RIGA TECHNICAL UNIVERSITY

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# DEVELOPMENT OF STUDENT MODEL FOR SUPPORT OF INTELLIGENT TUTORING SYSTEM FUNCTIONS

**Summary of Doctoral Thesis**

**Riga 2012**

**RIGA TECHNICAL UNIVERSITY**
Faculty of Computer Science and Information Technology
Institute of Applied Computer Systems



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# DOCTORAL THESIS
# SUBMITTED IN RIGA TECHNICAL UNIVERSITY FOR OBTAINING DOCTORAL DEGREE IN ENGINEERING (Computer Systems)

The defence of the thesis submitted for doctoral degree of computer systems will take place at an open session on November 21, 2012 in Meza Street 1/3, auditorium 202, Riga Technical University Faculty of Computer Science and Information Technology.

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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.

Romans Lukasenko ……………………………….. (signature)

Date: ……………………………………..

The doctoral thesis is written in Latvian and includes an introduction, 5 chapters, conclusions, bibliography, 3 attachments, 67 figures and 32 tables in the main text, there are in total 156 pages. The bibliography contains 118 references.

# CONTENT

# INTRODUCTION

Computer-based tutoring systems provide people with an opportunity to study at any convenient time and place, however much and however quickly they want to do it. The technology implementing the teaching process partially takes over the human teacher's role and, thus, in order to be able to fulfill this role effectively, it is necessary to provide it with the intelligent and adaptive abilities (functions), which a human teacher has [ANO 2006a, BRU 1999, DEV 2000, FRA 1997, KEL 2002, LIE 2000, WEN 2007]. Therefore, nowadays the emphasis is put on the design of the so-called Intelligent Tutoring Systems (ITS) which, based on a variety of artificial intelligence techniques and the knowledge of what to teach and how to teach, is able to provide intelligent support and adaptation of the learning process (or learning personalization) for an individual learner, thereby increasing the effectiveness of the learning process [GIL 1999, MON 1995]. Examples of intelligent and adaptive functions of ITS are: the ability to provide learners with the necessary help (explanations, leading questions, hints, etc.) while solving a task; the ability to find mistakes in a learner's solution and determine the knowledge gaps that caused these mistakes; the ability to present the learning material in the form that is the most suitable for the learner, and the ability to create an individual training plan (variety of tasks) for each learner [BLO 1956, BRU 2003, KIN 2004, LAZ 2007].

In order to provide intelligent and adaptive functions of ITS, student modeling is used [BRU 2001, GOU 2004, WEN 2007, БУЛ 2003]. Student modeling is a process during which information about the learner is gathered and used to build a model for him/her. Among the data that is stored in the student model are the learner's levels of knowledge, achievements, skills, training goals, learning styles, and other data. Student model data are used further in the system in order to personalize the learning environment for each learner.

After reviewing the relevant literature extensively, the author of this thesis concluded that there was no single study that would compile information on the ITS functions (including intelligent and adaptive functions) and the student model data correlations. Such a study would facilitate the development of ITSs, it would allow the developers to quickly choose the most appropriate student model for the ITS depending on what functionality the system will have. At the moment, the lack of such a study means that each ITS developer needs to analyze many ITSs to select the appropriate student model or modify and adapt one to the particular situation, and that takes a lot of time.

## Relevance of the Topic

The aim of any ITS is to provide training at a level that is not worse than good learning practices of a human teacher. Therefore, one of the most important parts of an ITS is its intelligent and adaptive functions in terms of the ability of the ITS to analyze and personalize the learning environment for each learner's needs. For this reason, a study on student modeling as the main data source for providing an ITS with the intelligent and adaptive functions is a relevant topic.

The topic of this doctoral thesis is relevant in particular for Riga Technical University in order to further develop the RTU-created computerized knowledge assessment system IKAS [ANO 2011, GRU 2009a]. Currently the developers of IKAS agree that it is necessary to expand its intelligent and adaptive functions so that the system would fit the learners' needs better and so that it would be possible to use it for training purposes as well, not just as a knowledge assessment tool. Because of this reason, the student model research results in this thesis are also used to select a student model for IKAS in accordance with its intelligent and adaptive functions.

## Goal of the Thesis

The goal of the thesis is to identify the intelligent and adaptive functions of the intelligent tutoring systems, to define the complete content of a student model for the support of these functions and to develop a tool that would create student models automatically, as well as to expand the intelligent and adaptive functions of the knowledge assessment system IKAS and to experimentally verify the effect obtained after implementing these functions.

## Tasks of the Thesis

In order to achieve the goal set for the thesis, the following tasks have been specified:

- To analyze the ITSs to: 1) distinguish their main intelligent and adaptive functions, 2) define as complete a student model as possible, 3) to find a relationships between the student model data and the ITSs functions.
- To develop a software system for obtaining the student model's structure depending on the necessary intelligent and adaptive functions of the ITS.
- To identify specific requirements regarding the extension of the intelligent and adaptive functions of IKAS based on IKAS developers' aims to improve the system, as well as based on the learners' and teachers' feedback on the operation of IKAS.
- To use the newly developed software system to automatically create an IKAS-specific student model.

- To develop algorithms that would enable the implementation of the new IKAS's intelligent and adaptive functions, and to carry out this implementation.
- To evaluate the algorithms in real courses and to conclude whether the algorithms actually improve the training.

**Object of the Research**

The object of the research is ITSs and the student models used in them.

**Subject of the Research**

The subject of this doctoral thesis is student models of ITSs, focusing on the use of the student model's data for the support of intelligent and adaptive functions.

**Scientific novelty of the thesis**

The scientific novelty of the thesis is as follows:

- A full list of intelligent and adaptive functions of ITSs has been defined, and the relationship between the ITSs' functions and the student model's data has been identified.
- A complete student model for the support of all intelligent and adaptive functions of ITSs has been established.
- An algorithm to explain concepts in an adaptive manner has been developed.
- An algorithm to select the initial difficulty degree of a concept map task for each learner depending on his/her knowledge level in the course and on the learning style has been developed.
- A formula to calculate the degree to which a student has mastered a concept and an algorithm to generate an individual repetition list of concepts for the learner has been developed.

**Theoretical Value of the Thesis**

The theoretical value of the thesis is as follows:

- ITS definitions have been analyzed and classified and four main ITS features have been distinguished: 1) adaptation to the learner, 2) student modeling, 3) use of artificial intelligence methods and 4) system's structure.
- The intelligent and adaptive functions of ITSs have been compiled, and the distribution of these functions in different groups of ITSs has been analyzed.
- The content of the theoretical and practical student models has been obtained, the content of a complete student model has been defined, and the relationships between complete student model data and ITS functions have been identified.

- The profile of a modern learner's learning style, which is Visual - Global - Active – Sensitive, has been identified with the help of a survey.
- Student models should be open and learners should be able to modify them, because they want to involve themselves actively in the management of their data.

**Practical Value of the Thesis**

The practical value of the thesis is as follows:

- A complete student model has been created and a software system that generates student models automatically depending on ITS's intelligent and adaptive functions has been developed.
- The intelligent and adaptive functions of IKAS have been extended with the support of a new student model so that IKAS can support both the knowledge assessment and new knowledge acquisition stages.
- An algorithm that explains concepts in an adaptive manner has been implemented in IKAS.
- An algorithm that selects the initial difficulty degree of a concept map task for each learner has been implemented in IKAS.
- An algorithm that generates an individual repetition list of concept for a learner has been implemented in IKAS.

**Approbation of the Thesis**

Approbation of the thesis was done using the improved IKAS to train students and assess their knowledge in several courses of the Spring 2011 term in the Department of System Theory and Design of RTU: „Introduction to Artificial Intelligence", „Fundamentals of Artificial Intelligence" and „Fundamentals of Artificial Intelligence: Free Choice".

The results of the doctoral thesis were presented in 9 international scientific conferences (5 abroad and 4 in Latvia):

1. October 6, 2011. 2nd International Workshop on Intelligent Educational Systems and Technology-enhanced Learning (INTEL-EDU 2011), Riga, Latvia.
2. July 20-23, 2011. IADIS International Conference e-Learning 2011, Rome, Italy.
3. May 19-21, 2011. International Conference on Internationalization of Post-Soviet University, Kiev, Ukraine.
4. October 14, 2010. 51$^{st}$ Scientific Conference of RTU, Riga, Latvia.
5. July 5-7, 2010. International Conference on Education and New Learning Technologies (EDULEARN 2010), Barcelona, Spain.

6. October 16, 2009. 50th Scientific Conference of RTU, Riga, Latvia.
7. June 17-20, 2009. IADIS International Conference e-Learning 2009, Algarve, Portugal.
8. October 15, 2008. 49th Scientific Conference of RTU, Riga, Latvia.
9. June 12-13, 2008. International Conference on Computer Systems and Technologies (CompSysTech'08), Gabrovo, Bulgaria.

The results of this thesis are reflected in 13 papers in international scientific journals:

1. Lukasenko R., Grundspenkis J. IKAS as a Tool for Internationalization of Education. Proceedings of the 2nd International Workshop on Intelligent Educational Systems and Technology-enhanced Learning (INTEL-EDU'11), October 6, 2011, Riga, Latvia (in publishing).
2. Anohina-Naumeca A., Lukasenko R., Skripkins, D. Conception of the Animated Interface Agent for the Concept Map Based Intelligent Knowledge Assessment System. Scientific Proceedings of Riga Technical University „Computer Science. Applied Computer Systems", 5th series, Vol. 47, RTU Publishing, 2011, Riga, Latvia, pp. 29-37 (paper is indexed in VERSITA Emerging Science Publishers database - http://versita.metapress.com)
3. Lukasenko R. Intelligent Knowledge Assessment Tool. Proceedings of the IADIS International Conference (e-Learning'11), June 20-23, 2011, Rome, Italy, Vol. I, pp. 369-377.
4. Anohina-Naumeca A., Lukasenko R. Intelligent knowledge assessnebt system: student model and methodology for experimental evaluation for adaptation algorithm. Educational Technologies and Society, 2nd series, Vol. 14, 2011, pp. 346-362 (in Russian).
5. Lukasenko R., Vilkelis M., Anohina-Naumeca A., Grundspenkis, J. Feedback in the Concept Map Based Intelligent Knowledge Assessment System. Scientific Proceedings of Riga Technical University „Computer Science. Applied Computer Systems", 5th series, Vol. 43, RTU Publishing, 2010, Riga, Latvia, pp. 17-26. (paper is indexed in VERSITA Emerging Science Publishers database - http://versita.metapress.com)
6. Lukasenko R., Anohina-Naumeca A. Development of the Adaptation Mechanism for the Intelligent Knowledge Assessment System Based on the Student Model. Proceedings of the International Conference on Education and New Learning Technologies (EDULEARN'10), July 5-7, 2010, Barcelona, Spain, pp. 005140-

005149. (paper is indexed in IATED Digital Library database - http://library.iated.org/)

