The concept map-based assessment system: functional capabilities, evolution, and experimental results

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Abstract: The paper is devoted to the concept map-based intelligent assessment system that promotes students' knowledge self-assessment and supports teachers in improvement of study courses through systematic assessment and analysis of students' knowledge on the basis of concept maps. During the last five years, both the system's functionality and knowledge assessment approach were improved persistently, and at the moment, certain level of maturity is reached in both directions. The paper focuses on general principles of functioning of the last prototype, tasks provided, teachers' and students' support, scoring and adaptation mechanisms. At the end of the paper, retrospection of the system's evolution and evaluation results is provided.

Keywords: concept maps; CMs; computer-based assessment; intelligent knowledge assessment system; IKAS.

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1 Introduction

Today, several factors determine changes in societies all around the world: information and communication technologies (ICTs) are becoming an integral part of professional, social, and private life, new generation of students using computers from childhood has appeared, the course towards the knowledge society is already taken, lifelong learning is becoming an inevitable necessity. As a result, educational process is also changing and modern ICTs are widely used to provide more effective turning of information into knowledge. The main problem attracting developers of e-learning systems is how to achieve the same operation flexibility and adaptivity that can be provided by human-teachers in the learning process. Flexible knowledge assessment in such systems is in special focus because objective tests provide too simplified assessment, but evaluation of free-text answers demands processing of natural language.

A concept map-based *i*ntelligent *k*nowledge *a*ssessment *s*ystem (IKAS) has been under development for several years. The system is a good example of combination of modern ICTs and an advanced didactic method. It assesses students' knowledge on the basis of concept maps (CMs) and provides possibilities for teachers to improve their courses and teaching methods.

Regardless of the fact that nowadays there are a lot of tools supporting different activities with CMs, IKAS has several superior advantages. Firstly, the great part of known systems provide only such functions as CM construction, navigation, and sharing, but do not assess students' CMs, as it is done in IKAS. Secondly, both appropriate support and adaptation to students' characteristics are rarely considered, but that is not a case of IKAS (Anohina and Grundspenkis, 2008). Thirdly, systems supporting assessment use small set of tasks and rather primitive scoring schemes (Anohina-Naumeca et al., 2010). IKAS, in its turn, uses a mathematical model for scoring students' CMs.

The paper describes the main functional capabilities of IKAS and discusses its evolution. Section 2 considers CMs as a knowledge assessment tool. Section 3 gives a detailed description of IKAS. Section 4 is devoted to the evolution of the system. Section 5 presents a summary on results of experimental evaluation. Conclusions are given at the end of the paper.

2 CMs as a knowledge assessment tool

CMs – a pedagogical tool developed by Novak in 1970s (Novak and Cañas, 2008) – are based on two cognitive theories: Ausubel's assimilation theory (Ausubel, 1968) considering conceptual nature of human learning and hierarchical organisation of knowledge and Deese's associationist memory theory (Deese, 1965) advocating networked arrangement of concepts.

A CM is a semi-formal knowledge representation tool visualised by a graph consisting of finite, non-empty set of nodes, which depict concepts, and finite, non-empty set of arcs (directed or undirected), which express relationships between pairs of concepts. A linking phrase can specify the kind of a relationship between concepts. As a rule, natural language is used to represent concepts and linking phrases. Moreover, all arcs of the graph can have the same weight, or weights can be different. A proposition – concept-relationship-concept triple – is a semantic unit of CMs. It is a meaningful statement about some object or event in a problem domain (Cañas, 2003). According to Novak and Cañas (2008), CMs are represented in a hierarchical fashion with the most general concepts at the top of the map and the more specific concepts below them, but cross-links can be used to indicate relationships between concepts in different domains of a CM in such a way forming some kind of a network.

There is a wide variety of CM tasks which allow providing of knowledge assessment adaptable to students' characteristics. However, two main groups of them are:

a 'fill-in-the-map' tasks where the structure of a CM is given, and a student must fill it using the provided set of concepts and/or linking phrases

b 'construct-the-map' tasks where a student must decide on the structure of a CM and its content by him/herself.

