes of the study plan. Rank values of each course need to be analysed. If the rank value of a study course is high, excluding this course from the study plan may endanger the implementation of courses related to this course and the achievement of the study program's goals, as well as increases the risk of not reaching the desirable level of knowledge. Furthermore, replacing this course with another one may change the program's structure, since new prerequisite links appear;
- to help the learner to establish a qualitative study plan. The courses, that are more significant according to the rank, need to be set as mandatory in order to be included in the personalized study plan;
- to help a specific commission in the recognition of study results obtained in previous education or professional experience. It means that when evaluating the learner's knowledge, the greatest attention should be paid to major courses;

- to predict whether the course will have a relatively large number of learners. This can be determined by calculating the rank R^1_{LP} ;
- to identify courses that are included in most study scenarios (rank R^1_{CE});
- to find courses after which there is the biggest opportunity of branching (rank R^2_{CE}), which represents the possible diversity of study routes.

The structural analysis of the study course described by $G_2(V_2, Q_2)$, by using ranks and determining the most important nodes of the study course is important:

- when recognizing the study results obtained in previous education or professional experience. For testing knowledge, the commission (developed according to the corresponding regulations of the university) definitely needs to include topics that, according to the rank, are the most important;
- if the lecturer wants to make corrections in the structure of the study plan — to exclude a topic or replace it with another one. Then, the most important study topics need to be determined, in order to analyse the topic's significance in relation to other related courses. If a topic that gives prerequisite knowledge to other courses is to be excluded from a course, a solution of how to provide the necessary knowledge to learners needs to be found;
- when course recognition is done for learners after they have participated in a mobility program, a deeper analysis of course topics needs to be done. If the most important topics coincide (the percentage of concurrence is determined by the university's authority) a decision on study course recognition can be made;
- to make a decision on recognizing study results obtained in previous education or professional education, the learner's knowledge cannot always be assessed according to the course. In this case, a deeper analysis needs to be done and the knowledge compliance with the topics needs to be assessed.

The structural analysis of concepts described $G_3(V_3, Q_3)$ by using ranks and determining the most important nodes is important:

- if the lecturer creates a concept map. Then he can show the most important concepts as a structure to the learner so that it would be easier for the learner to develop the rest of the structure;
- for the learner to pay increased attention to acquire the most important concepts;
- if the learner develops a concept map and a lower degree of difficulty for learning has been set. Then, in the given structure of concept maps, additional concepts may be added in order to help the learner to carry out the task;
- if the lecturer wants to make corrections — exclude a concept or replace it with another one. Then, the most important concepts need to be determined in order to analyse the concept's relation with other concepts.

There will not be a structural analysis for the study object graph $G_4 (V_4, Q_4)$ since the study objects are chosen by the learner, according to his/her own priorities in acquiring the study material or learning styles.

Additionally to the structural analysis of graphs, it is essential to choose their visual presentation.

3.3. Algorithms of Graph Visualization

As a result of the intellectual study system analysis described in subchapters 2.1 and 2.2, the author required that several ways of representing study plans and course graphs need to be offered.

For the visualisation of graphs, the author has chosen 8 algorithms supported by the open code library Graph# [92]. In the prototype of the personalized study planning framework the following algorithms are used: *Tree* [93], that represents the structure of the graph hierarchically (available at: <http://1drv.ms/1qnd8ct>); *Circular* [94] that places the elements of the graph in a circle around an imagined centre (available at: <http://1drv.ms/1qndm3q>); *EfficientSugiyama* [95], where nodes are represented in lines but links, connecting the nodes, are targeted from top to bottom (available at: <http://1drv.ms/1qndBvt>); *Fruchterman-Reingold — FR* [96] which is based on the operation of a power-oriented algorithm (available at: <http://1drv.ms/1qndRua>); *BoundedFR* [97] executes operation principles analogue to the FR algorithm, but is in addition expanded with the criteria of area limitation of common graph deployment (available at: <http://1drv.ms/1qne7JT>); *ISOM* [98, 99] which is based on a competitive study strategy that has a tendency to create clusters from the related nodes (available at: <http://1drv.ms/1qnepQI>); *Kamada – Kawai – KK* [100] which is based on a power-oriented collocation of nodes, but additionally evaluates the distances between every two nodes (available at: <http://1drv.ms/1qneG6t>); *LinLog* [101] which is based on a power-oriented collocation. This algorithm uses cluster development in the graph (available at: <http://1drv.ms/1qneO5W>).

When analysing the propriety of the previously mentioned 8 visualisation algorithms, it was concluded that the most appropriate is the *Efficient Sugiyama* algorithm. Since this propriety analysis of visualisation algorithms is not based on mathematical calculations or technical characteristics, in order to practically ascertain their propriety in different use cases, all of the 8 algorithms are executed in a prototype in order to examine their propriety for the specific scenarios practically. The results are described in the subchapter 4.1.

3.4. Summary and Conclusions

The main conclusions are as follows:

- it has been shown that a set of four graphs combined in one system can be used in personalized study planning — the system provides a complex approach to the implementation of the pedagogical module of intelligent tutoring system;

- in order to determine the significance of course or topic nodes, it is possible to use methods of structural modelling, that substantiate certain decisions on the structural changes of a study plan, course or topics for learners, lecturers, as well as the administrative staff.

The new theoretical result — a new framework of personalized study planning has been developed. Furthermore, the utility of using methods of structural modelling in personalized study planning systems for the structural analysis of study plans, courses and concept maps, which supports planning and development of studies as well as implementation of changes, has been described and validated. A new solution for calculating the value of nodes' structural significance has been introduced.

4. IMPLEMENTATION OF A PERSONALIZED STUDY PLANNING SYSTEM

4.1. Prototype of a Personalized Study Planning System

In order to execute a personalized study planning framework, a prototype has been designed — a Study Planning System (SPS) [102] which has been developed according to the personalized study planning framework described in the previous chapter. This prototype allows to individually visualize and plan the study plan according to the graph $G_1(V_1, Q_1)$ as well as the acquisition of a study course according to the graph $G_2(V_2, Q_2)$. The graph for presenting course topics with a concept map $G_3(V_3, Q_3)$ is obtained with the help of a concept-map-based knowledge evaluation system IKAS. Whereas the graph for representing learning objects $G_4(V_4, Q_4)$ is not visually represented in the prototype, still, input of learning objects is provided. A system database (*SPSDB*), software of data examination and input form (*SPS.DataManager*) as well as software for the construction of study plans and software for choosing the sequence of acquiring study courses (*SPS.StudentStudyProgramBuilder*) has been implemented in the prototype. The SPS prototype has been developed by using the software development platform *Microsoft.NET Framework 4.5* [103, 104]. It contains the following technologies: *Windows Presentation Foundation (WPF)* [105] for the development of graphical user interfaces and *LightSwitch* [106, 107] for the development of data examination and input forms. *Server 2012 Express LocalDB* [108] has been used as the database management system for the local database. Since *SPS* does not use the specific functions provided by *SQL Server 2012 Express LocalDB*, solutions may be found by using other versions of *SQL Server* [109]. *Microsoft.NET Framework 4.5* is included in *Visual Studio 2012* [110]. For operating graphs and for the visualisation of them, the open code software libraries *QuickGraph* [111] and *Graph#* [92], since they support *Microsoft.NET Framework 4.5* are used.

In the next chapters, the operation of previously mentioned tools has been described in detail.

4.1.1. Data Input Tool *SPS.DataManager*

SPS.DataManager (Figure 4.1) is a data input tool for personalized study planning systems that has been developed by using the technologies of *LightSwitch*.