7. Lukasenko R, Grundspenkis J. Adaptation of Intelligent Knowledge Assessment System Based on Learner's Model. Proceedings of the 16th International Conference on Information and Software Technologies (IT'10), 2010, Kaunas, Lithuania, pp. 332-339
8. Lukasenko R., Anohina A. Architecture and application of knowledge assessment systems: an overview. Scientific Proceedings of Riga Technical University „Computer Science. Applied Computer Systems", 5th series, Vol. 38, RTU Publishing, 2009, Riga, Latvia, pp. 25-36. (paper is indexed in VERSITA Emerging Science Publishers database - http://versita.metapress.com)
9. Vilkelis M., Lukasenko R., Anohina A. Technical Evolution of the Concept Map Based Intelligent Knowledge Assessment System. Proceedings of the 13th East-European Conference on Advances in Databases and Information Systems, 2009, Riga, Latvia, pp. 214-221.
10. Lukasenko R., Grundspenkis J. A Conception of Agents-Based User Modeling Shell for Intelligent Knowledge Assessment System. Proceedings of the IADIS International Conference (e-Learning'09), June 17-20, 2009, Algarve, Portugal, Vol. I, pp. 98-106. (paper is indexed in IADIS Digital Library database - http://www.iadisportal.org/digital-library)
11. Anohina A., Vilkelis M., Lukasenko R. Incremental Improvement of the Evaluation Algorithm in the Concept Map Based Knowledge Assessment System. International Journal of Computers, Communication and Control, 1st series, Vol. 4, 2009, pp. 6-16. (paper is indexed in Microsoft Academic Search database - http://academic.research.microsoft.com/)
12. Vilkelis M., Anohina A., Lukasenko R. Architecture and Working Principles of the Concept Map Based Knowledge Assessment System. Proceedings of the 3rd International Conference on Virtual Learning, October 31 – November 2, 2008, Constanta, Romania, pp. 81-90.
13. Lukasenko R., Vilkelis M., Anohina A. Deciding on the Architecture of the Concept Map Based Knowledge Assessment System. Proceedings of the International Conference on Computer Systems and Technologies (CompSysTech'08), June 12-13, 2008, Gabrovo, Bulgaria, pp. V.3-1 - V.3-6. (paper is indexed in ACM Digital Library database - http://dl.acm.org/)

The results of the doctoral thesis are included in reports of 4 scientific projects:

1. „Development of a mathematical model for the determination of concept map complexity and degree of task difficulty and its implementation adapting to characteristics of a student model” (project leader J.Grundspenkis, 2010, research project of RTU, FLPP-2010/19).
2. „ Development of the algorithm for generating concept maps from unstructured text in the knowledge assessment system with the student modelling component” (project leader J.Grundspenkis, 2000, research project of RTU, ZP-2009/33).
3. „ Development of the intelligent adaptive multiagent knowledge assessment system based on comparison algorithms of concept maps and mathematical model for the determination of concept maps similarity” (project leader J.Grundspenkis, 2009, research project of RTU, FLPP- 2009/9).
4. „Implementation of adaptive feedback in the concept map based intelligent knowledge assessment system” (project leader J.Grundspenkis, 2008, project funded by Ministry of Education and Science of Latvia and RTU, R7387).

**Structure of the Thesis**

The thesis consists of an introduction, 5 chapters, a conclusion, bibliography, and 3 attachments.

In the *Introduction* part of the thesis the relevance of the research is justified, the goal and tasks of the thesis are formulated, the scientific novelty of the thesis and the practical value of the obtained results is described, as well as the approbation of the thesis is reflected.

*Chapter 1* contains the analysis and classification of the ITS definitions, a description of the structure of ITSs and their operating principles as well as a classification of the intelligent and adaptive functions of ITSs. The chapter also contains the analysis of several ITSs, paying particular attention to their intellectual and adaptive functions and the usage of student models to support these functions.

*Chapter 2* contains the analysis of the student model’s content, the contents of the theoretical and the practical student models, a complete student model and the definition of the relationship between the intelligent and adaptive functions of an ITS and its student model data. The chapter also contains the description of the software tool that was developed by the authors, called „SM Builder”. This tool can assist in defining the student model for any ITS based on the functions that this ITS needs to provide.

*Chapter 3* contains the description of the intelligent knowledge assessment system IKAS, including its structure, operating principles, the intelligent and adaptive functions, the contents of its student model, and the results of the use of the system. The last part of the chapter lists the requirements for extending the intelligent and adaptive functions of IKAS, as well as the new student model generated with the help of „SM Builder".

*Chapter 4* describes the improvement process of IKAS and the three new algorithms to extend its functions based on the new student model – an algorithm to explain a concept in an adaptive manner, an algorithm to generate individual concept repetition lists and an algorithm for selecting the initial difficulty degree of a task.

*Chapter 5* describes the experimental evaluation of these algorithms in three courses. It contains an analysis of the results of the evaluation, as well as conclusions about the efficiency of each of the algorithms and the new IKAS functionality as a whole.

The *final part* of the thesis contains the main results and conclusions as well as possible directions for a future research.

There are 3 *attachments* in the thesis: 1) the software tool „SM builder"; 2) the questionnaire in IKAS to clarify the learner's learning style according to the Felder-Silverman learning style model; 3) the questionnaire in IKAS about the operation of the system.

# 1. ANALYSIS OF INTELLIGENT TUTORING SYSTEMS

In order to introduce the reader to intelligent tutoring systems and their capabilities, Chapter 1.1 of contains an analysis of the ITS definitions, Chapter 1.2 contains a summary of the main functions of ITSs, and Chapter 1.3 contains an analysis of several ITSs to determine the role of student models in providing the intelligent and adaptive functions in these systems.

## 1.1. Definitions of ITS

During the relevant literature research [BRE 2002, CON 2009, FRE 2000, KOE 2006, MUR 1999, ROD 2005, SEL 1999, SHU 1996], the author of this thesis found 34 different definitions of the term „Intelligent Tutoring Systems" and divided them into four groups:

1. Definitions that highlight the adaptative functions of ITSs. The adaptive functions allow ITSs to create an individual learning plan (a sequence of tasks) for each learner in the most suitable format (text, video, sound, etc.). An example definition from this group is: „An intelligent tutoring system is a computerized training system that is able to adapt the content of learning and its presentation according to each learner's needs" [SHU 1996].

2. Definitions that mention AI (artificial intelligence) techniques. In order for a computer-based learning system to be intelligent, AI techniques such as machine learning, plan recognition, intelligent software agents need to be used. An example definition from this group is: „An intelligent tutoring system is the use of artificial intelligence methods (production rule, Beies network, Markow model, neural net etc.) in training” [SEL 1999].
3. Definitions that highlight student modeling. Student modeling is a process in which information about the learner is retrieved, and his/her portrait or the so-called model is created. The student model is used afterwards as the main source for the adaptive learning process. An example definition from this group is: „An intelligent tutoring system is an educational computer system that evaluates every learner’s activity and creates a model of the learner’s knowledge, skills and competency” [FRE 2000].
4. Definitions that highlight the structure of the ITS. ITS has three main components: an expert module that contains knowledge of what to teach; a teaching module that contains knowledge of how to teach and a student module that contains knowledge about the learner. An example definition from this group is: „An intelligent tutoring system is a system that contains: (a) knowledge of the problem field, (b) knowledge about the learners and (c) knowledge about learning strategies” [SHU 1996].

The distribution of definitions of “Intelligent Tutoring Systems” in the four identified groups is shown in Figure 1.1. Definitions that highlight the adaptation functions of the ITSs form the largest group of ITS definitions. ITS adaptation abilities play an important role in ensuring the quality of the learning process [GIL 1999, MON 1995], so adaptability is regarded as one of the main ITS characteristics and values.

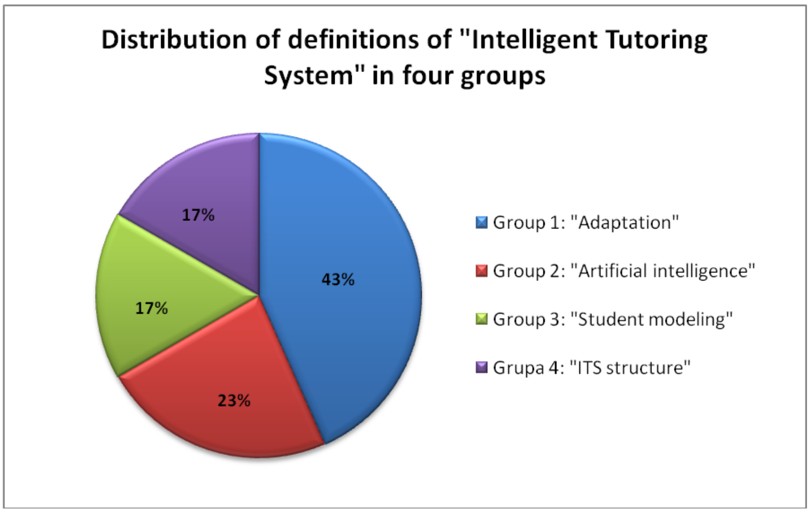


Fig. 1.1. Distribution of ITS definitions in groups

Taking into account the aforementioned analysis of various definitions, the opinion of the author of this thesis is that only systems that satisfy the following four requirements can be regarded as complete ITSs: a) the system adapts its learning environment for each learner, b) the system uses student models, c) the system uses artificial intelligence techniques, d) the system is composed of at least three modules: expert, teacher and student module. The satisfaction of these requirements ensures that the ITS will be able to demonstrate both intelligent and adaptive behavior.

## 1.2. Intelligent and adaptive functions of ITS

According to P.Brusilovskis *et al.* [BRU 2003], there are two main adaptive functions (adaptive presentation and adaptive navigation) and three main intelligent functions (adaptive curriculum sequencing, intelligent solution analysis and problem solving support) in ITS behavior. During the review of literature, 6 adaptive and 11 intelligent subfunctions in total were identified in ITS (see Table 1.1.). The function "Learner Identification in the System" is neither an intelligent nor an adaptive function but it is added to the table in order for the table to be complete and to contain all the functions of ITSs.

Table 1.1.