The step-by-step construction of a CM and a sequence of CMs constructed by a student can illustrate the evolution of person's understanding of the topic (da Rocha and Favero, 2004). According to Cañas (2003), CMs can foster the learning of well-integrated structural knowledge as opposed to the memorisation of fragmentary, unintegrated facts and externalise the conceptual knowledge that students hold in a knowledge domain. The representation of knowledge structure is the topmost quality which substantiates the use of CMs as an alternative tool for knowledge assessment in relation to different forms of tests and essays.

3 Functionality of IKAS

3.1 General principles of functioning

The initial goal of IKAS was the promotion of process-oriented learning by supporting assessment focused on the process of knowledge acquisition by students (Anohina and Grundspenkis, 2006). Further, two main sub-goals were defined (Lukashenko at al., 2010):

a to promote students' knowledge self-assessment

b to support teachers in improvement of study courses through systematic assessment and analysis of students' knowledge.

Knowledge self-assessment is supported by the automatic evaluation of students' CMs and provision of informative and tutoring feedback. Systematic knowledge assessment is based on the possibility to extend an initially created CM for other assessment stages. Statistics on differences between students' and teacher's CMs allow teachers to improve their courses.

The usage scenario of IKAS (Lukashenko at al., 2010) assumes that a teacher divides a course into several assessment stages. A stage can be any logically completed part of the course, for example, a chapter. For each stage, a CM is created by specifying relevant concepts and relationships among them in such a way that a CM of particular stage is nothing else than an extension of the previous one. During knowledge assessment, a student solves a CM-based task corresponding to the assessment stage and after the submission of his/her solution the system compares student's and teacher's CMs and generates feedback.

The system can operate;

a in a mode of knowledge self-assessment allowing a student to assess his/her knowledge level and to learn more about a specific topic in case of incomplete knowledge

b in a mode of knowledge control intended for the determination of students' knowledge level by a teacher (Anohina-Naumeca et al., 2010).

At the moment, six tasks of different degrees of difficulty (Table 1) are implemented (Lukashenko and Anohina-Naumeca, 2010). Four of them are 'fill-in-the-map' tasks. Their obligatory component is the structure of a CM. Last two tasks are 'construct-the-map' tasks. Ten transitions between tasks are realised. Five transitions increase the degree of task difficulty. They are carried out automatically if a student has reached the teacher's specified number of points in the current assessment stage without reducing the degree of difficulty of the original task. Other five transitions reduce the degree of difficulty after the voluntary request from a student when solving a task.

Table 1 Tasks implemented in IKAS

Degree of difficulty	*Task*	*Structure of a CM*	*Concepts*	*Linking phrases*
1st – the simplest	Fill-in-the-map	Provided	One part is inserted into the structure, other part is provided as a list and must be inserted by a student	Inserted into the structure
2nd			Provided as a list and must be inserted by a student	
3rd				Not used
4th				Provided as a list and must be inserted by a student
5th	Construct-the-map	Must be created by a student	Provided as a list and must be related by a student	Not used
6th – the most difficult				Provided as a list and must be inserted by a student

Appearance of a particular CM depends on the assessment stage. At the first stage, a student receives a task which corresponds to his/her knowledge level (Section 3.5). In case of the reduction of the degree of difficulty, transition is always performed by making one step down the scale of difficulty degrees, in case of increase – one step up (Table 1).

3.2 Teachers' and students' support

IKAS provides teachers' and students' support along two dimensions (Anohina and Grundspenkis, 2008): help and feedback (Table 2). Help assists a student in carrying out a task by finding such degree of its difficulty which corresponds to his/her knowledge level. Feedback presents information about student's progress towards the completion of a task. Help is provided when solving tasks, but feedback can be given both when solving tasks and after their completion.