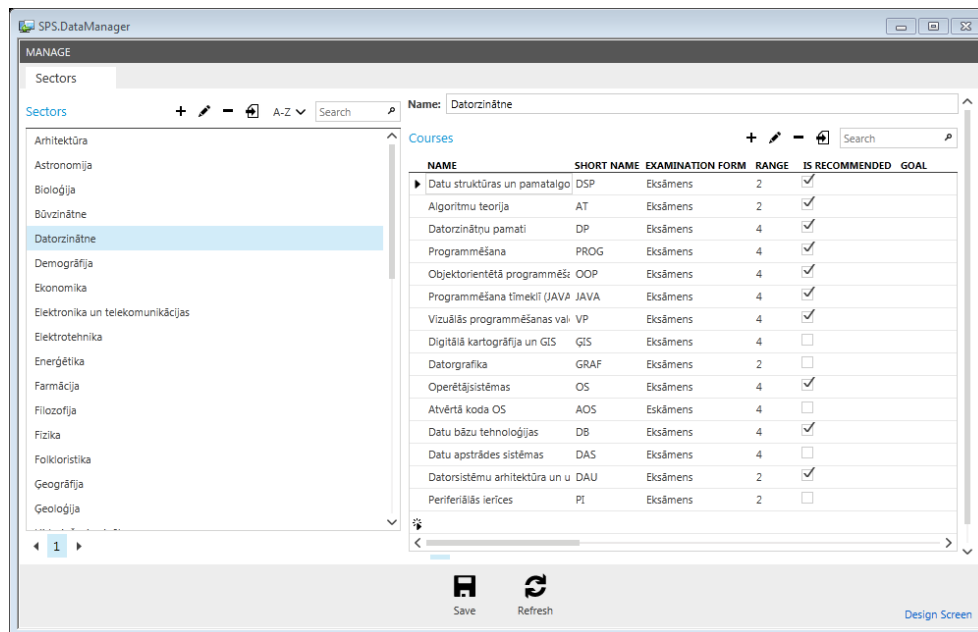


Figure 4.1 *SPS.DataManager* tool interface

Here, the functionality of the *SPS.DataManager* tool is shown.

1. Input window for the directions corresponding to the study courses allows to enter, edit and delete the names of directions. In the additional panel, the study course data of the selected direction are shown.

2. Input window of study program data allows to enter, edit and delete the data on study programs. In the additional panel, information on the active study program is shown.

3. Input window of the titles of study program parts allows to enter, edit and delete the study program part titles. In the additional panel, the data on the study program parts and courses are shown.

4. Input window of lecturers' data allows to enter, edit and delete data on lecturers. In the additional panel, the titles of study courses taught by the selected lecturer are shown.

5. Input window of study courses allows to enter, edit and delete study courses. In the additional panel, two tabs are used for representing study courses: *Main Information* and *Additional Information*. Below that, the prerequisite courses, post-requisite courses, lecturers and course topics are shown.

6. Input window of study course topic learning objects allows to enter, edit and delete learning objects of the study course topics. In the additional panel, the learning objects of the

selected course topic are shown — the type and content of the learning object as well as topics related to this learning object.

7. Input window of study course topics allows to enter, edit and delete study course topics. In the additional panel, the titles of related courses, prerequisite topics, post-requisite topics and learning objects of the selected topic are shown.

8. Input window of learner's data allows to enter, edit and delete data on learners. In the additional panel, data on the learner are shown. Below that, the selected learner's study plans and the date and time of their development are shown.

9. Input window of the learner's chosen study program allows to enter, edit and delete data on the learner's chosen study program. In the additional panel, the courses and course topics of the learner's chosen study program are shown.

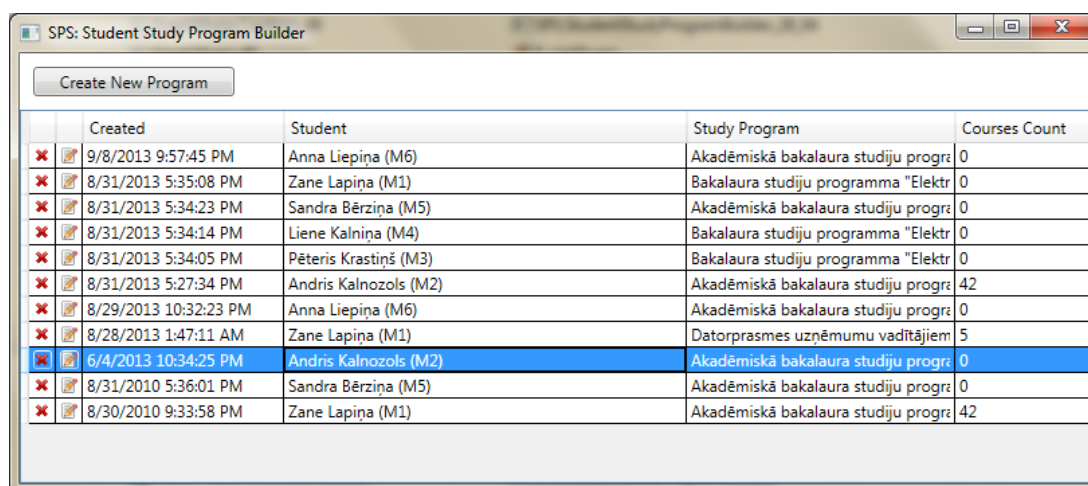
After entering data into the tool *SPS.DataManager* it is possible to start developing a personalized study plan and determining the acquisition sequence of course topics in the tool *SPS.StudentStudyprogramBuilder*, which is described in the next chapter.

4.1.2. Tool for Personalized Study Planning *SPS.StudentStudyprogramBuilder*

SPS.StudentStudyprogramBuilder is intended for determining a personalized study plan and the acquisition sequence of course topics. It has been developed by using the technologies of *Windows Presentation Foundation (WPF)*.

1. Developing a new study plan for the learner allows to choose a learner and adapt a study program to him/her.

2. The window of learner's chosen study program (Figure 4.2) shows the title of the study program and the number of chosen courses.



	Created	Student	Study Program	Courses Count
✖	9/8/2013 9:57:45 PM	Anna Liepiņa (M6)	Akadēmiskā bakalaura studiju progr	0
✖	8/31/2013 5:35:08 PM	Zane Lapīņa (M1)	Bakalaura studiju programma "Elektr	0
✖	8/31/2013 5:34:23 PM	Sandra Bērziņa (M5)	Akadēmiskā bakalaura studiju progr	0
✖	8/31/2013 5:34:14 PM	Liene Kalniņa (M4)	Bakalaura studiju programma "Elektr	0
✖	8/31/2013 5:34:05 PM	Pēteris Krastiņš (M3)	Bakalaura studiju programma "Elektr	0
✖	8/31/2013 5:27:34 PM	Andris Kalnozols (M2)	Akadēmiskā bakalaura studiju progr	42
✖	8/29/2013 10:32:23 PM	Anna Liepiņa (M6)	Akadēmiskā bakalaura studiju progr	0
✖	8/28/2013 1:47:11 AM	Zane Lapīņa (M1)	Datorprasmes uzņēmumu vadītājiem	5
✖	6/4/2013 10:34:25 PM	Andris Kalnozols (M2)	Akadēmiskā bakalaura studiju progr	0
✖	8/31/2010 5:36:01 PM	Sandra Bērziņa (M5)	Akadēmiskā bakalaura studiju progr	0
✖	8/30/2010 9:33:58 PM	Zane Lapīņa (M1)	Akadēmiskā bakalaura studiju progr	42

Figure 4.2 Window of trainee's chosen study program

From this window it is possible to open a window for developing a new study plan just by activating the button <Create New Program>. It is also possible to edit and delete the already existing study plans. By choosing to edit the learner's study plan a window (Figure 4.3) opens, where the learner can start developing a personalized study plan.

3. The window for personalized study planning consists of 3 tabs:

- **Overview** — the left panel of the Figure 4.3 shows an overall description of the study program while the right panel — the chosen study plan courses and their value in CPs;

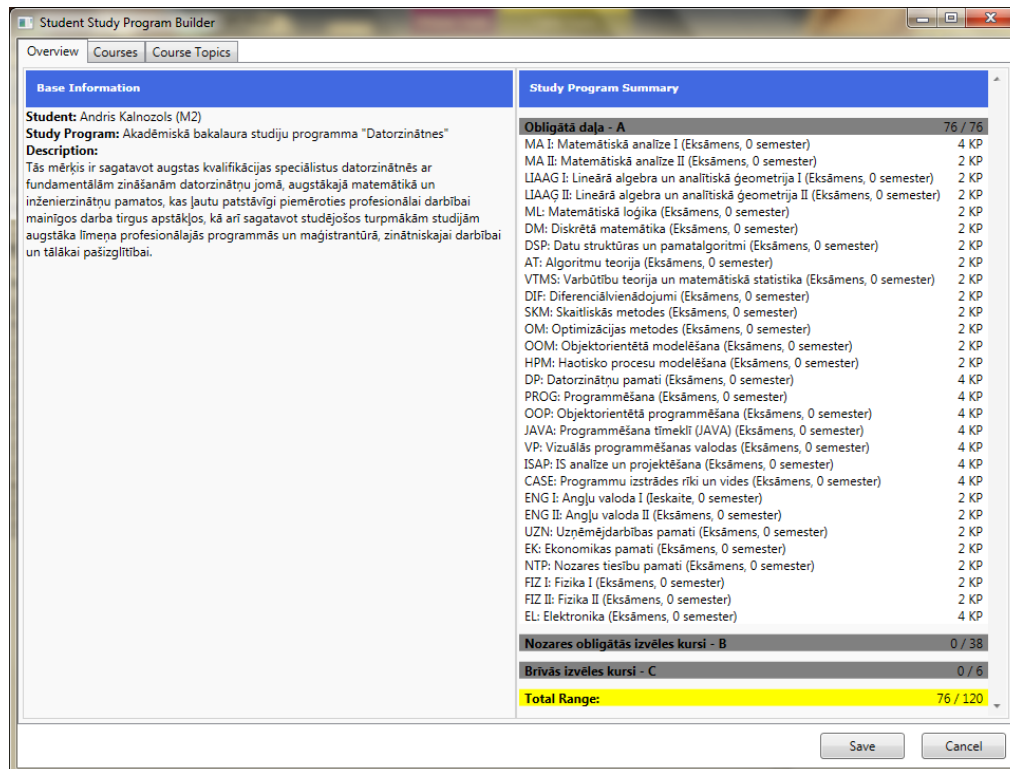


Figure 4.3 Window for personalized study planning (tab — Overview)