Functions of ITSs

| Function | Subfunction | Explanation of function/subfunction |
|---|---|---|
| **Learner's identification in the system** | – | This function identifies the user during logon and creates (if the user is new) or activates (if the user is already registered in the system) his/her student model. |
| **Adaptive presentation** | Presentation of learning materials, depending on the cognitive style | This subfunction displays learning materials in different ways, depending on the learner's cognitive style – inductive, deductive, etc. For example, if the learner uses induction in order to gain new knowledge, the learner is first provided with some specific examples of problem solving and then is introduced to the general rules that were used in the solution. |
| | Presentation of learning material, depending on the form of perception | This subfunction displays learning materials in different ways, depending on what kind of information – visual, verbal, etc. – the learner is more receptive to. For example, for a learner with a dominating visual perception, the learning materials are given in the form of figures and graphs, etc. |
| | Presentation of learning material in different difficulty levels | This subfunction displays learning materials in different ways depending on the level of learning difficulty – low, medium or high – that a particular learner has. For example, if the difficulty level is low, the learner is provided with easy tasks. |
| | System interface in different languages | This subfunction provides the user's interface in different languages depending on the user's choice. |

Table 1.1. (continued)

| Function | Subfunction | Explanation of function/subfunction |
|---|---|---|
| **Adaptive navigation** | Display of references to related training materials | This subfunction displays references to additional materials or resources depending on the learner's current topic or task. |
| | Display of references to the next topic/ question | This subfunction displays a reference to the next topic or task that the trainee has to study or solve. |
| **Adaptive curriculum sequencing** | Preparation of training/ testing plans | This subfunction takes into account the learner's goals and his/her knowledge level about the current topic and provides an individual learning or review plan about the topic. |
| | Selection of the next topic/ question | This subfunction chooses the next topic or question for the learner, depending on the results of previous learning. |
| **Intelligent solution analysis** | Assessment of the accuracy of the learner's actions | This subfunction evaluates the accuracy of the learner's actions when he/she is trying to solve a task provided by the system. This information is used afterwards to assist or to motivate the learner. |
| | Identification of easy/ difficult topics for the learner | This subfunction identifies the easy and hard parts for the learner in the study process. This information is used afterwards when giving feedback to the learner. |
| | Calculating the knowledge level of course / topic/ concepts | This subfunction calculates mastering degree of the whole course or separate concepts at the end of the training. The obtained information is used in the feedback afterwards. At the end of the training, this subfunction calculates the degree to which the whole course or some specific topics were mastered. This information is used afterwards when giving feedback. |
| | Generating individual feedback | This subfunction provides feedback for each learner after the completion of a task. The feedback includes a summary of the learning material acquisition results, mistakes that were made, and guidance on reviewing concepts that were not learned to a sufficient level. |
| | Preparing a plan for review of the study materials | This subfunction creates a review plan of the study materials for each learner based on his/her results after the completion of a training or part of it. The plan is part of the feedback that the learner receives. |
| **Problem solving support** | Providing results-dependent help | This subfunction gives hints, explanations, leading questions, the correct solution to help the learner when he/she encounters difficulties in completing a task. The help provided is based on the learner's current training results. |
| | Providing reaction/ state-dependent help | This subfunction provides explanations, leading questions, the correct solution based on the learner's psychophysiological state. |
| | Providing results-based motivation of the learner | This subfunction displays messages that either praise the learner if his/her results are good or encourage them to keep studying if the results are less than good. The display of these messages is based on the learner's current results in training. |
| | Providing reaction/ state-based motivation of the learner | This subfunction displays messages to the learner based on the learner's psychophysiological state. |

In order to see how rich and varied the intelligent and adaptive functions in existing ITSs are, an analysis of several ITSs was carried out in this thesis.

## 1.3. Examples of ITS

Currently, there are several classifications of ITSs [СИС 2009, СОБ 2002]. In the author's opinion, the most successful classification is given in the paper [ДУП 2003], because it is related to the three main stages of the learning process: learning of the theory, control of the theory learning and acquisition of practical skills. According to this classification, the three ITS groups are:

1. ITSs for learning theoretical materials. The primary purpose of this group of ITSs is to supply the learner with theoretical materials in a convenient format (text and/or audio/video recording) and at the end to check the gained knowledge with the help of tests. The following ITS were selected for analysis within this group: ABITS [CAP 2000], ActiveMath [MEL 2001], ALLEGRO [VIC 2007], ANDES [GER 2000], EDUCE [KEL 2003], ELM-ART [BRU 1999], ERM-Tutor [MAR 2004], FLUTE [DEV 2000], KBS-Hyperbook [HEN 2001], RATH [HOS 1998], SHARP [GIL 2008], SQL-Tutor [MIT 2003], TANGOW [CAR 2000], WILEDS [KAS 2001].
2. ITSs for testing theoretical knowledge. The primary purpose of this group of ITSs is to check the learner's theoretical knowledge with the help of a test, an essay or other means (for example, the construction of concept maps). The following ITSs were selected for analysis within this group: CALKAS [DJO 2000], COMPASS [GOU 2008, GOU 2009], SIETTE [CON 2004], WILLOW [PAS 2011, PER 2006].
3. ITSs for practical skill development. The primary purpose of this group of ITSs is to develop the learner's practical skills by offering to solve practical problems in a virtual environment. The following ITSs were selected for analysis within this group: ADELE [SHA 1999], AMPLIA [FLO 2004], HPAC [RIC 1997], INES [HOS 2003, NIJ 2005], MAEVIF [IMB 2007].

Figure 1.2. shows the distribution of intelligent and adaptive functions in the groups. The most common function of ITSs for learning theoretical materials is adaptive curriculum sequencing, which means generating an individual learning plan for each learner based on his/her learning goals and the level of knowledge about the topic. The most common function of ITSs for testing theoretical knowledge is an intelligent solution analysis which generats feedback for the learner that indicates gaps in the knowledge and suggests how to fill them. The most common function of ITSs for practical skill development is a problem solving support that provides assistance (explanations, hints, leading questions) when the learner encounters difficulties in completing a task.

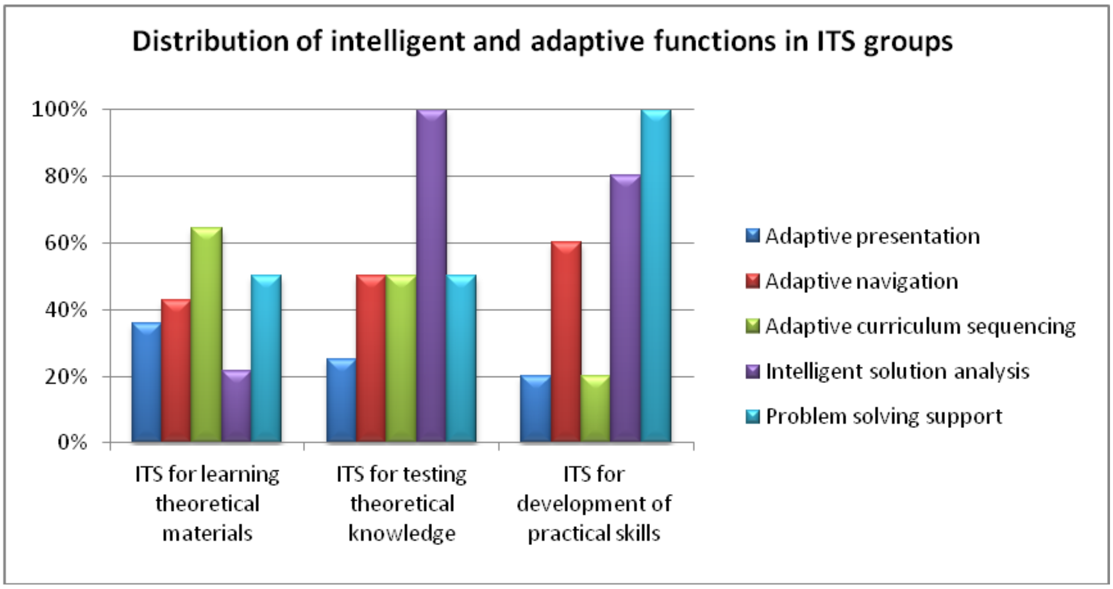


Fig. 1.2. Distribution of intelligent and adaptive functions in different ITS groups

During the analysis of ITSs, it was determined that student modeling and individual student models are present in all the analyzed systems. In addition, a correlation between the completeness of the student model and the diversity of the ITS intelligent and adaptive functions was detected: the less intelligent and adaptive functions there are in the ITS, the simpler the student model is in the system, and vice versa. Thus, in order to extend the intelligent and/or adaptive functions of an ITS, first one must choose a student model that would support these functions. The relationship between the student model data and the ITS functions is decribed in Chapter 2.

## Summary of Chapter 1

Summarizing the analysis given in Chapter 1, the following conclusions can be drawn:

- Modern ITSs must be both intelligent and adaptive. The ITS intelligent functions manifest the use of the artificial intelligence methods in the ordering of the learning material, in an intelligent analysis of solutions or in the support for problem solving. In turn, the ITS adaptive functions are related to the ITS's ability to present information in an adaptive manner and to provide adaptive navigation in the learning space. The adaptive functions of an ITS are considered its main value because a personalized access to learning increases the efficiency of the learning process.
- The intelligent and adaptive functions of ITSs are dependent on the use of student model data. Specifically, in order for an ITS to behave intelligently and adaptively, it should have knowledge about the learner. For example, the ITS has to know the

learner's knowledge level in the problem field, the best format to display learning materials, and so on. Therefore, student modeling is one of the most important processes in the ITSs and the student model is an indispensable part of any ITS.

- A clear correlation exists between the intelligent and adaptive functions of an ITS and its student model data: the diverser the intelligent and adaptive functions are, the more complete a student model they need, and vice versa. For this reason, there is a need to solve the task of how to choose the best student model for an ITS, a model that would contain exactly the data that are necessary to support the intelligent and adaptive functions of the ITS.

# 2. ANALYSIS OF THE CONTENTS OF THE STUDENT MODEL

Based on the previous chapter's findings that the intelligent and adaptive functions of ITS need to use the student model data, Chapter 2 of the thesis contains an analysis of the student model's contents, defines the relationship between the intelligent and adaptive functions of an ITS and its student model data, and describes the software system „SM builder" thatautomatically generates the structure of the student model for any ITS.

## 2.1. Definition of the Student Model

Paper [SIS 1998] gives the student model the following definition: „*a student model* is an approximate, possibly partial, mainly qualitative representation of the learner's knowledge about a specific problem field/ domain or a particular topic, or abilities in the problem field, which may be wholly or partially responsible for specific aspects of the learner's behavior."

Some typical applications of student models are [URB 1996, VAN 1988, AHO 2011]:

- a student's learning goals stored in the student model are used to generate an individual learning plan for the student;
- the student's knowledge level about a specific topic represented in the student model is used to select tasks of a suitable difficulty degree for the student;
- the most appropriate information presentation format for a student stored in his/her student model is used to adapt educational materials and feedback to the student.

Thus, the student model data serve as the input parameters for making pedagogical decisions and for adapting the learning environment. In order to understand the student model better and to see the importance of the model in ITS, the content of the student model needs to be explored.