Table 2 Support provided in IKAS

Support	*Users**	*Tasks**	*Nature**	*Provision**
Help				
Changing the degree of task difficulty	S	F-M, C-M	H	SO
Additional insertion of concepts	S	F-M	H	SO
Explanation of a concept	S	F-M, C-M	H, TU	SO
Feedback				
A labelled student's CM	S, T	F-M, C-M	I	CO
Quantitative data	S, T	F-M, C-M	I	CO
Qualitative data	S, T	F-M, C-M	I	CO
Checking of a proposition	S	F-M, C-M	H, TU, I	SO
A teacher's CM	S	F-M, C-M	I	CO
Differences between students' and teacher's CMs	T	F-M, C-M	I	CO
Statistics on students' use of concept explanation types	T	F-M, C-M	I	CO
Answers on questionnaires	T	N/a	I	F

Notes: *S-student, T-teacher, F-M-'fill-in-the-map', C-M-'construct-the-map', H-help, TU-tutoring, I-informative, SO-when solving tasks, CO-after the completion of tasks, F-after filling-in a questionnaire, N/a-Not applicable

Explanation of a concept is supported at all degrees of difficulty. A student chooses a concept and asks the system to explain it using one of the following types of explanations: definition, description, or example. The type of explanations offered to the student depends on his/her student model (Section 3.5). This kind of help provides tutoring because the student has the possibility to acquire knowledge about particular concepts.

Additional insertion of concepts can be initiated by a student in 'fill-in-the-map' tasks by choosing a concept and asking the system to insert it into the right node of a CM. This help does not provide tutoring because it only reduces the total number of concepts that the student must insert by him/herself.

In the labelled student's CM, relationships are coloured in different tones according to their correctness. A student can acquire detailed information about each relationship such as its weight, the total number of points received for a particular relationship and contribution to the correctness of a relationship of all constituent parts (Section 3.4).

The most important quantitative data are difficulty degree, score received, time spent, description of the score calculation process and average results of other students who completed the same task at other degrees of difficulty. They are interpreted by a student him/herself without any pedagogical remarks from the system's side.

Qualitative description includes concept mastering degrees (CMDs) and an individual study plan. The calculation of CMDs is based on the analysis of correctness of incoming and outgoing relationships of a concept (Lukashenko et al., 2010):

$$CMD = \frac{\sum_{i=1}^{N} lc_i}{\sum_{i=1}^{N} lc_i^{\max}} * 100, \quad (1)$$

where lc_i – the number of points received for an i-th relationship of a concept, $lc_i^{\max}$ – the weight of an i-th relationship in the teacher's CM, and N – the number of relationships of a concept. The value of CMD is in a range from 0 (the student does not understand a concept at all) to 100% (perfect understanding of a concept).

The individual study plan advises kindly to revise learning materials regarding poorly known concepts (the middle interval of CMD values) and insists on studying hard unknown concepts (the lower interval of CMD values). Intervals of CMD values are configured by the administrator of IKAS.

Checking of a proposition is supported at all degrees of difficulty. A student points out his/her created proposition, and the system shows contribution of each constituent part (Section 3.4) to the correctness of the proposition. In case of incorrectness, the system provides tutoring presenting explanations of both concepts involved in the proposition.

The teacher's CM is shown to students after tasks of all assessment stages are completed.

Differences between students' and teacher's CMs focus on relationships;

a typically created by students, but missing in the teacher's CM

b existing in the teacher's CM, but usually remaining unrevealed by students

c defined as important in the teacher's CM, but presented as less important in students' CMs.

Statistics on students' use of concept explanation types include priorities for each type of explanations, approach used (Section 3.5), and frequency of use of a certain type of explanations.

3.3 Questionnaire system

A questionnaire system embedded in IKAS consists of:

1 a questionnaire designer

2 a questionnaire filler

3 a questionnaire reporting system (Lukashenko et al., 2010).

The questionnaire designer provides tools for the creation of questionnaires by teachers. For each questionnaire its title, a course, and an assessment stage must be specified. Essay, multiple response, multiple choice, and ranking questions are supported. Each questionnaire can be assigned to one course only. However, there might be several questionnaires for the same course. A questionnaire becomes available to students after its publishing by the teacher.

The questionnaire filler is available for students only. It contains questions and their answers or fields for entering answers. A questionnaire created for a particular assessment stage is offered immediately after completing that stage.

The questionnaire reporting system allows a teacher;

a to view and to sort students' questionnaires

b to receive a report on students' answers by questions and a report on answers' statistics.

3.4 Scoring students' CMs

In IKAS, students' CMs are compared with the teacher's one. Two types of relationships are used (Anohina and Grundspenkis, 2006):

a important relationships (weighted by five points) showing that relationships between concepts are considered as important knowledge in a course

b less important relationships (weighted by two points) specifying desirable knowledge.