- **Courses** — in the Figure 4.4 the window for personalized study planning shows the study program course sequence as a graph. For representing the study plan, 8 types of graph presentation, supported by *Graph#* – *Graph#* – *BoundedFR*, *Circular* [112], *EfficientSugiyama* [113], *Fruchterman-Reingold* – *FR* [97], *ISOM*, *Kamada* – *Kawai* – *KK*, *LinLog* and *Tree*, are offered. The author suggests to use *EfficientSugiyama* as the basic way of presentation, but the user can change the way of presentation according to his/her opinion.

The right side of the Figure 4.4 consists of a list with the personalized study planning courses. Originally, this panel contains the mandatory study courses, while the part of field obligatory choice (limited choice) courses and the part of free choice courses is empty. The learner him-/herself must fill in these two pages with the courses of his/her interest. The learner adds the courses to the study plan panel from the study course graph. The nodes coloured in blue symbolize the courses that are added to the learner's personalized study plan, while the nodes in grey symbolize the courses that are not. Pointing with the cursor on the link connecting the courses, an information window appears showing the courses that are joined by this link. Pointing the study course with the cursor, the predecessor links turn into red, but the successor links — blue.

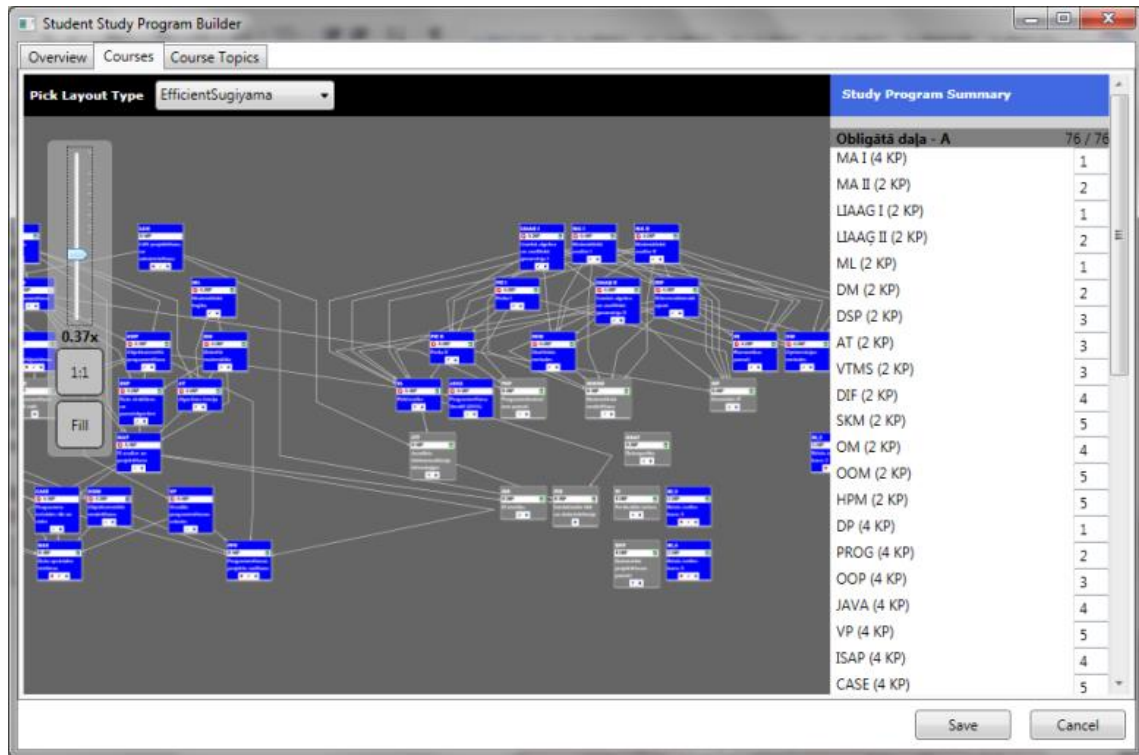


Figure 4.4 Presenting the study course graph

- **Course Topics** — output the topic sequence of the study course as a graph (Figure 4.5).

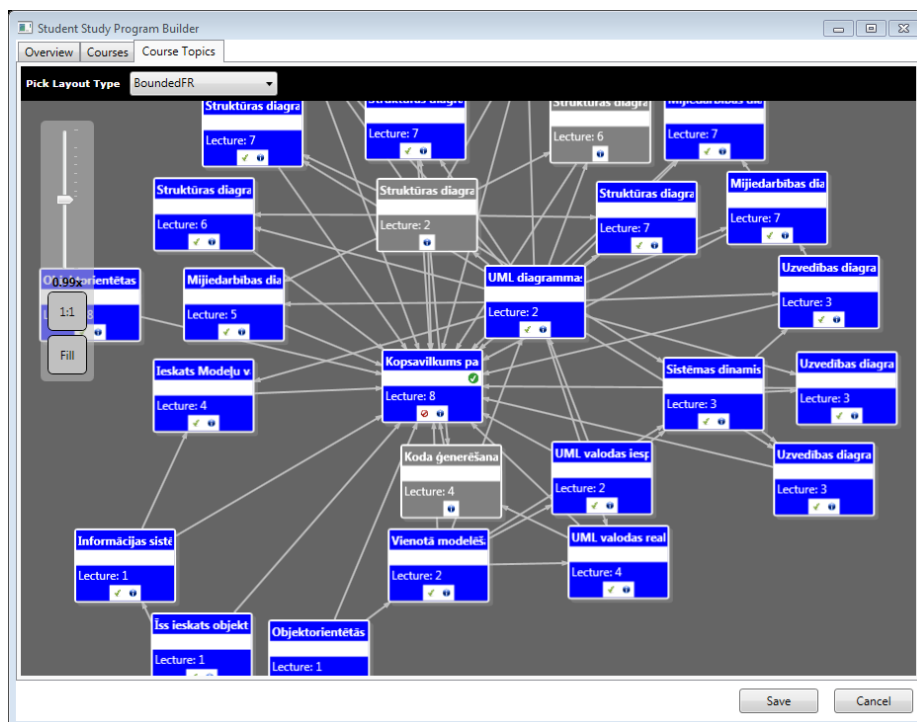


Figure 4.5 Window for determining the sequence of acquiring study course topics

The learner chooses the way of representing the graph. In Figure 4.5, the graph nodes are study course topics, while the links between nodes indicate the relations between the topics' predecessors and successors. Pointing the topics' links with the cursor, the predecessor links turn into red, while the successor links — blue. The information window

contains not only information on the theme and its content, but also information on the courses in which the theme is been acquired, the prerequisite themes, post-requisite themes and learning objects. This window is intended for study purposes. By activating the tab *Course Topic Structures* in the information window, the learning objects of the chosen theme (corresponding to the graph G_4) are shown.

The development of graph G_3 is described in the subchapter 4.3.1 of the Doctoral Thesis.

4.1.3. Individualizētu studiju plānošanas sistēmas prototipa aprobācijas scenāriji

A prototype approbation of a personalized study planning system is executed by using two approaches: the performance test of the prototype by using four scenarios and the test of personalized study planning approach by assessing expert evaluations.