## 2.2. Contents of the student model

The literature review on ITS student models shows that there is a theoretical foundation for student models (the theoretical student model) and there are practical implementations of student models (the practical student models), but there are substantial differences between them. Figure 2.1. shows the contents of both models – the information categories in each model. The theoretical model of a student is taken from paper [HEC 2005] that describes the GUMO (General User Model Ontology) ontology of the student model. GUMO has been developed for the semantic web to provide adaptive computing systems (including ITS) with a common vocabulary for describing a learner. In turn, the practical student model is obtained by analyzing the contents of the student models in 23 specific ITS (see the names of the ITS in Chapter 1.3). The characteristics of information categories in the models are as follows:

- **Contact and Demographic Information / General Information.** The parameters in these categories contain general information about the learner like his/her name, age, native language, education level, e-mail address, etc.
- **Personality Characteristics / Learning Skills.** The parameters in these categories describe the constant or slowly changing behavior patterns that characterize a learner, for example, whether the learner is extrovert or introvert, innovative or conservative, etc.
- **Mood and Emotion**. The parameters in this category describe the learner's temporary state, for example, whether the learner is happy or unhappy, active or apathetic.
- **Facial Expression**. Analysis of the facial expressions of a learner helps to understand what the current emotional state of the learner is - whether he/she is excited or bored or scared, etc.
- **Mental State.** The parameters in this category provide information on the learner's current mental state, such as whether a learner is time-limited, what is his/her current cognitive load or is the learner depressed.
- **Physiological State.** The parameters in this category (such as pulse, blood pressure, respiratory rate) provide information about the learner's mood and emotions.
- **Profession, Skills, Abilities, Interests / Education and Skills.** The parameters in these categories contain information about the learner's knowledge and skills in a problem field(-s) prior to the ITS use.

- **Learner's Choices.** The parameters of this category hold information about student's learning goals (for example, what topics learner wish to learn), and information about student's directly specified knowledge levels in the course or of separate concepts.
- **Learning Process.** The parameters in this category contain information about the learning process with the ITS (for example, the topics learned, the tasks solved, the mistakes made), and information on the outcomes of studying (for example, the levels of mastering a course/concept).
- **Use of System and Navigation History.** The parameters of this category (for example, the requested assistance – its types and frequency) contain information on how often the learner has used the functional options of the system.
- **Learner's System Settings.** The parameters in this category contain information on the learner's direct choices for displaying learning material, such as interface language or format (text, audio or video) in which the learner wants to receive learning materials.
- **Movement, Location, Orientation.** The parameters in this category (such as the learner's location and velocity) are used to support mobile learning.

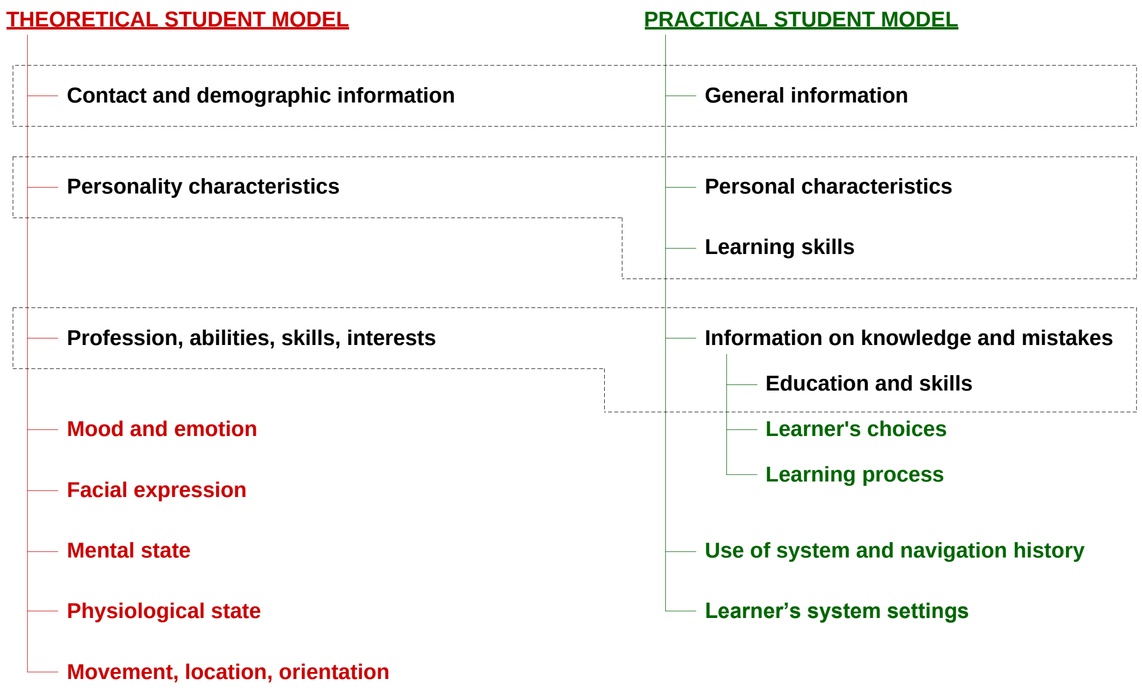


Fig. 2.1. Comparison of the theoretical and the practical student models*

**Note:* the common parts of both models are marked in black, unique parts of the theoretical model – in red, unique parts of the practical model – in green

Figure 2.1. shows that the greatest difference between the practical student model and the theoretical student model is that in the practical student model there is no information about the learner's temporary state – the mood and emotions, the facial expression, the mental and physiological state. The reason for not including this information in the practical student model is related to the difficulties in collecting and processing such information. For example, the collection and analysis of information about the learner's facial expressions and physiological state requires special hardware and software [RIK 2008, RIK 2009]. But given the fact that the information about the learner's temporary state is important for the learning process adaptation [HEC 2005], by adding this information to the practical student model one can get a complete student model.

The complete student model is a student model that contains as many parameters as needed to support all the ITS intelligent and adaptive functions (see Table 1.1.). By combining the two student models, the complete student model was obtained. The content of the complete model is given in Table 2.1.

Table 2.1.

Parameters of the complete student model

| Category of student model | Parameter of student model | Explanation of parameter |
|---|---|---|
| Contact information | Login/ password | Parameters used to identify the learner in the system and to activate his/her student model. |
| | Name/ surname/ ID | Parameters used to assign training results to the learner. |
| | E-mail address | Parameter used for communication with the learner. |
| Personality characteristics | Learning style | A student's learning style according to the Felder-Silverman model (see the model description below). |
| Current state of the learner | Mood | These parameters are generalized. It is the developer's responsibility to further divide these parameters to get an accurate representation of the current state of the learner. |
| | Mental state | |
| | Facial expression | |
| | Physiological state | |
| Current knowledge and skills | Knowledge level in a problem field | The learner's level of knowledge in the problem field before beginning a course, as indicated by the learner or obtained by a knowledge test. |
| Learning goals | Topics chosen for learning | The learner's chosen topics to study. |
| Learning progress | Solutions of tasks and results obtained | The learner's given solutions of tasks and the results after verifying the solutions (includes information about mistakes). |
| | Provided help | System help that was given to the learner while solving tasks. |
| | Attempts made/ time spent | The number of attempts committed by the learner to solve a task, and the time spent solving each task. |
| | Mastering level of course/ topics/ concepts | The level that the lerner has mastered a course/topic/concept to, calculated by the system. |

Table 2.1. (continued)

| Category of student model | Parameter of student model | Explanation of parameter |
|---|---|---|
| Use of system | Topics reviewed/ tasks completed in a course | The course topics that the learner has viewed/studied. The tasks that the learner has solved. |
| User interface settings | Information presentation type | The learner's specified information presentation type: text, audio or video. |
| | Interface language | The system interface language preferred by the learner. |

The complete student model includes information about the student's learning style, as it was concluded that the learning style has a significant impact on the effectiveness of the learning process [FAR 2008, GAV 1999, GIL 1999, LIM 2008, БУЛ 2003]. The learning style stands for the learner's cognitive behavioral patterns that determine how the learner perceives and cooperates with the learning environment [TIN 2003]. In the complete student model, the learning style is denoted by the currently most widely distributed and most commonly used Felder-Silverman model [GRA 2006, SLE 2002]. The model divides learners into several categories according to their learning styles: *sensory* (the learner is concrete, practical, oriented towards facts and procedures), *intuitive* (the learner is conceptual, innovative, oriented towards theories), *visual* (the learner prefers images, charts, graphs), *verbal* (the learner prefers text or audio information), *inductive* (the learner prefers explanations from the specific to the general), *deductive* (the learner prefers explanations from the general to the specific), *active* (the learner is studying through experimentation and collaboration with others), *reflective* (the learner is studying through thinking about things alone), *sequential* (the learner studies in an organized, logical manner going sequentially from one subject to another) and *global* (the learner studies in a disorganized, chaotic manner switching from one subject to another).

The following section shows how the complete student model data is used to support ITS functions.

## 2.3. Use of Student Model Data

The relationship between the ITS functions and the complete student model data is shown in Table 2.2. Identification of the relationship is based on the literature review that was carried out during the development of the theoretical and practical student models, as well as based on the research of functionality of 23 ITS.

Table 2.2.

Relationship between ITS functions and the complete student model data

| ITS functions | Complete student model data that are used to support functions |
|---|---|
| Learner's identification in the system | Login/ password<br>Name/ surname/ ID<br>E-mail address |
| Presentation of learning materials, depending on the cognitive style | Learning style |
| Presentation of learning material, depending on the form of perception | Learning style<br>Information presentation type |
| Presentation of learning material in different difficulty levels | Knowledge level in a problem field<br>Mastering level of course/ topics/ concepts |
| System interface in different languages | Interface language |
| Display of references to related training materials | Solutions of tasks and results obtained<br>Attempts made/ time spent |
| Display of references to the next topic/ question | Solutions of tasks and results obtained<br>Mastering level of course/topics/concepts<br>Topics reviewed/ tasks completed in a course |
| Preparation of training/ testing plans | Knowledge level in a problem field<br>Topics chosen for learning<br>Solutions of tasks and results obtained<br>Attempts made/time spent<br>Mastering level of course/topics/concepts<br>Topics reviewed/ tasks completed in a course |
| Selection of the next topic/ question | Solutions of tasks and results obtained |
| Assessment of the accuracy of the learner's actions | Solutions of tasks and results obtained |
| Identification of easy/difficult topics for the learner | Solutions of tasks and results obtained<br>Attempts made/time spent |
| Calculating the knowledge level of course / topic/ concepts | Solutions of tasks and results obtained |
| Generating individual feedback | Solutions of tasks and results obtained<br>Attempts made/time spent<br>Mastering level of course/topics/concepts<br>Provided help |
| Preparing a plan for review of the study materials | Solutions of tasks and results obtained<br>Mastering level of course/topics/concepts<br>Reviewed topics/completed tasks in a course |
| Providing results-dependent help | Solutions of tasks and results obtained<br>Attempts made/time spent |
| Providing reaction/ state-dependent help | Facial express<br>Physiological state |
| Providing results-based motivation of the learner | Solutions of tasks and results obtained<br>Attempts made/time spent |
| Providing reaction/ state-based motivation of the learner | Mood<br>Mental state<br>Facial expression<br>Physiological state |

Two important consclusions can be drawn from the analysis of the contents of Table 2.2. First, the table contains all the ITS intelligent and adaptive functions (see Table 1.1.). This means that the complete student model is sufficient in the sense that the model data support all the functions identified in ITS. Second, the table contains all the data of the complete student model (see Table 2.1.). This means that the complete student model is effective in the sense that there are no unused parameters (i.e., every parameter is used to support a function).