In some cases, a student's CM is not exactly the same as a teacher's one, but is also correct. Such differences are determined by existence of relationships, locations of concepts in a CM, correctness of linking phrases, type and direction of relationships. A comparison algorithm (Anohina et al., 2009) that takes into account the mentioned differences is developed. It evaluates each proposition by considering relative contribution of its parts: presence of a relationship in a student's CM – 40%, correct linking phrase – 30%, correct direction of the arc – 15%, correct type – 10%, correct location of both concepts related by the relationship – 5%. At the moment, the algorithm can recognise more than 36 different patterns of partly correct propositions in students' CMs, for example, a relationship that exists in the teacher's map, but has an incorrect linking phrase and different location of concepts gives a student only 60% from the maximum weight.

Recently, the mentioned algorithm was improved by considering 'hidden' relationships (Grundspenkis and Strautmane, 2009) in students' CMs. They are derivations of relationships presented in a teacher's CM and can be recognised as correct. 'Hidden' relationships are determined on the basis of six standard linking phrases: 'is a' – a relationship between a class and its sub-class, 'kind of' – a relationship between concepts from two adjacent levels of hierarchy, 'part of' – a relationship between a part and a whole, 'example' – a relationship between a general concept and its example, 'attribute' – a relationship between a concept and its attribute, 'value' – a relationship between an attribute and its value. Linguistic relationships may exist as well, but due to their variety those relationships are difficult to process.

A set of patterns allowing IKAS to deal with 'hidden' relationships is developed. Table 3 demonstrates some examples. A pattern is a combination of two relationships: Rel. 1 and Rel. 2. In some cases a 'hidden' relationship (Rel. 3) can be deduced from a pattern. The patterns are represented in the form of production rules describing each relationship in the following way: *Relationship (<concept_1>, <concept_2>, <relationship_type>),* where *<concept_1>* and *<concept_2>* are variables indicating concepts, *<relationship_type>* is one of the six standard linking phrases mentioned before.

Table 3 Examples of patterns for the detection of 'hidden' relationships

Rel. 1	*Rel. 2*	*Rel. 3*	*Production rule*
Is a	Is a	Is a	IF Relationship (X, Y, 'Is a') AND Relationship (Y, Z, 'Is a') THEN Relationship (X, Z, 'Is a')
Part of	Attribute	Cannot be specified*	-
Kind of	Example	Example	IF Relationship (X, Y, 'Example') AND Relationship (Y, Z, 'Kind of') THEN Relationship (X, Z, 'Example')

Note: *There can be situations when a 'hidden' relationship can be added, but not always.

'Hidden' relationships are scored by 0 if a student creates all obligatory relationships (Rel. 1 and Rel. 2) and also their derivation (Rel. 3), and 1 – if not all of obligatory relationships are presented in a student's CM.

IKAS uses the previously mentioned production rules to expand a teacher's CM by adding all possible 'hidden' relationships. Students' CMs are compared to this expanded structure. The rules can be used to process longer chains by iteratively going through a CM, searching for patterns, and adding 'hidden' relationships whenever it is possible.

The student's score (P_S) is calculated as follows:

$$P_S = \left(\sum_{i=1}^{n} p_i * c_i \right) * d - h, \tag{2}$$

where p_i – the maximum number of points according to the type of an i-th relationship (important – 5, less important – 2, 'hidden' – 0 or 1), c_i – the degree of the correctness of an i-th relationship, n – the number of relationships in a CM (including 'hidden' ones), d – a coefficient representing the degree of difficulty, and h – the number of points spent on support.

Introduction of the coefficient d is based on the necessity to compare results of students who complete tasks at the higher difficulty degree and those who complete the same tasks at the lower one. Degrees of task difficulty and values of the coefficient d (Table 4) are aligned with Latvian grading system (Anohina-Naumeca et al., 2010). If a student completes a task without reducing the degree of difficulty, the value of the coefficient d is 1. If a student reduces the degree of difficulty, the value of the coefficient d is also reduced (area above the main diagonal in Table 4). When the system increases the task difficulty and a student is able to complete a task without reducing its difficulty, the value of the coefficient d exceeds 1 (area below the main diagonal in Table 4).