Performance test of the prototype by using four scenarios. In order to approbate the operation of a personalized study planning system's prototype, four approbation scenarios are offered:

- 1) Development of a study plan, determination of a sequence for acquiring study courses and selection of learning objects.
- 2) Development of learning modules for lifelong learning courses, determination of a sequence for acquiring study courses and selection of learning objects.
- 3) Development of a study plan after the learner's participation in a mobility program, determination of a sequence for acquiring topics and selection of learning objects.
- 4) Development of a study plan after recognizing credit points or in take from another university or study program, determination of a sequence for acquiring topics and selection of learning objects.

All of the proposed scenarios were successfully approbated and the following results were acquired:

Approbation result of the 1st scenario. A personalized study plan, visualized as a graph, has been developed in the tool *SPS.StudentsStudyProgramBuilder* and different learning objects have been chosen.

Approbation result of the 2nd scenario. A personalized lifelong learning study plan, visualized as a graph, has been developed in the tool *SPS.StudentsStudyProgramBuildera*, the sequence of acquiring topics has been chosen, the topics have been represented as a graph and different learning objects have been chosen.

Approbation result of the 3rd scenario. In the tool *SPS.StudentsStudyProgramBuilder*, courses have been recognized within the mobility program.

Approbation result of the 4th scenario. A personalized study plan, visualized as a graph, has been developed in the tool *SPS.StudentsStudyProgramBuilder*.

Test of personalized study planning approach by assessing expert evaluations.

Approbation aim:

To introduce experts with the personalized study planning approach and a prototype of personalized study planning system SPS in order to get feedback and assessment.

Realization of the approbation:

To select five experts including students of Bachelor, Master and Doctoral programs, professors, researchers and program directors. Furthermore, the experts must represent different higher education institutions, study programs and fields.

Each of the experts is introduced with the approach of personalized study planning and the prototype of a personalized study planning system SPS.

Conclusions:

In general, the experts evaluated the approach of personalized study planning positively. All of the experts chose graph as the most acceptable type for representing a study plan, course and concept. One expert additionally notes that “not everyone is ready to work with them”. Furthermore, the experts agree that without the determination of learning styles it would be much more difficult to understand which learning object from the learning object list to choose. The experts could easily develop a personalized study plan and make decisions on what courses to include in the study plan since the links between the courses helped to navigate between the sequence of courses. All experts agree that they would like to use a personalized study planning system that has been realized according to the SPS prototype in order to carry out personalized study planning.

The next subchapter contains the structural analysis of a study plan, study course content and a concept map implementation in the SPS prototype.

4.2. Implementation of Rank Calculation in the personalized Study Planning System SPS

In order to analyse the structure of study plan and study course graphs in the personalized study planning system SPS, ranks are calculated for each of the graph's nodes. The ranks of a concept map are calculated separately since the concept map is implemented by using the IKAS system. For the structural analysis of a study plan, the Bachelor's study program “Computer Sciences”, that has been developed in the personalized study planning system SPS, is used [114]. When moving the cursor on the study course in the tab *Courses* of the personalized study planning system SPS tool *SPS.StudentsStudyProgramBuilder*, an information window appears (Figure 4.6). The window shows:

- A rank according to the local grade R_{LP}^1 (in Figure 4.6 marked as R1);
- A rank according to the number of routes in the graph that comprise the given node R_{CE}^1 (in Figure 4.6 marked as R3);

- A rank according to the number of nodes to be reached R_{CE}^2 (in Figure 4.6 marked as R2);
- A total rank of nodes R_{tot} (in Figure 4.6 marked as Rtot);
- The structural significance of nodes $N(i)$ (in Figure 4.6 marked as N).

In structural modelling, when obtaining ranks, the total rank is taken into consideration [88]. In this Doctoral Thesis each rank has been analysed separately. In this way it is possible to obtain information on the ranks of each study course, but in order to get an overview of all the study courses and the calculated rank values, the button *<Export Ranks to CSV>* (Figure 4.6) needs to be activated in the course window of the personalized study plan. This button exports the rank values to a Microsoft (MS) Excel file.

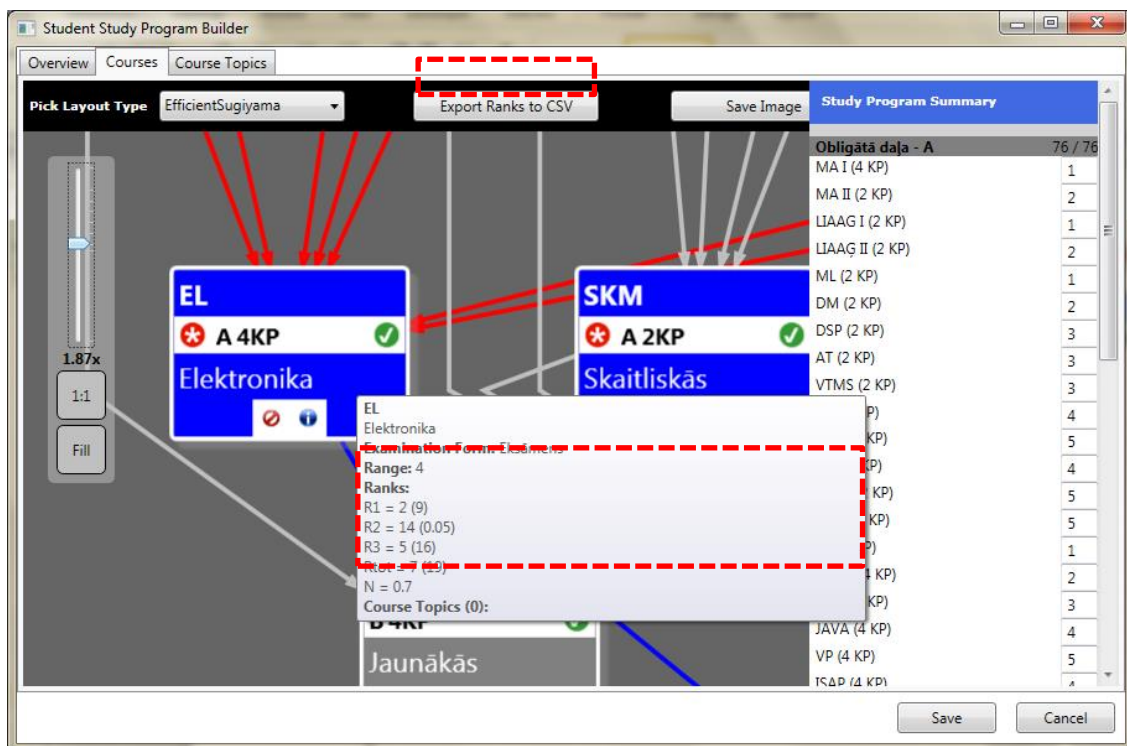


Figure 4.6 Ranks calculated in the SPS tool *SPS.StudentsStudyProgramBuilder* [115, 116]

The calculated value of structural significance in the study plan graph G_1 helps to separate the study courses in parts, i.e. study courses with higher values of structural significance can be added to the part A, while courses with lower values — to the part C. The rest of the courses with average values can be added to the part B. In order to determine borders on how many courses to include in each of the program's parts, the CP value of each part program needs to be considered.

For the structural analysis of study course topics, the study course “Object-oriented Modelling” was used. In order to analyse the graph structure of the study course topic, one needs to act the same way as when analysing the graph of a study plan. It is necessary to define the most important elements in graph G_2 in order to help the lecturer to decide which

themes should be included in an exam. When preparing the exam questions, the lecturer can award each question with points that draw up the final mark. Again, the determination of most significant elements helps to make a decision on how many points will each of the questions be awarded with. The most significant themes will receive the highest number of points. Determining the most important topics helps the lecturer to prepare the study material, since the lecturer can pay greater attention to the topics with greater significance.

In the structural analysis of concept maps, the concepts of the theme “Class diagram components” are used. Determining the most significant concepts helps the lecturer to evaluate knowledge and to develop a concept map. When comparing the concept maps developed by a learner and a lecturer, the significance of nodes should be considered. This means that if a learner has correctly identified a more significant concept (and its relations with other concepts) and not a less significant concept, he needs to receive more points.

4.3. The Opportunities of Integration of Personalized Study Planning Systems with Other Tutoring Systems

In this subchapter, there has been described the integration opportunities of personalized study planning systems as part of the ITS pedagogical module with other study systems, two of which have been chosen. The chosen study systems are the concept-map-based knowledge evaluation system IKAS [117] and the study environment Moodle.