The complete student model along with the relationship between the student model data and the ITS functions were used in the development of the „SM builder" tool.

## 2.4. „SM builder" tool

„SM builder" is a tool developed by the author of this doctoral thesis. The tool allows users to generate a student model automatically depending on the student's intelligent and adaptive functions that are necessary to implement in the ITS. This tool is aimed at ITS developers because it allows to easy identify the sufficient contents of the student model.

The use of this tool is a two-step process. In the first step, the ITS developer chooses the intelligent and adaptive functions that have to be implemented in the ITS. In the second step, the developer gets an XML file that contains information on what data must be included in the student model to support the selected intelligent and adaptive functions. A detailed description of the tool's functionality is available in Attachment 1 of the thesis.

The „SM builder" tool has been tested with 23 ITS. The testing process for each ITS was organized as follows: at first, the intelligent and adaptive functions of the ITS were chosen in the tool, then a student model to support the selected functions was generated, and finally the student model generated by the tool was compared with the actual ITS student model that was given in the description of the ITS. The testing results showed that in 20 out of 23 cases (or 87% of cases) the automatically-generated student models were similar to the student models given in the systems' description.

„SM builder" was used to get a student model for the intelligent knowledge assessment system IKAS that is described in Chapter 3.

## Summary of Chapter 2

Summarizing the results of Chapter 2, the following conclusions can be drawn:

- There is a theoretical foundation for a student model and several practical implementations of student models. The analysis shows that theoretical and practical student models are different in terms of content and none of these models can fully support all the intelligent and adaptive functions of ITS.

- By combining theoretical and practical student models, the complete student model was defined in the thesis. The model, on the one hand, is complete because the model data support all functions of ITS, but, on the other hand, it is effective because there are no redundant parameters (i.e., each parameter is used to support a function).
- On the basis of the complete student model, the tool „SM builder" was developed. It allows automatical creation of a specific student model depending on the ITS intelligent and adaptive functions. Testing results show that the complete student model really supports all the intelligent and adaptive functions of ITS.

# 3. ANALYSIS OF IKAS IMPROVEMENT POSSIBILITIES

This chapter contains the description of IKAS (an intelligent knowledge assessment system) at the point of time before the author of this thesis took part in its design and development. Chapter 3.1 details the operating principles of IKAS, its intelligent and adaptive functions, the contents of its student model, and the results of its practical use. Chapter 3.2 lists the requirements for extending the intelligent and adaptive functions in IKAS, and Chapter 3.3 shows the new sudent model generated by "SM builder" for IKAS.

## 3.1. Description of IKAS

IKAS (**I**ntelligent **K**nowledge **A**ssessment **S**ystem) [ANO 2006b, GRU 2009b, VIL 2008] is a computerized knowledge assessment system that has been developed at the Department of Systems Theory and Design of Riga Technical University, Faculty of Computer Science and Information Technology since 2005. To assess the knowledge of students, IKAS uses concept maps that were introduced in learning in 1970s by Novak [NOV 2008].

A concept map is a specific knowledge presentation form. Concept map is represented by a graph that consists of: (1) a set of nodes corresponding to concepts, and (2) a set of edges that stand for relationships between concepts. The descriptive phrases on the edges denote the type of relationship between concepts. Threesome „concept-relationship-concepts" is the semantic unit of a concept map that corresponds to a significant statement about an object or an event in the problem field [CAN 2003]. An example of a concept map in the field of chemistry is given in Figure 3.1.

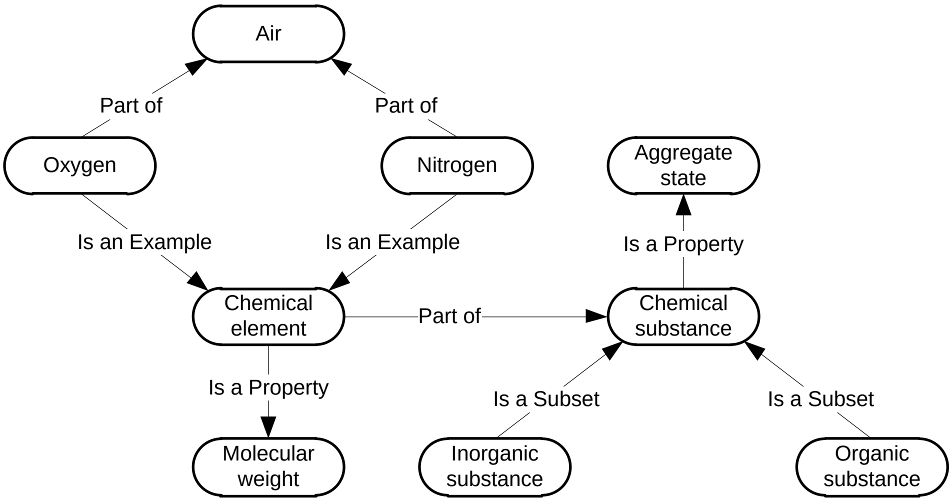


Fig. 3.1. Example of a concept map

The step by step construction of a concept map and the sequential construction of multiple concept maps shows the evolution in a learner's understanding of the problem domain [ROC 2004]. According to [CAN 2003], concept maps facilitate the acquisition of well-structured knowledge and help learners to externalise their conceptual knowledge in a problem domain.

The unique feature of IKAS in comparison to other knowledge assessment computer systems (RFA [CON 2006], JavaMapper [HIS 2002], Verified Concept Mapper [CIM 2003], Compass [GOU 2004], HIMATT [PIR 2008]) is the option for a teacher to carry out a systematic knowledge assestment by dividing a learning course into several assessment stages and offering concept map-based knowledge assessment tasks to the learners at the end of each stage. A stage can be any logical part of the course, such as a chapter or a topic. In the first concept map the teacher includes all the concepts and relationships that are taught in the early stages of the course. In the next stage the teacher extends the initial concept map by adding new concepts and relationships without changing relationships between the already existing concepts in the map. At the final stage the concept map represents all the concepts in the course and the relationships between them. Thus, a systematic assestment of knowledge allows the teacher to see the progress in the learners' knowledge and, if necessary, the teacher can change the teaching methods in order to facilitate the learning of the course [GRU 2008].

The computerized knowledge assessement system IKAS is used in the following way (see Figure 3.2.). First, a teacher creates and publishes concept maps for each stage of the course with the help of the system interface. Then, during knowledge assestment, the learner receives an assessment task that corresponds to the current learning stage and creates his/her own concept map for the stage using the given list of concepts. Once the learner has completed his/her concept map, the system compares it with the teacher’s concept map for that stage. Finally, the learner gets feedback on his/her concept map that contains the number of points that the learner could have got if his/her concept map was completely correct, the points that the learner actually got for his/her concept map, and his/ her concept map with all the mistakes highlighted.

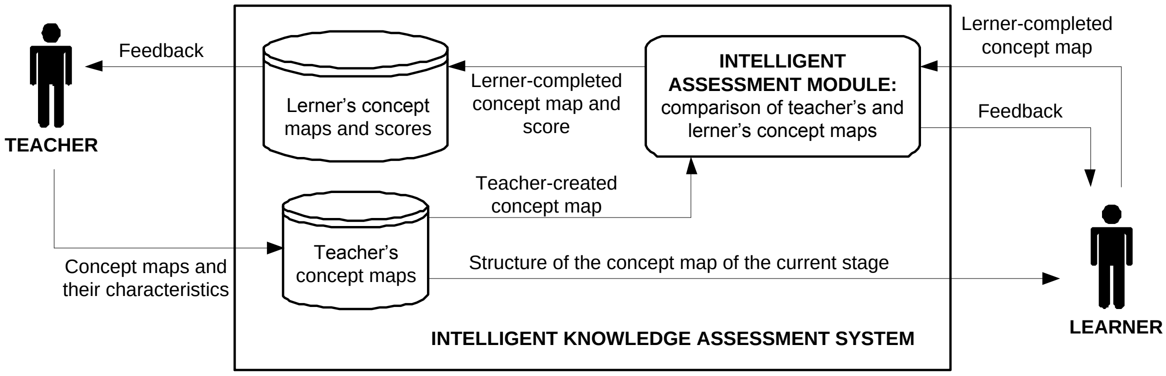


Fig. 3.2. IKAS usage scenario

In IKAS (in contrast to other concept map based knowledge assessment systems), each concept map can have six different types of assessment tasks that are arranged from the easiest to the most difficult based on how much information the task contains and what the student needs to do him/herself. Types of tasks in IKAS are given in Table 3.1.

Table 3.1.

Types of tasks in IKAS [ANO 2011]

<table>
<tr><th>Degree of difficulty</th><th>Type of task</th><th>Structure of a concept map</th><th>Concepts</th><th>Linking phrases for relationships</th></tr>
<tr><td>1st - the simplest</td><td rowspan="4">Fill in the map</td><td rowspan="4">Provided</td><td>One part is inserted into the structure, other part is provided as a list and must be inserted by the learner</td><td rowspan="2">Inserted into the structure</td></tr>
<tr><td>2nd</td><td rowspan="3">Provided as a list, must be inserted by the learner</td></tr>
<tr><td>3rd</td><td>Not used</td></tr>
<tr><td>4th</td><td>Provided as a list, must be inserted by the learner</td></tr>
<tr><td>5th</td><td rowspan="2">Construct the map</td><td rowspan="2">Must be created by the learner</td><td rowspan="2">Provided as a list, must be related by the learner</td><td>Not used</td></tr>
<tr><td>6th - the most difficult</td><td>Provided as a list, must be inserted by the learner</td></tr>
</table>

When starting the assessment, every learner receives the task with the degree of difficulty specified by the teacher. Later, during the execution of the assessment task, the learner may request reducing the difficulty degree of the task by one if he/she has difficulties with it. But, if the learner achieved good results in the previous task, IKAS increases the difficulty degree for the next assessment task by one. In this manner, IKAS responds adaptively to the learner's behaviour and study results [ANO 2011, LUK 2010].

The practical use of IKAS began in 2005. Since then the system has been used in a number of courses to assess students' knowledge: „Information Systems Analysis and Design", „Modeling and Formal Specification", „Methods of Systems Theory", „Fundamentals of Artificial Intelligence", „Pedagogy", „Discrete Structures in Computer Science", „Semantic Web", „Business Software". 357 students in total have participated in the system's use.

A survey was conducted in each course in order to determine students' attitude towards the concept map based knowledge assessment and to get proposals for the improvement of IKAS functionality. The results of the surveys show that most students (79%) accept the knowledge assessment based on concept maps. Students pointed out in their replies that the concept map-based knowledge assessment develops logical thinking and helps to structurize learning materials.