Table 4 Values of the coefficient *d*

		Teacher's pre-defined degree of difficulty					
		1	*2*	*3*	*4*	*5*	*6*
Student's used degree of difficulty	*1*	1.00	0.82	0.60	0.56	0.50	0.45
	2	1.22	1.00	0.73	0.69	0.61	0.55
	3	1.67	1.36	1.00	0.94	0.83	0.75
	4	1.78	1.45	1.07	1.00	0.89	0.80
	5	2.00	1.64	1.20	1.13	1.00	0.90
	6	2.22	1.82	1.33	1.25	1.11	1.00

A correction coefficient *h* is introduced in order to compare results of those students who complete an original task without using support and those who use it:

$$h = h_{EXP} + h_{INS} + h_{PROP}, \quad (3)$$

where h_{EXP} – the number of points spent on explanations of concepts, h_{INS} – the number of points spent on insertion of concepts, and h_{PROP} – the number of points spent on checking of propositions. Initially, all coefficients are equal with 0. Moreover, they are applied differently in each mode of system's operation. During knowledge self-assessment, h_{EXP} and h_{PROP} are not used because of tutoring nature of the corresponding support. However, h_{INS} reduces student's score because this kind of help substantially facilitates the task completion:

$$P_S = \left(\sum_{i=1}^{n} p_i * c_i \right) * d - h_{INS} \quad (4)$$

In the mode of knowledge control all kinds of support contribute to the reduction of student's score:

$$P_S = \left(\sum_{i=1}^{n} p_i * c_i \right) * d - h_{EXP} - h_{INS} - h_{PROP} \quad (5)$$

In order to stimulate a student to complete a task by him/herself, the penalty for the use of support increases each time when the student uses a certain kind of support:

$$\begin{aligned} h_{EXP,INS,PROP} = {} & p_{EXP,INS,PROP} * n_{EXP,INS,PROP} \\ & + \Delta_{EXP,INS,PROP} * \left(n_{EXP,INS,PROP} - 1 \right)^2 \end{aligned} \quad (6)$$

where $p_{EXP,INS,PROP}$ – the penalty for the use of the corresponding support, $\Delta_{EXP,INS,PROP}$ – the increase of the penalty, $n_{EXP,INS,PROP}$ – frequency of use of the corresponding support. The possibility to change values of the penalties and their increase is provided for a teacher.

3.5 Student model and adaptation

Data in a student model (Lukashenko and Anohina-Naumeca, 2010) used in IKAS are divided in five sections (Table 5). An initial knowledge level is the student's own evaluation of how well he/she masters a course. It can have one of three values: low (a student knows up to ≈25% of a course), average (a student knows up to ≈50% of a course), or high (a student knows almost all study material).

Four dimensions of learning styles according to Felder-Silverman learning styles model (Felder and Silverman, 1988) are considered: visual/verbal, sensory/intuitive, sequential/global, and active/reflective. The default values of the mentioned dimensions – visual, sensory, global, and active – are set for each student after his/her registration in IKAS. However, further learning styles could be modified by a student by filling-in the 'index of learning styles questionnaire' (Soloman and Felder, 2010).

Table 5 Content of the student model

Sections	*Parameters*	*Initially set by*	*Updated by*	*Usage**
General data	First and last name, ISEC number, e-mail, group, login name, password, role	Administrator	Administrator student (excluding group and role)	C: T
Knowledge and mistakes	Initial knowledge level, CMs, scores, incorrect relationships, CMDs, individual study plan	Student	System	C: D
Psychological characteristics	Learning styles	System (default setting)	Student	C: D P: E
Preferences	Priorities for types of concept explanations, language of user interface, themes, colours	System (default setting)	Student system	P: E, G
Other characteristics	Statistics on the use of different types of concept explanations	-	System	P: E

Notes: *C-adaptation of content, P-adaptation of presentation, T-selection of assessment tasks, D-selection of the difficulty degree of assessment stages, E-selection of type of concept explanations, G-graphical and language preferences

Due to the fact, that some parameters in the student model can be acquired from more than one information source, all sources in IKAS are ranged on the basis of their reliability. The highest reliability has information that comes from a student because it is assumed that the student knows better what is best for him/her. Then information concluded by the system after monitoring of student's behaviour is considered. At the end, parameters set by teachers or administrators are taken into account because information that comes from them is impersonalised. Reliability of different sources is used to resolve conflicts when assigning values to parameters in the student model.