Integration Opportunities with IKAS

IKAS has been chosen in order to obtain the graph G_3 , since the framework of personalized study planning developed in the Doctoral Thesis is as a complement to the IKAS pedagogical module. Figure 4.7 shows a concept map on the topic “Class diagram components” developed in the teacher access mode. The concept map contains 35 concepts. According to the structural analysis of the concept map, the primary concepts have been defined. Other concepts need to be entered by the learner him-/herself. The learner fills in the concept map with the concepts shown below, and connects them. In order to understand a concept, the learner can open the window “Help” that shows the definition, description and an example of the concept. When the learner has filled in the concept map, an evaluation on the learner’s concept map development is presented.

The personalized study planning system prototype SPS does not include a learner’s knowledge test, while IKAS does. Therefore, the learner can develop his/her own study plan in the personalized study planning system, determine the sequence of acquiring topics, then select concepts by using IKAS, move to SPS in order to acquire the learning objects and then come back to IKAS in order to carry out a knowledge test. After the knowledge test, the learner marks that the topic is acquired in the personalized study planning system, and starts acquiring the next topic. The learner continues the task sequence to acquire all the other study course topics until the whole study plan has been acquired.

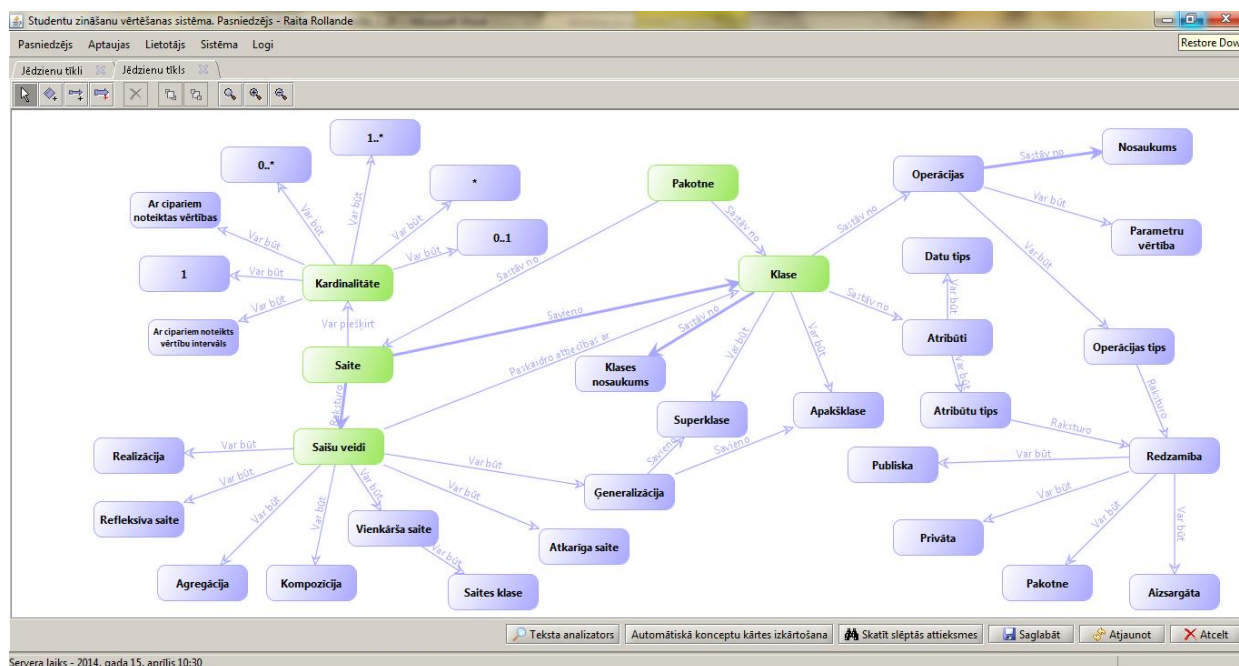


Figure 4.7 A concept map on the topic “Class diagram components” developed in the teacher access mode of IKAS

Integration Possibilities with Moodle

Since Moodle is the system used by Latvian universities and other education centres, it was chosen as the second system for analysing the integration of the prototype. In Latvia, it is used by 97 organisations. This learning environment is used in 232 countries and 79 438 organisations. The total number of registered users worldwide is 68 037 647 [118]. Moodle supports the SCORM [119] standard and other formats that allows the content developed by Moodle to be included in different course-management systems.

One of the most important features of the learning environment Moodle is the development of study courses. The development of study courses consists of modules. More information on the operation of modules can be found in the source [118]. When developing a course content, the most important module is the module of a lesson — it allow to collocate several course pages in different learning routes. The choice of a learning route depends on the answers to the control questions given by the learner or the learner simply chooses the learning route.

Moodle does not offer to the learner to build a study plan (according to G_1), does not allow to define the structure of a study course (according to G_2), and does not carry out concept maps (according to G_3). Meanwhile, Moodle offers to describe learning objects (according to G_4) and to carry out a knowledge test.

4.4. Summary and Conclusions

In this chapter of the Doctoral Thesis the prototype for the implementation of a personalized study planning system, its architecture and the results of its approbation scenarios has been described.

The main conclusions are the following:

- The realization of a *SPS* shows that it is possible to develop such a prototype by using the software development platform *Microsoft.NET Framework 4.5* [103, 104]. *Server 2012 Express LocalDB* [108] can be used as the database management system for a local database. Since the *SPS* does not use the features of *SQL Server 2012 Express LocalDB*, the solutions can be used by other versions of the *SQL Server* [109]. The prototype has been developed by the software development tool *Visual Studio 2012* [110]. The open code software libraries *QuickGraph* [111] and *Graph#* [92] are suitable for implementing operations with graphs and their visualisation.
 - The system operation was successfully examined by four approbation scenarios:
 - Development of a study plan, determination of a sequence for acquiring study courses and selection of learning objects;
 - Development of learning modules for lifelong learning courses, determination of a sequence for acquiring study courses and selection of learning objects;
 - Development of a study plan after the learner's participation in a mobility program, determination of a sequence for acquiring topics and selection of learning objects;
 - Development of a study plan after recognizing credit points or in take from another university or study program, determination of a sequence for acquiring topics and selection of learning objects.
 - The approbation results show that:
 - The tool *SPS.StudentsStudyProgramBuilder* ensures the development of a study plan, determines the sequence of acquiring topics and ensures the familiarization of the study material;
 - The tool *SPS.StudentsStudyProgramBuilder* ensures the development of a study plan for lifelong learning courses, determines the sequence of acquiring topics and ensures the familiarization of the study material;
 - The tool *SPS.StudentsStudyProgramBuilder* ensures the development of a study plan for trainees after participating in mobility programs, determines the sequence of acquiring topics and ensures the familiarization of the study material;
 - The tool *SPS.StudentsStudyProgramBuilder* ensures the development of a study plan for learners after the procedure of credit point recognition or after in take from another university or study program, determines the sequence of acquiring topics and ensures the familiarization of the study material.
 - Integration solutions are possible with the systems of IKAS and Moodle.
- New practical results:
- A personalized study planning system prototype *SPS* has been developed;
 - The prototype has been approbated and it has proven that it carries out the main functions defined.

THE MAIN RESULTS AND CONCLUSIONS

The aim of the Doctoral Thesis is to offer the framework of personalized study planning so that the learner could not only build his/her own personalized learning scenario but also define the most significant courses, topics and corresponding to them concepts as well as implement the framework practically as a prototype of the personalized study planning system and pilot its testing.

To achieve the aim of the Doctoral Thesis the following objectives have been set:

- to analyse the evolution of the development of the learning systems;
- to accomplish the analysis of architecture and pedagogical modules of intelligent tutoring systems (ITS) in order to clarify their components;
- to investigate the existing personalized study planning systems in order to clarify their opportunities and drawbacks;
- to develop the personalized study planning framework as a component of ITS pedagogical module, which allows to create the study plan, define the structure of the study course, create the concept map of the course topics and choose learning objects for each topic;
- to test the opportunities of structure modelling approach for defining the importance of courses, topics, and concepts in personalized study planning, and define the most important courses, topics and concepts;
- to develop the prototype of personalized study planning system, and accomplish the test of its operation.

As a result of the research the following conclusions have been made:

- Analyzing the evolution of tutoring systems and the planning documents of the field of education it is concluded that the development of tutoring systems are moving towards the personalized study process. To achieve that it is necessary to ensure the opportunity to personalize the studies including the building of the personalized study plan, the study course structure, topic concept maps and corresponding learning objects.
- Analyzing the architectures of the existing ITS, new guidelines have been defined for the personalized study planning system which:
 - allow the learner to personalize the study process;
 - show the study plan and the study courses in the graph mode;
 - determine the prerequisite courses for the study courses so that the learner could build the study plan based on the prerequisite restrictions;
 - define prerequisite topics for the study course topics so that the learner could choose the sequence of the topic acquisition;
 - the concepts corresponding to the study course topic depict in the concept map mode;

- show the acquisition opportunities of the study course topics and concepts in a learning object mode.