In addition, students suggested the following items regarding the future development of IKAS: to extend student's support in the system during execution of an assessment task, to provide a more detailed feedback at the end of the task, and to make the student's knowledge levels and the initial difficulty degree of the task more balanced. These students' comments were taken into account while developing IKAS.

## 3.2. Requirements for improvement of IKAS

Taking into account the large potential of application of concept maps in training (Axon Idea Processor Tools, Inspiration, Knowledge Master, SMART Ideas, IHMC CMAP Tools and others [GRU 2008]) as well as taking into account the results of the surveys that showed students positive attitude toward application of concept maps for new knowledge acquisition, the IKAS development team (that included the author) began to extend IKAS functionality in order to support new knowledge acquisition through concept maps. Reaching this goal would mean that IKAS is transformed into an intelligent tutoring (not only knowledge assessment) system.

The IKAS functionality was extended within 3 scientific research projects: FLPP-2010/19, ZP-2009/33, R7387. The conception to transform IKAS into a training system was developed, the requirements for improving IKAS were defined, the design of the new functionality was created and implemented into the system. The new IKAS version was also tested in several learning courses within the project.

The proposed concept of the new functionality of IKAS includes two innovations. The first is related to the utilisation of the repository of learning materials, i.e. during the execution of a concept map task, the learner can request learning materials on any concept and thus learn more. In turn, in the feedback that is given to the student after the completion of a task, the learner receives guidance on which training materials can help in the acquisition of knowledge about a particular topic.

The second innovation is related to adjusting the first stage task according to the learner's knowledge level in the problem domain or his/her cognitive style. The purpose of this innovation is to make the first stage task correspond to the learner's abilities so that it wouldn't be too difficult.

Based on the IKAS improvement concept, the requirements for extending the IKAS functionality were defined. The requirements are presented in Table 3.2.

Table 3.2.

Requirements for improvement of IKAS

| **Requirements for the improvement of IKAS** | **Compliance of the requirement with the needs of students** | **Compliance of the requirement with ITS intelligent and adaptive functions** |
|---|---|---|
| 1. To offer the learner the option to get an explanation (definition, description, usage example) of the selected concept. The explanation must be adapted to the learner's preferences and his/her behavior in the system. | Learner's support in the system during the execution of an assessment task should be extended | Presentation of learning material, depending on the form of perception |
| 2. To calculate the mastering degree of each concept at the end of the task and to communicate the concepts that require reviewing to the learner. | A more detailed feedback at the end of the task should be provided | Calculating the knowledge level of a course/ topic/ concept<br>Preparing a plan for the review of study materials |
| 3. To select a task's initial degree of difficulty based on the learner's knowledge level or cognitive style | Student's knowledge levels and the initial difficulty degree of the task should be better balanced | Presentation of the learning material in different difficulty levels<br>Presentation of the learning materials, depending on the cognitive style |

The implementation of the new functionality for IKAS required an extension of the intelligent and adaptive functions of IKAS and the creation of a new student model for IKAS with the help of the „SM builder” tool. Figure 3.3. shows all IKAS functions and the new IKAS student model after the improvement of the system.

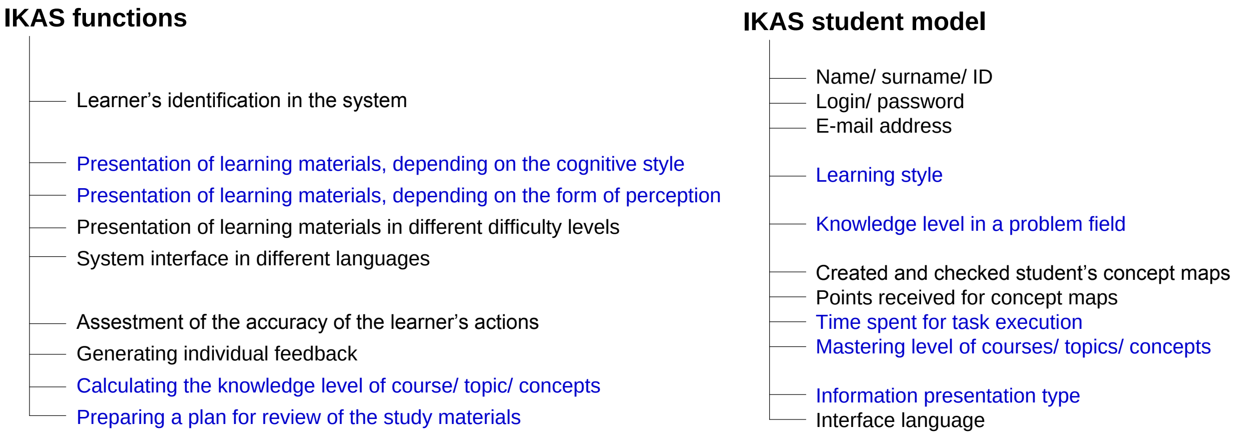


Fig. 3.3. IKAS functions and content of the IKAS student model after the improvement

**Note:* functions and student model data that were in IKAS before the improvement are marked in black, IKAS new functions and IKAS student model new data are in blue

The implementation details of the new IKAS functionality are described in Chapter 4.

## Summary of Chapter 3

Summarizing the results of Chapter 3, the following conclusions can be drawn:

- The results of the use of the RTU-created knowledge assessment system IKAS showed that the system's intelligent and adaptive functions were not enough for the learners. For example, the system did not show learners the gaps in their knowledge in the feedback. In addition, there was no first stage task adaptation to the learner.
- In order to make IKAS more adaptive and efficient for learners and to transform IKAS into a system that also supports the acquisition of new knowledge, the new conception of IKAS was created and the requirements for the IKAS improvement were defined. The new student model was created with the help of the „SM builder” tool to support the new IKAS functionality.

# 4. IMPLEMENTATION OF THE NEW IKAS FUNCTIONALITY

Based on the requirements for the improvement of IKAS defined in the previous chapter, the technical implementation details of these requirements are described in Chapter 4.

## 4.1. Implementation of the „Concept explanation” requirement

The „Concept explanation” requirement means that the learner can request the explanation of the selected concept during the execution of a task in order to understand the meaning of the concept and its possible relationships with other concepts. Thus, the learner acquires new knowledge in the problem field.

The explanation of a concept is available in three different ways: *definition* (this type of explanation provides the definition of the concept), *description* (this type of explanation gives a free text description of the concept) and *example* (this type of explanation provides an example of the use of the concept using the image with the part of a concept map). The explanations of concepts are added by the teacher during the preparation of the map.

The explanations of concepts are displayed to the learner according to priorities of types of explanations (see Figure 4.1.). The following default priorities are set in IKAS: definition – the highest priority, description – medium priority, example – the lowest priority. These priorities are based on the experimental evaluation of IKAS.

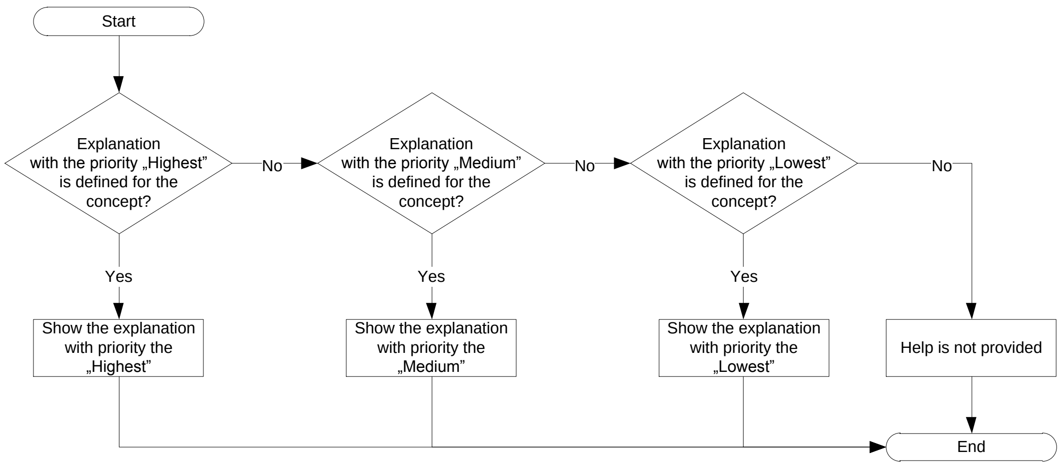


Fig. 4.1. Algorithm for choosing the type of explanation for a concept

When the system is in real use, it’s possible that the default explanation priorities will not be suitable for all students. For example, when a learner requests the explanation of a concept, the system shows the definition first by default; however, some learners might always go to the description in order to get information about the concept. Therefore, IKAS implements an algorithm for the adaptive change of priorities of explanation types. The algorithm works as follows: if at the end of the current task the system concludes that, according to the statistics collected so far, the learner has used the description more often in comparison with other explanation types, then the description is the most informative explanation type for the learner and starting with the next task, the system gives the highest priority to the description so that the description is shown first to the learner when he/she requests an explanation of concepts.

## 4.2. Implementation of the „Concept mastering degree" requirement

The „Concept mastering degree" requirement means that at the end of each task, IKAS calculates concept mastering degrees (CDR) and reports concepts that need to be reviewed to the learner. This kind of feedback allows the learner to see how well he/she understands each concept at present and where the knowledge gaps are.

In order to calculate the concept mastering degree, the following formula is used:

$$CMD_{(i)} = \frac{MD_{(i)in} + MD_{(i)out}}{MD_{(i)in}^{\max} + MD_{(i)out}^{\max}} \cdot 100\% \tag{4.1}$$

where $CMD_{(i)}$ – mastering degree of i-concept;

$MD_{(i)in}$ – accuracy of incoming edges of i-concept in the learner's concept map;

$MD_{(i)out}$ – accuracy of outgoing edges of i-concept in the learner's concept map;

$MD^{max}{}_{(i)in}$ – maximum amount of points (calculated from the teacher's concept map) that can be obtained if all the incoming edges of i-concept are constructed correctly;

$MD^{max}{}_{(i)out}$ – maximum amount of points (calculated from the teacher's concept map) that can be obtained if all the outgoing edges of i-concept are constructed correctly.

Formula (4.1) was obtained empirically on the basis of the method that was used in IKAS to compute the accuracy of a learner's concept map (see [ANO 2011]).

Thus after the completion of the current task, IKAS displays the concept mastering degrees in a table. Each concept in the table is colored in green, yellow or red depending on the $CMD_{(i)}$ value. Table 4.1. shows how the CMD values in IKAS are aligned with the RTU 10-points grading system.

Table 4.1.