The student model is used to perform four adaptation operations: to select the degree of difficulty of the first assessment stage and to change the difficulty degree of the next assessment stages in a course, to set and to change priorities of types of concept explanations.

The algorithm allowing selection of the initial difficulty degree includes three steps:

1 checking if the student has set the initial knowledge level for a course

2 checking if the questionnaire on learning styles is filled-in by the student

3 assigning the degree of difficulty set by the teacher for the course.

Transition to the next step is performed only if the previous one gives negative result. ‘Knowledge level (KL) – degree of difficulty (DD)’ rules are applied if the initial knowledge level is set. They assume that if the higher is the knowledge level then the more difficult task must be offered to the student:

$$IF\ KL = Low\ THEN\ DD = 2$$
$$IF\ KL = Medium\ THEN\ DD = 4$$
$$IF\ KL = High\ THEN\ DD = 6$$

‘Learning style (LS) – degree of difficulty (DD)’ rules based on sequential/global dimension of the learning style model are used if the student has given answers on the questionnaire on learning styles:

$$IF\ LS = Sequential\ THEN\ DD = 3$$
$$IF\ LS = Global\ THEN\ DD = 5$$

As a result, sequential students can logically progress toward the creation of a CM at the third degree of difficulty, but global students can construct a CM from scratch by thinking globally at the fifth degree of difficulty.

The degree of difficulty of the second and other forthcoming assessment stages in a course is changed according to the description given before (Section 3.1). Increase of the degree of difficulty always depends only on the student’s result in the previous assessment stage.

The algorithm for selection of initial priorities of types of concept explanations also has three steps and the same logic of them:

1 checking if initial priorities of types of explanations are set by the student

2 checking if the questionnaire on learning styles is filled-in by the student

3 use of default priorities: ‘highest’ – definition, ‘average’ – description, ‘lowest’ – example.

‘Learning style (LS) – explanation type (ET)’ rules allow selection of initial priorities if the questionnaire on learning styles is completed:

$$IF\ (LS = Visual)\ THEN\ (ET : Example = Highest)$$
$$IF\ (LS = Verbal\ and\ Sensory)\ THEN\ (ET : Description = Highest)$$
$$IF\ (LS = Verbal\ Intuitive)\ THEN\ (ET : Definition = Highest)$$

The rules are based on two dimensions of the learning style model – visual/verbal and sensitive/intuitive. As a result, visual students preferring pictures and graphs receive an example that typically contains picture demonstrating a concept, verbal-sensory students – a description because it gives practical description on concept usage, but verbal-intuitive students – a definition because it provides more theoretical and abstract description of a concept.

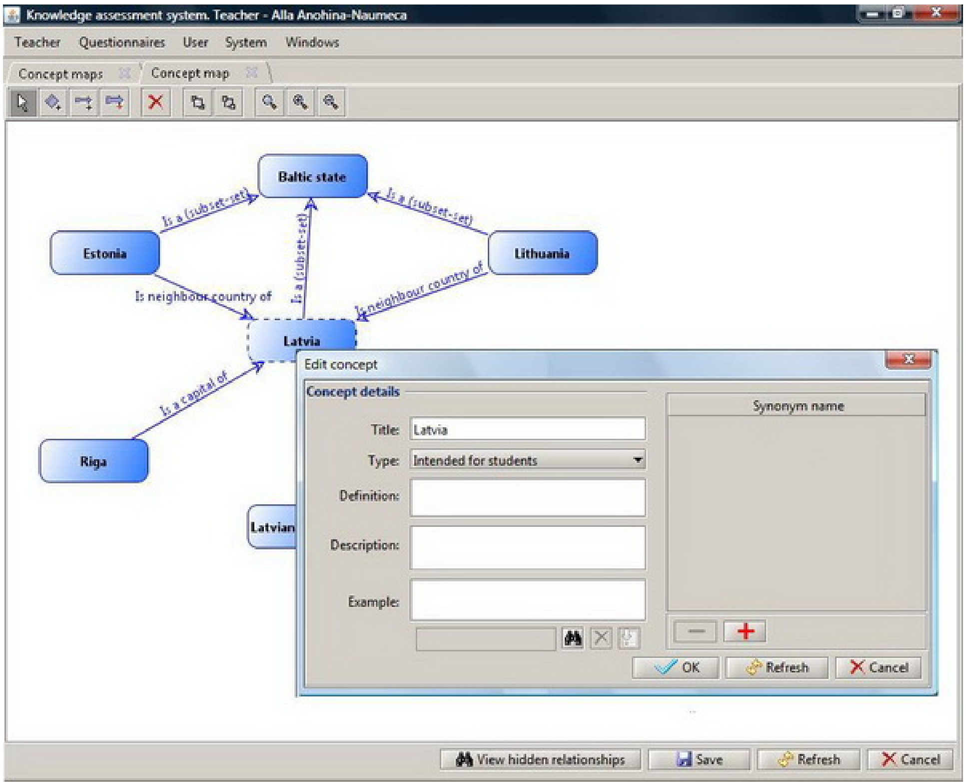
Priorities of types of concept explanations are changed according to statistics collected by the system during the monitoring of student's task solving behaviour and approach chosen by the student. In both cases, the system compares results of the analysis of statistics with priorities of explanation types in the student model. In static approach, if there are some differences then the system informs the student about them and offers to change priorities according to the collected data. In adaptive approach, the system automatically alters priorities without informing the student.