- Personalized study planning is implemented by mutually related set of four graphs.

While solving the identified tasks, there are achieved the following main new theoretical results in the Doctoral Thesis:

- developed and described the approach for implementation of the pedagogical module component of intelligent tutoring system that is based on the set of four graphs united into one system and ensures complex approach to personalized study planning;
- developed and described the framework of personalized study planning which is applicable at the universities for personalized study planning in the usual tutoring mode, after the learner's participation in the mobility program, after the recognition of the achieved study results during the previous education or the professional experience, after in take from other study program or after the resumption of the studies, as well as in the lifelong education building training courses based on modules;
- is well founded usefulness of the application of the structure modelling method for the analysis of the three graphs of personalized study planning framework: study plan, study courses, and concept map, which supports the building of the study plan and the implementation of changes, and there is offered new solution of value calculation of structural significance of the nodes.

The achieved theoretical results are practically implemented in the prototype SPS of the personalized study planning system the operation of which has been approbated in four scenarios. The personalized study planning approach has been approbated as well assessing the reviews of five experts. The result of the prototype approbation shows that the system accomplishes the defined tasks.

SPS prototype is useful to apply at the institutions of higher education and lifelong education in order to implement personalized study planning. It is basically designed for distance learning. The prototype of the personalized study planning system suggested by the author of the given doctoral thesis is designed for the learners who study in such study programs where it is not necessary to use the facilities of the educational institution, namely, lecture rooms and different laboratories. SPS prototype includes:

- designing of the study plan using the graph depiction which includes the following activities:
 - building the study plan;
 - development of learning modules for lifelong education courses;
 - building the study plan after the learner's participation in the mobility program;
 - development of the study plan after the recognition of the credit points;
 - building the study plan after in take from another university or another study program.

- setting the sequence of the acquisition of study course topics.

Directions for further research:

- accomplish practically the integration of SPS of personalized study planning system with IKAS and Moodle;
- investigate and assess the integration possibilities of SPS of personalized study planning system with other tutoring systems;
- expand the architecture of the developed solution in order to integrate other ITS modules such as, for example, student's module and problem domain module.

BIBLIOGRAPHY

- [1] Central Statistical Bureau of Latvia. Available: <http://www.csb.gov.lv/en>. [Accessed 26.05.2013].
- [2] Nwana H. S. Intelligent Tutoring Systems: An Overview, Artificial Intelligence Review 4, pp. 251–277, 1990.
- [3] Nkambou R., Bourdeau J., Mizoguchi R., Advances in Intelligent Tutoring Systems, Berlin: Springer, 2010.
- [4] BBC, BBC News. Available: <http://www.bbc.co.uk/news/education-20498356>. [Accessed 11.04.2013].
- [5] Ministry of Environmental Protection and Regional Development, Latvia 2030, 2008. Available: http://www.latvija2030.lv/upload/latvija2030_lv.pdf. [Accessed: 25.03.2013].
- [6] The Council Of The European Union, Council conclusions on the modernisation of higher education, Official Journal of the European Union, pp. 36–41, 2011.
- [7] The Council Of The European Union, Council Conclusions on investing in education and training — a response to ‘Rethinking Education: Investing in skills for better socio-economic outcomes’ and the ‘2013 Annual Growth Survey’, Official Journal of the European Union, pp. 5–8, 2013.
- [8] Cabinet of Ministers, About the program «Information and communication technologies for the quality of education 2007.–2013. gadam», Latvijas Vestnesis, Latvija, 2006.
- [9] Finland Ministry of Education and Culture, Education and Research 2011–2016, Government, Finland, 2012.
- [10] Geer R., Sweeney T., Students' Voices about Learning with Technology, Journal of Social Sciences, vol. 8, no. 2, p. 294, 2012.
- [11] Cabinet of ministers of the Republic of Latvia, Cabinet Regulations No.36 "The previous education or professional experience to achieve the recognition of learning outcomes", Riga, Latvia, 2012. Available: www.likumi.lv [Accessed 08.03.2014].
- [12] The Latvian Parliament, Law on Higher Education, Latvijas Vestnesis, Riga, Latvia, 1995.
- [13] Ministry of Economics of the Republic of Latvia, Available: http://www.em.gov.lv/images/modules/items/tsdep/darba_tirgus/EMZino_21062013.pdf. [Accessed 13.08.2013].
- [14] European Commission, Cultural Heritage and Technology Enhanced Learning, Community Research and Development Information Service, 31.07.2012. Available: http://cordis.europa.eu/fp7/ict/telearn-digicult/telearn_en.html. [Accessed 10.03.2013].
- [15] Urban-Lurain M., Intelligent Tutoring Systems: An Historic Review in the Context of the Development of Artificial Intelligence and Educational Psychology, 1999. Available: <http://www.cse.msu.edu/rgroups/cse101/ITS/its.htm>. [Accessed 12.02.2013].
- [16] Wenger E., Artificial intelligence and tutoring systems: computational and cognitive approaches to the communication of knowledge, San Francisco: Morgan Kaufmann, 1987.
- [17] Shute V. J., Psotka J., Intelligent Tutoring Systems: Past, Present and Future, Human resources directorate manpower and personnel research division., pp. 570–600, 1994.

- [18] Chakraborty S., Roy D., Basu A., Development of Knowledge Based Intelligent Tutoring System, *Advanced Knowledge Based Systems: Model, Applications & Research*, vol.1, pp. 74–100, 2010.
- [19] Limongelli C., Sciarrone F., Temperini M., Vaste G., Lecomps5: A Web-Based Learning System For Course Personalization And Adaptation, *IADIS International Conference on e-Learning*, Amsterdam, The Netherlands, pp. 325–332, 2008.
- [20] Marquez J. M., Ortega J. A., Gonzalez-Abril L., Velasco F., Defining Adaptive Learning Paths For Competence-Oriented Learning, *IADIS International Conference on e-Learning*, Amsterdam, The Netherlands, pp. 403–410, 2008.
- [21] Felder R. M., Silverman L. K., Learning and Teaching Styles in Engineering Education, *Engineering Education*, vol. 78, no. 7, pp. 674–681, 1988.
- [22] Montgomery M., Groat L. N., Students' Learning Styles and Their Implications for Teachers, *CRLT Occasional Paper No. 10*, University of Michigan, Center for Research on Learning and Teaching, pp. 1–8, 1998.
- [23] Lathama A., Crockett K., McLeana D., Edmonds B., A conversational intelligent tutoring system to automatically predict learning styles, *Computers & Education*, vol. 59, no. 1, pp. 95–109, 2012.
- [24] Graf S., Kinshuk, Q. Z., Maguire P., Shtern V., An Architecture for Dynamic Student Modelling of Learning Styles in Learning. Systems and its Application for Adaptivity, *IADIS International Conference on Cognition and Exploratory Learning in Digital Age*, Timisoara, Romania, pp. 103–111, 2010.
- [25] Rajamenakshi R., Pal S., E-learning: state of art survey, analysis and recommendations towards user personalized e-learning framework, *IADIS International Conference on e-Learning*, Amsterdam, The Netherlands, pp. 128–133, 2008.
- [26] Kerdprasop K., Kerdprasop N., A rough set approach to personalization in web-based learning systems, *IADIS International Conference on e-Learning*, Amsterdam, The Netherlands, pp. 60–67, 2008.
- [27] Anohina A., Grundspenkis J., A Concept Map Based Intelligent System for Adaptive Knowledge Assessment. *Frontiers in Artificial Intelligence and Applications* (O. Vasilecas et al., eds.), vol. 155, Databases and Information Systems IV, Amsterdam, pp. 263–276, 2007.
- [28] Grundspenkis J., Development of Concept Map Based Adaptive Knowledge Assessment System, *IADIS International Conference e-Learning 2008*. vol.1, Amsterdam, pp. 395–402, 2008.
- [29] Grundspenkis J., Anohina A., Agents in Intelligent Tutoring Systems: State of the Art, *Scientific Proceedings of Riga Technical University*, 5th series, Computer Science, Applied Computer Systems, vol. 22, Riga, pp. 110–121, 2005.
- [30] Mohan R., Teacher Education, New Delhi: PHI Learning Pvt. Ltd., 2011.
- [31] Mohan R., Innovative Science Teaching: For Physical Science Teachers 3rd Ed., New Delhi: PHI Learning Pvt. Ltd., 2007.
- [32] Thomas C. A., Davies I. K., Openshaw D., Bird J. B., Programmed Learning in Perspective: A Guide to Program Writing, London: Transaction Publishers, 2007.
- [33] Coulson J. B., Adaptive Teaching Machines, NY: John Wiley and Sons, 1962.
- [34] Senders J., Adaptive teaching machines, Programmed learning and computer-based instruction, New York, Wiley, pp. 129–133, 1962.
- [35] Haque U., The Architectural Relevance of Gordon Pask, *Archit Design*, pp. 54–61, 2007.
- [36] Uhr L., Teaching machine programs that generate problems as a function of interaction with students, *Proceedings of the 24th National Conference*, pp. 125–134, 1969.
- [37] Richardson J. J., Foundations of Intelligent Tutoring Systems, Broadway: Routledge, 1988.
- [38] Nkambou R., Frasson C., Gauthier G., A new approach to ITS-curriculum and course authoring: the authoring environment, *Computers & Education*, vol. 31, no. 1, pp. 105–130, 1998.
- [39] Self J. A., Student models in computer-aided instruction, *International Journal of Man-Machine Studies*, pp. 261–276, 1974.
- [40] Sleeman D., Brown J. S., Intelligent Tutoring Systems, Introduction: Intelligent Tutoring Systems, New York: Academic Press, pp. 1–11, 1982.
- [41] Padayachee I., Intelligent Tutoring Systems: Architecture and Characteristics, SCALA, Eastern Cape, 2002.
- [42] Freedman R., What is an Intelligent Tutoring System?, Published in *Intelligence* vol. 11, no. 3, pp. 15–16, 2000.