Correspondence between CMD values and RTU grading system

| Color of concept | CMD interval | Assessment in the RTU 10-points grading system |
|---|---|---|
| Green | 80%-100% (Very good – With distinction) | 10 (with distinction) |
| | | 9 (excellent) |
| | | 8 (very good) |
| Yellow | 40%-79% (Almost satisfactory – Good) | 7 (good) |
| | | 6 (almost good) |
| | | 5 (satisfactory) |
| | | 4 (almost satisfactory) |
| Red | 0%-39% (Unsatisfactory) | 3 (weak) |
| | | 2 (very week) |
| | | 1 (very, very weak) |

Concepts from the yellow and especially from the red intervals are not very well studied and require repetition of the learning materials. Therefore, at the end of the task, IKAS generates an individual concept review list (CRL) for every learner that includes all the yellow-colored and red-colored concepts.

The table with the concepts mastering degrees and the concept review list are given to the learner at the end of each assessment stage, not just at the end of the last stage of the course because receiving a timely feedback allows the learner to monitor his/her progress during the studying process and to make changes in his/her study plan if necessary.

## 4.3. Implementation of the „Task adaptation” requirement

The „Task adaptation” requirement means that IKAS selects a different difficulty degree for the first assessment task in the course based on the learner's knowledge level in the course or his/her learning style. Before that, the first task was never adapted and all students were given the same task with the difficulty degree specified by the teacher.

In order to provide the adaptation of the first stage task, an algorithm for the selection of the initial degree of difficulty (IDD) for a task was developed (see Figure 4.2). The knowledge level is considered as dominant over the learning style in the algorithm because during the experimental evaluation of IKAS it was determined that the task's adaptation by the learner's knowledge level is more efficient in comparison with an adapatation by the learning style (see Chapter 5).

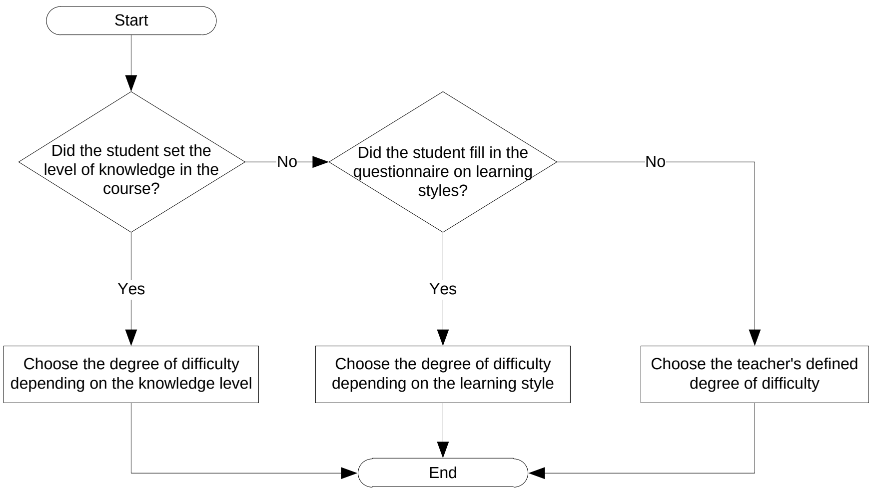


Figure 4.2. Algoritm for selecting initial difficulty degree for a task

The algorithm works as follows: first the system checks whether the learner has set his/her knowledge level – high, medium or low – in the course; if the learner has set the knowledge level, the system selects the task's IDD depending on the knowledge level (see

Table 4.2.). Allowing learners to set their knowledge level directly in the course is a practically used approach in student modeling (see in ABITS [CAP 2000], ActiveMath [MEL 2001] SQL-Tutor [MIT 2003], Willow [SPC 2011] systems).

Table 4.2.

Selecting IDD depending on knowledge level

| **Knowledge level set by the learner** | **Corresponding grade in the RTU 10-points grading system** | **Selected IDD** | **Explanation of the selected task** |
|---|---|---|---|
| **High** | 10 (with distinction) | **6** | Task where the structure of a map is not provided. The learner has to construct the whole map him/herself, inserting concepts, linking them together and setting names and types of relationships between concepts. |
| | 9 (excellent) | | |
| | 8 (very good) | | |
| **Medium** | 7 (good) | **4** | Task where the structure of a map is provided, all the relationships are given, but the names of the relationships are not provided. The learner has to insert concepts in the map structure and set names for the relationships. |
| | 6 (almost good) | | |
| | 5 (satisfactory) | | |
| | 4 (almost satisfactory) | | |
| **Low** | 3 (weak) | **2** | Task where the structure of a map is provided, all relationships and their names are given. The learner needs to insert concepts in the map structure. |
| | 2 (very week) | | |
| | 1 (very, very weak) | | |

If the learner has not set his/her knowledge level in the course, then the system checks whether the student has completed an electronic questionnaire on learning styles. The Felder-Soloman questionnaire [FEL 2010] is used in IKAS, and it allows identifying a student's learning style in the Felder-Silverman learning style model (see the description of the model at the end of Chaper 2.2.). The electronic questionnaire is given in Attachment 2 of the full thesis.

So, if the learner has completed an electronic questionnaire on learning styles, then the system selects the task's IDD depending on the learning style (see Table 4.3.). Only two out of the eight learning styles are used in the selection of the task's IDD because other styles have no connection with the concept map-based tasks in IKAS.

Table 4.3.

Selecting IDD depending on learning style

| **Learner's learning style** | **Selected IDD** | **Explanation of selected task** |
|---|---|---|
| **Global** | **5** | The task, where a list of concepts is given, but a structure of the map is not given. This allows learners to build their own concept maps, allows to think globally and to see the solution in general. |
| **Sequential** | **3** | The task, where a list of concepts and a structure of the map are given allowing learners to progress in creation of their concept maps logically in a small steps. |

According to the algorithm for selecting a task's IDD, if the learner has not set his/her knowledge level in the course and has not completed a questionnaire on learning styles, then the learner gets a task with the IDD that the teacher set for this task.

## 4.4. Summary of the improvement of IKAS

The functionality described above extends the intelligent and adaptive functions of IKAS and ensures that IKAS supports both the new knowledge acquisition and the knowledge assessment stages of the learning process. The new intelligent functions of IKAS facilitate the calculation of concept mastering degrees and the creation of individual plans for the review of study materials for each learner. In turn, the new adaptive functions of IKAS are: 1) the selection of the difficulty degree of the first task depending on the learner's knowledge level in the course or his/her learning style, 2) the adaptation of priorities of the explanation type of concepts for each learner.

A new student model is used to support the new functionality of IKAS (see Figure 3.3.). The model is open and editable by the learner. That means that the learner is able to view the contents of his/her student model and to update the values in the model if needed. The learner is able to change the general information about him/herself, to set knowledge level in courses, to make the test on learning styles, to choose priorities of the explanation types for concepts and to choose the system interface language. The results of the experimental evaluation of IKAS described in Chapter 5 show that the decision to build an open and editable student model turned out to be correct.

## Summary of Chapter 4

Summarizing the results of Chapter 4, the following conclusions can be drawn:

- In order to expand the functionality of IKAS and to transform IKAS into a system that supports both knowledge assessment and new knowledge acquisition, three new requirements were implemented in IKAS: 1) the provisioning of explanation of concepts; 2) the calculation of mastering degrees of concepts; 3) adapting the difficulty degree of the first stage task. With the implementation of the new functionality, the intelligent and adaptive functions of IKAS were expanded.
- The new student model in IKAS is open and editable. In particular, the learner can see the content of his/her model and to update values in the model if needed.

# 5. IKAS JAUNĀS FUNKCIONALITĀTES PĀRBAUDE

This chapter contains the results of the experimental evaluation of the new functionality of IKAS and conclusions about the efficiency of the new functionality.

## 5.1. Organization of evaluation process of IKAS new functionality

In order to assess the efficiency of the new functionality, statistical data and students' responses in the questionnaire were analyzed. Statistical data are different kinds of statistics on the usage of IKAS functions, as well as student results in assessment tasks. These data are collected and stored automatically in the database while using IKAS. In turn, the answers in the questionnaire are the opinions of students that they expressed on various aspects of the system – usability, efficiency and so on. The printed version of the questionnaire used in IKAS is given in Attachment 3 of the full thesis.

The evaluation of the new functionality in IKAS was held in the 2010-2011 academic year in three courses – „Introduction to Artificial Intelligence (IAI)", „Fundamentals of Artificial Intelligence" (FAI) and „Fundamentals of Artificial Intelligence: Free Choice (FAIFC)". The number of students who participated in the evaluation and the distribution of students among the courses is given in Table 5.1.

Table 5.1.

Number of students and their distribution in the evaluation of the new functionality of IKAS

| Course | Number of students | Number of responses in the questionnaire |
|---|---|---|
| Introduction to Artificial Intelligence (IAI) | 34 | 32 |
| Fundamentals of Artificial Intelligence (FAI) | 233 | 208 |
| Fundamentals of Artificial Intelligence: Free Choice (FAIFC) | 31 | 21 |
| **TOTAL** | **298** | **261** |

The IAI course was held at the Faculty of Computer Science and Information Technology of RTU for the second year bachelor degree students, FAI – for the third year bachelor degree students, and FAIFC was applied to by students and the academical staff of various faculties of RTU.

## 5.2. Evaluation of the „Concept explanation" requirement

Table 5.2. shows statistical data on how many students used the concept explanation functionality and what were the students' average results in assessment tasks.

Table 5.2.

Statistics on how many students used the concept explanation functionality and the students' average results in assessment tasks

| Course | Number of students | Students, who used the concept explanation | | Students' results in assessment tasks (percentage from the maximum result) |
|---|---|---|---|---|
| | | Number | Percentage | |
| IAI | 34 | 12 | 35% | 62% |
| FAI | 31 | 21 | 68% | 55% |
| FAIFC | 233 | 69 | 30% | 82% |

The results of the experimental evaluation showed that the frequency of use of concept explanations depends on the student's knowledge level in the course. In particular, students with a lower knowledge level in a course asked for the concept explanation more often and vice versa. In general, considering the fact that at least one third of students in each course used the concept explanation functionality, it can be concluded that this functionality is needed for the support of students during the execution of a task.

Table 5.3. table shows the distribution of students' responses to the question „Did the explanation of concepts make the task execution easier?".

Table 5.3.

Distribution of students' responses to the question
„ Did the explanation of concepts make the task execution easier?"

| Answer to the question | Course | | |
|---|---|---|---|
| | IAI | FAIFC | FAI |
| Yes | 36% | 36% | 38% |
| Partially | 64% | 55% | 51% |
| No | 0% | 9% | 11% |

Table 5.3. shows that according to the students' opinion, the functionality developed for concept explanation makes the execution of a task easier thanks to provisioning of training materials about concepts.

## 5.3. Evaluation of the „Concept mastering degree" requirement

Table 5.4. shows the distribution of students' responses to the question „Did you review your individual concept repetition list?". The table shows that the majority of students in all courses reviewed their individual concept repetition lists. After comparing the data in this table with data in the last columns in Table 5.2, the following conclusion can be made: the lower the results the students got in assessment tasks, the more often they reviewed their concept repetition lists. This conclusion is absolutely logical because the repetition list shows

the students their gaps in knowledge and provides advice for improving the performance, so the repetition list is most useful for those students who show low results in assessment tasks.