- [43] Ghaoui C., Janvier W. A., Artificial Intelligence in Intelligent Tutoring Systems — An Evaluation, 2001. Available: <http://www.cms.livjm.ac.uk/cmswjnv/main/papers/ITS-anEvaluation.pdf>. [Accessed 22.08.2012].
- [44] Beck J., Stern M., Haugsjaa E., Applications of AI in Education, 2001. Available: <http://www.ent.mrt.ac.lk/~ekulasek/en577/Applications%20of%20AI%20in%20Education.htm>. [Accessed 21.08.2012].
- [45] Russell S., Norvig P., Artificial Intelligence. A Modern Approach., Upper Saddle River: Prentice Hall, 2003.
- [46] Russell S., Norvig P., Artificial Intelligence. A Modern Approach., Upper Saddle River: Prentice Hall, 2010.
- [47] Lavendelis E., Grundspenķis J., MASITS Methodology Supported Development of Agent Based Intelligent Tutoring System MIPITS, Communications in Computer and Information Science, vol. 129, pp. 119–132, 2011.
- [48] Grundspenķis J., MIPITS and IKAS — Two Steps towards Truly Intelligent Tutoring System Based on Integration of Knowledge Management and Multiagent Techniques, Proceedings of the International Conference on e-Learning and the Knowledge Society (e-Learning'10), Riga, Latvia, pp. 22–39, 2010.
- [49] Lavendelis E., Grundspenķis J., Multi-Agent Based Intelligent Tutoring System Source Code Generation Using MASITS Tool, Scientific Journal of Riga Technical University. Computer Sciences 41, no. 1, pp. 27–36, 2010.
- [50] Hatzilygeroudis I., Prentzas J., Knowledge Representation Requirements for Intelligent Tutoring Systems, Intelligent Tutoring Systems: 7th International Conference, Maceió, Alagoas, Brazil, pp. 87–97, 2004.
- [51] Jeremić Z., Devedžić V., Gašević D., An Intelligent Tutoring System for learning design patterns, Proceedings of the ICWE2004 WSh. on Adaptive Hypermedia and Collaborative Web-based Sys., Munich, Germany, p. 6, 2004.
- [52] Half H., Curriculum and instruction in automated tutors, Foundations of intelligent tutoring systems, Hillsdale, New Jersey, Lawrence Erlbaum Associates, Inc., Publishers, pp. 79–108, 1988.
- [53] Murray T., Principles for pedagogy-oriented knowledge based tutor authoring systems: Lessons learned and a design meta-model, In Authoring Tools for Advanced Technology Learning Environments, Netherlands, Springer, pp. 439–466, 2003.
- [54] Murray T., Authoring Intelligent Tutoring Systems: An Analysis of the, International Journal of Artificial Intelligence in Education, pp. 98–129, 1999.
- [55] Morales R., Aguera A. S., Dynamic Sequencing of Learning Objects, Proceedings of the IEEE International Conference on Advanced Learning Technologies, pp. 502–506, 2002.
- [56] Chakraborty S., Roy D., Basu A., Shikshak: An Architecture for an Intelligent Tutoring System, International Workshop of Cognitive Aspects in Intelligent and Adaptive Web-based Educational Systems (CIAWES) held in conjunction ICCE, Taipei, Taiwan, pp. 24–41, 2008.
- [57] Chakraborty S., Roy D., Bhowmick P. K., Basu A., An authoring system for developing Intelligent Tutoring System, Proceedings of IEEE TechSym, pp. 196–205, 2010.
- [58] Chakraborty S., Bhattacharya T., Bhowmick P., Basu A., Sarkar S., Shikshak: An Intelligent Tutoring System Authoring Tool for Rural Education, I ICTD, Bangalore, India, pp. 1–10, 2007.
- [59] Nkambou R., Frasson M. C., Frasson C., Generating courses in an intelligent tutoring system, IEA_AIE'96, The Ninth International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems, ACROS Fukuoka, Tenjin Chu-ku Fukuoka, Japan, pp. 261–266, 1996.
- [60] Nkambou R., Frasson C., Gauthier G., CREAM-Tools: An authoring environment for knowledge engineering in intelligent tutoring systems, In Authoring Tools for Advanced Technology Learning Environments, Springer, Netherlands, pp. 269–308, 2003.
- [62] Nkambou R., Gauthier G., Frasson C., CREAM-Tools: An authoring environment for curriculum and course building in an intelligent tutoring system, CALISCE '96 Proceedings of the Third International Conference on Computer Aided Learning and Instruction in Science and Engineering, Springer Berlin Heidelberg, pp. 186–194, 1996.
- [62] Russell D. M., IDE: The interprener, Intelligent Tutoring Systems: Lessons Learned, In Psotka, Massey, & Mutter (Eds.), Hillsdale, New Jersey, Lawrence Erlbaum Associates, pp. 321–351, 1988.

- [63] Jones M., Wipond K., Teaching Knowledge and Intelligent Tutoring, Intelligent Environments for Curriculum and Course Development, Norwood, New Jersey, Ablex, pp. 379–396, 1991.
- [64] Kabicher S., Derntl M., Visual Modelling for Design and Implementation of Modular Curricula, Zeitschrift für Hochschulentwicklung, pp. 23–33, 2008.
- [65] Kabicher S., Motschnig-Pitrik R., Coordinating Curriculum Implementation Using Wiki-supported Graph Visualization, Ninth IEEE International Conference on Advanced Learning Technologies, ICALT, pp. 742–743, 2009.
- [66] Gestwicki P., Work in progress — Curriculum visualization, Proceedings of the 38th. Annual Frontiers in Education Conference, Saratoga Springs, NY, pp. 13–14, 2008.
- [67] Gestwicki P., Toombs A., Poster: Design and evaluation of an interactive curriculum visualization system, VisWeek 2010, Salt Lake City, USA, p. 2, 2010.
- [68] Zucker R., ViCurriAS: a curriculum visualization tool for faculty, advisors and students, Journal of Computing Sciences in Colleges, vol. 25, no. 2, pp. 138–145, 2009.
- [69] Auvinen T., Curriculum Development Using Graphs of Learning Outcomes, First EUCET Association Conference New Trends and Challenges in Civil Engineering Education, Patras, Greece, pp. 27–37, 2011.
- [70] Rollande R., Using graph for tutor module construction of intelligent tutoring system, 4th International Conference: Information Society and Modern Business, The Role of Regional Centers in Business Development, Ventspils, Latvia, pp. 39–48, 2009.
- [71] The Latvian Parliament, Education Law, Latvijas Vestnesis, no. 343/344 Riga, 1998.
- [72] Krathwohl D. R., A revision of Bloom's taxonomy: An overview, Theory into practice, vol. 41, no. 4, pp. 212–218, 2002.
- [73] Anderson L. W., Krathwohl D. E., Bloom B., A Taxonomy for learning teaching and assessing: A revision of Bloom's taxonomy of educational objectives [Abridged], New York: Addison Wesley Longman, p. 336, 2000.
- [74] Forehand M., Bloom's taxonomy: Original and revised, Emerging perspectives on learning, teaching, and technology, 2005.
- [75] Novak J., Learning, Creating and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations., Mahwah, NJ: Lawrence Erlbaum Associates, 1998.
- [76] Novak J. D., Canas A. J., The Theory Underlying Concept Maps and How to Construct and Use Them, Technical Report IHMC CmapTools 2006-01, Rev 01-2008, Florida, 2008.
- [77] Grundspenkis J., Usage Experience and Student Feedback Driven Extension of Functionality of Concept Map Based Intelligent Knowledge Assessment System, Communication and Cognition, vol. 43, no. 1&2, pp. 1–20, 2010.
- [78] Vanides J., Yin Y., Tomita M., Ruiz-Primo M. A., Concept maps, Science Scope, vol. 28, no. 8, pp. 27–31, 2005.
- [79] Learning Technology Standards Committee of the IEEE, Draft Standard for Learning Object Metadata, IEEE Standards Department, Piscataway, NJ, USA, 2002.
- [80] Keefe J., Learning Style: An Overview, In NASSP's Student Learning Styles: Diagnosing and Prescribing Programs, Reston, VA, National Association of Secondary School Principals, pp. 1–17, 1979.
- [81] Irvine J., York D., Learning Styles and Culturally Diverse Students: A Literature Review. James A. Banks (Ed.), In Handbook of Research on Multicultural Education, New York, Simon & Schuster Macmillan, pp. 484–497, 1995.
- [82] Byrne E. P., Teaching and learning styles in engineering at UCC, In International Symposium on Engineering Education, 2007.
- [83] Peter S. E., Bacon E., Dastbaz M., Learning styles, personalisation and adaptable e-learning, 2009.
- [84] Graf, S., Liu, T. C., Supporting Teachers in Identifying Students' Learning Styles in Learning Management Systems: An Automatic Student Modelling Approach, Educational Technology & Society, vol. 12, no. 4, pp. 3–14, 2009.
- [85] Felder R. M., Soloman B. A., Index of learning styles. Available: <http://www.engr.ncsu.edu/learningstyles/ilsweb.html>. [Accessed 18.03.2014].
- [86] Litzinger T. A., Lee S. H., Wise J. C., Felder R. M., A Psychometric Study of the Index of Learning Styles, Journal of Engineering Education. Reliability, factor structure, and construct validity of the Index of Learning Styles., vol. 96, no. 4, pp. 309–319, 2007.

- [87] Felder R. M., Soloman B. A., Index of learning styles. Available: <http://www.engr.ncsu.edu/learningstyles/ilsweb.html>. [Accessed 18.03.2014].
- [88] J. Osis, J. Grundspenkis and Z. Markovics, Complex heterogeneous systems topological modelling, Riga: Riga Technical University, 2012.
- [89] Nikolaev V., Bruk V. M., Sistemotekhnika: metody i prilozhenija, Leningrad: Mashinostroyeniye, 1985.
- [90] Nečiporenko V. I., Strukturnyj analiz sistem: effektivnost' i nadežnost', Moskva: Sovetskoe radio, 1977.
- [91] Grundspenkis J., Structural Modelling of Complex Technical Systems in Conditions of Incomplete Information, Research Paper Reviews for habilitated doctor's degree, Riga, p. 33. 1993.
- [92] Microsoft, Graph#. Available: <http://graphsharp.codeplex.com/>. [Accessed 02.05.2013].
- [93] Battista G. D., Eades P., Tamassia R., Tollis I. G., Algorithms for drawing graphs: an annotated bibliography, Computational Geometry, vol. 4, no. 5, pp. 235–282, 1994.
- [94] Six J. M., Tollis I. G., Circular Drawing Algorithms, Handbook of Graph Drawing and Visualization, Boca Raton, Chapman and Hall/CRC, pp. 285–314, 2013.
- [95] Eiglsperger M., Siebenhaller M., Kaufmann M., An Efficient Implementation of Sugiyama's Algorithm for Layered Graph Drawing, Journal of Graph Algorithms and Applications, vol. 9, no. 3, pp. 305–325, 2005.
- [96] Fruchterman T. M., Reingold E. M., Graph drawing by force-directed placement, Software: Practice and experience, vol. 21, no. 11, pp. 1129–1164, 1991.
- [97] Fagnan J., Zañane O., Goebel R., Visualizing Community Centric Network Layouts, In Proceedings of the 2012. 16th International Conference on Information Visualisation, pp. 321–330, 2012.
- [98] Meyer B., Competitive Learning of Network Diagram Layout, IEEE, Published in the Proceedings of VL'98, Nova Scotia, Canada, pp. 56–63, 1998.
- [99] Meyer B., Self-organizing graphs — a neural network perspective of graph layout, Graph Drawing, Springer Berlin Heidelberg, 1998.
- [100] Kamada T., Kawai S., An Algorithm for Drawing General Undirected Graphs, Information Processing Letters, vol. 31, no.1, pp. 7–15, 1989.
- [101] Noack A., Energy Models for Graph Clustering, Journal of Graph Algorithms and Applications, vol. 11, no. 2, pp. 453–480, 2007.
- [102] Rollande R., Grundspenkis J., Representation of study program as a part of graph based framework for tutoring module of intelligent tutoring system, Proceedings of The Second International Conference on Digital Information Processing and Communications (ICDIPC 2012), Klaipeda, Lithuania, pp. 108–113, 2012.
- [103] Microsoft, .NET Framework. Available: <http://msdn.microsoft.com/en-US/vstudio/aa496123.aspx>. [Accessed 02.05.2013].
- [104] Microsoft, .NET Downloads, Developer Resources & Case Studies. Available: <http://www.microsoft.com/net/>. [Accessed 02.05.2013].
- [105] Microsoft, Windows Presentation Foundation. Available: <http://msdn.microsoft.com/en-us/library/vstudio/ms754130.aspx>. [Accessed 02.05.2013].
- [106] Microsoft, Visual Studio LightSwitch. Available: <http://msdn.microsoft.com/en-us/vstudio/ff796201.aspx>. [Accessed 02.05.2013].
- [107] Microsoft, Visual Studio 2012 LightSwitch. Available: <http://msdn.microsoft.com/en-us/library/vstudio/ff851953.aspx>. [Accessed 02.05.2013].
- [108] Microsoft, SQL Server 2012 Express LocalDB. Available: <http://msdn.microsoft.com/en-us/library/hh510202.aspx>. [Accessed 02.05.2013].
- [109] Microsoft, SQL Server Editions. Available: <http://www.microsoft.com/sqlserver/en/us/editions.aspx>. [Accessed 02.05.2013].
- [110] Microsoft, Visual Studio 2012. Available: <http://msdn.microsoft.com/en-us/library/vstudio/dd831853.aspx>. [Accessed 02.05.2013].
- [111] Microsoft, QuickGraph, Graph Data Structures And Algorithms for .NET. Available: <http://quickgraph.codeplex.com/>. [Accessed 02.05.2013].
- [112] Six J. M., Tollis I. G., A framework and algorithms for circular drawings of graphs, Journal of Discrete Algorithms, vol. 4, pp. 25–50, 2006.

- [113] Sugiyama K., Tagawa S., Toda M., Methods for visual understanding of hierarchical system structures, IEEE Transactions on Systems, Man, and Cybernetics, vol. 11, no. 2, pp. 109–125, 1981.
- [114] Ventspils University College. Available: <http://www.venta.lv>. [Accessed 27.11.2013].
- [115] Rollande R., Grundspenkis J., Graph based framework and its implemented prototype for personalized study planning, The Second International Conference on E-Learning and E-Technologies in Education (ICEEE2013), Lodz, Poland, pp. 137–142, 2013.
- [116] Rollande, R., Grundspenkis, J., Mislevics, A., The use of structural modelling methods for analysis of personalized study planning. IEEE Technically Co-Sponsored Science and Information Conference 2014, August 27–29, pp. 921–926, 2014, London, UK.
- [117] Grundspenkis J., Anohina-Naumeca A., Lukassenko R., Vilkelis M., Strautmane M., Knowledge assessment system, Riga Technical university, Department of Artificial Intelligence and Systems Engineering. Available: www.ikas.lv. [Accessed 15.04.2014].
- [118] Moodle, 2012. Available: <https://moodle.org>. [Accessed 09.04.2013].
- [119] U. S. Government, Advanced Distributed Learning, SCORM. Available: <http://www.adlnet.org/scorm/>. [Accessed 30.11.2013].