Table 5.4.

Distribution of students' responses to the question
„Did you review your individual concept repetition list?"

| **Answer to the question** | **Course** | | |
|---|---|---|---|
| | **IAI** | | **IAI** |
| Yes | 83% | 87% | 74% |
| No | 17% | 13% | 26% |

Table 5.4. shows that the majority of students in all courses reviewed their individual concepts repetition lists. After comparison of data in this table with data in the last columns in Table 5.2 the following conclusion can be made: the lower results students got in assessment tasks the more often they reviewed their concept repetition lists. This conclusion is absolutely logical, because the repetition list shows the students their gaps in knowledge and provides advices for improving the performance, so the repetition list is most useful for those students who show low results in assessment tasks.

The data in Table 5.5 demonstrates the usefulness of the review plan. The table shows the distribution of students' responses to the question „Did you use the concept repetition list to repeat the learning material in the course?".

Table 5.5.

Distribution of students' responses to the question
„Did you use the concept repetition list to repeat the learning material in the course?"

| **Answer on Question** | **Course** | | |
|---|---|---|---|
| | **IAI** | | **IAI** |
| Yes | 67% | 71% | 59% |
| No | 33% | 29% | 41% |

Table 5.5. shows that on average two-thirds of those students who reviewed their concept repetition list also used this list to review the learning materials. Thus, it can be concluded that the concept repetition list was really helpful for students. A more detailed analysis of the data revealed that the main reason why one third of the students did not use the individual list for the repetition of learning materials was a lack of motivation for students to review the material.

## 5.4. Evaluation of the „Task adaptation" requirement

In order to check what type of adaptation of the task's difficulty degree – adaptation by knowledge level, adaptation by learning style or no adaptation – is the most effective, all students who participated in the test were divided into three according groups. The students from the first group were asked to set their knowledge level in the course before the beginning of the assessment task. For this group of students, the task's difficulty degree was chosen depending on the student's knowledge level in the course (see Table 4.2.). The students from the second group had to fill in the questionnaire on learning styles before beginning the assessment task. For this group of students, the task's difficulty degree was chosen depending on the dominant learning style (see Table 4.3.). The students from the third group started the assessment task immediately without setting the knowledge level or filling out the questionnaire on learning styles. For this group of students, an assessment task with the difficulty degree defined by the teacher was given (in the evaluation process it was the highest ($6^{th}$) degree of difficulty).

The effectiveness of each type of adaptation of the task's difficulty degree was evaluated through the analysis of statistical data that shows in how many cases students requested the reduction of the degree of difficulty of a task, because each such a request indicates that the initial degree of difficulty was chosen wrongly for the learner. Figure 5.1. shows the statistics of such requests.

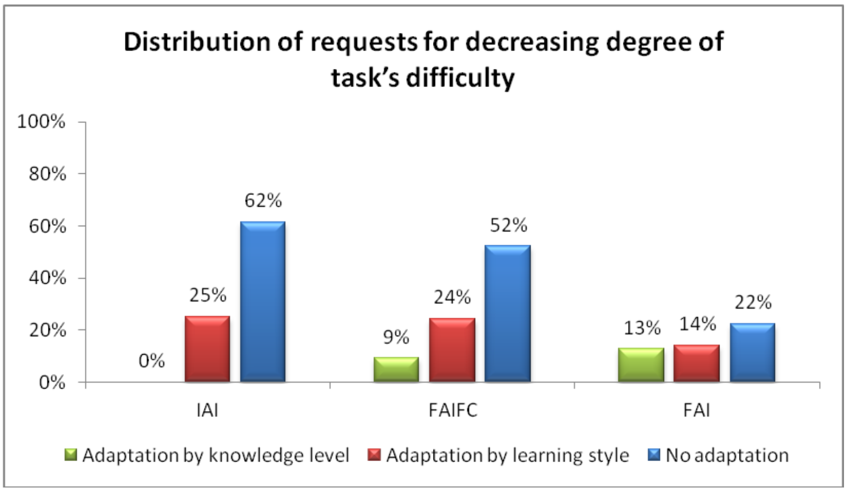


Fig. 5.1. Distribution of requests for decreasing the degree of difficulty of a task

Figure 5.1. shows that in all courses the distribution of the requests between different adaptation types remains the same – the most often a decrease of the difficulty degree of the task was requested by the students to whom the task was not initially adapted (see the blue bars in Figure 5.1.). Then follow the students to whom the task was adapted based on the learning style (see the red bars in Figure 5.1.), and finally, the students who requested a

decrease of the difficulty degree of the task the least frequently were those to whom the task was adapted based on the knowledge level (see green bars in Figure 5.1.). Thus, it can be concluded that the most effective form of adaptation is by knowledge level, an adaptation by learning style is medium effective, and the least effective way is not to adapt the difficulty degree of the task at all.

## Summary of Chapter 5

Summarizing the results of Chapter 5, the following conclusions can be drawn:

- The concept explanation functionality was used by at least one third of the students who noted that the concept explanation either eases (36-38%) or partially eases (51-64%) the task execution and allows getting new knowledge in a course.
- The individual concepts repetition list was reviewed by the majority of students (74-83%) and two thirds of them used it to repeat learning materials.
- When adapting the difficulty degree of the task, the most effective approach is to adapt it basen on the student's knowledge level in the course, a moderately effective approach is adaptation by the student's learning style, and the least effective approach is not to adapt the task at all and to give all students the task with the same initial degree of difficulty.

Evaluating the work that has been done to improve IKAS, we can note that IKAS has become more adaptive and more useful to the learners as a result of the new functionality, and the goal to transform IKAS into a system that supports the acquisition of new knowledge was achieved.

During the experimental evaluation of the new functionality of IKAS, 154 students filled out the questionnaire on learning styles. Figure 5.2. shows the expressiveness of each learning style according to the Felder-Silverman learning style model.

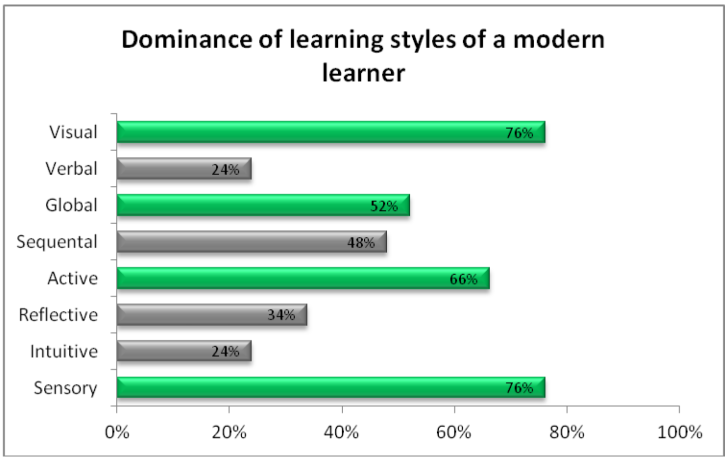


Fig. 5.2. Learner's learning style dominance in Felder-Silverman learning style model*

**Note:* the results are obtained by analyzing 154 filled questionnaires on learning styles

Figure 5.2. shows that the modern learner is Visual (prefers pictures, diagrams), Global (learns disorderly), Active (learns through experimentation and collaboration with others) and Sensitive (practical, oriented on facts and procedures).

During the experimental evaluation of IKAS, one third of the learners inspected the data stored in their student model, and one third updated their data. That shows the learner's interest in assuring the quality (accuracy and completeness of data) of their student models. Thus, it can be stated that the decision to make the student model open and editable for learners was correct.

## MAIN RESULTS AND CONCLUSIONS

The goal of the thesis was to identify the intelligent and adaptive functions of the intelligent tutoring systems, to define the complete contents of a student model for the support of these functions, and to develop a tool that would create student models automatically, as well as to expand the intelligent and adaptive functions of the knowledge assessment system IKAS and to experimentally verify the effect obtained after implementing these functions.

In order to achieve this goal, the following tasks were done:

- literature on the functions of ITS was reviewed, 17 intelligent and adaptive functions were distinguished, the implementation of these functions in 23 ITS was analyzed, and the conclusion was that all the functions utilize student model data;
- literature on student models was reviewed and the contents of the theoretical student model were obtained. In addition, the student models of 23 ITS were studied and the contents of the practical student model were obtained. A complete student model was obtained by merging the theoretical and practical student models;
- relationships between ITS functions and the complete student model data were identified. The „SM builder" tool that generates student models automatically depending on the intelligent and adaptive functions of the ITS was developed;
- improvement areas of the concept map-based knowledge assessment system IKAS were identified. The possible improvements were: 1) to adapt the initial difficulty degree of a concept map task for each learner, 2) to explain concepts from a map to a learner in an adaptive manner, 3) to calculate concept mastering degrees and to generate an individual concept repetition list at the and of a task.

The following tasks have been completed during improvement of IKAS:

- the intelligent and adaptive functions of IKAS have been extended and a new student model that supports all the IKAS functions has been obtained with the help of the „SM builder" tool;

- an algorithm to select the initial difficulty degree of a concept map for each learner based on his/her knowledge level in a course or his/her learning style has been designed and implemented in IKAS;
- an algorithm to select the appropriate concept's explanation type (definition, description or example of usage) for each learner has been designed and implemented in IKAS;
- a formula to calculate a concept mastering degree has been developed and an algorithm to generate an individual concept repetition list has been designed and implemented in IKAS;

The improved version of IKAS was experimentally evaluated in three courses. 298 students in total participated in the evaluation process and 261 of them filled out the questionnaire about the new functionality of IKAS.

The results of the experimental evaluation of the improved IKAS allow concluding that:

- the concept explanation functionality makes the task execution easier and allows learners to get new knowledge in a course;
- the individual concept repetition list is used actively by learners to review learning materials;
- the adaptation of the difficulty degree of a concept map task depending on the learner's knowledge level or his/her learning style allows to decrease the learners' unsatisfaction with the selected difficulty degree for the task significantly in comparison with the cases when there is no adapatation of the task's difficulty degree;
- IKAS became more adaptive and efficient for learners after the improvements and the goal to transform IKAS into a system that supports the acquisition of new knowledge in the course was reached;
- the learning style of a nowadays learner is Visual – Global – Active – Sensitive;
- learners demonstate interest in assuring the quality of their student models (accuracy and completeness of data). Therefore, the student model must be open and editable to the learner.

Possible future research directions are:

- a further improvement of the intelligent functions of IKAS by developing an animated interface agent which would help the learner as a virtual trainer to execute tasks, would motivate him/her and would communicate with the learner in a dialogue mode;

- a further improvement of IKAS related to the attachment of all possible learning materials (lecture notes, lecture presentations, audio/video recordings) to the concept maps. That would allow learners to get all the available information about concepts in the most suitable format.

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