3.6 Modules and architecture

IKAS consists of three logical modules corresponding to three user roles in the system. The administrator module allows managing of teachers, students, groups, and courses, configuring feedback, setting initial values of the coefficients used in scoring students' CMs, and configuring initial values of the student model.

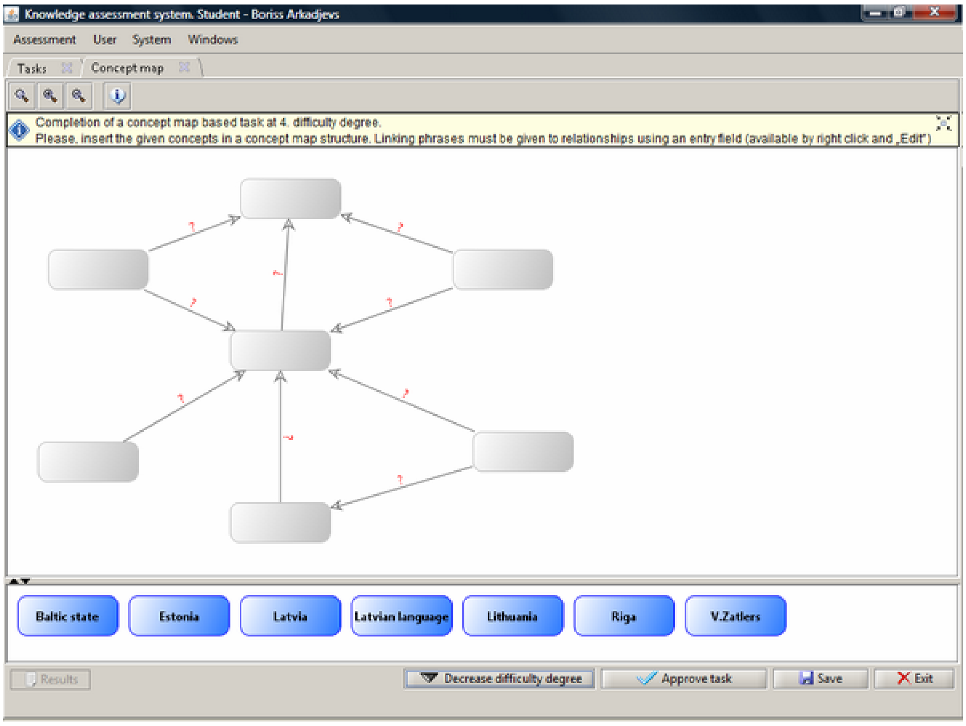
The teacher module supports creation of CMs (Figure 1), viewing students' results, managing differences between students' and teacher's CMs, changing the coefficients affecting students' scores, viewing statistics concerning students' use of concept explanation types, managing questionnaires and students' answers on them.

Figure 1 Teacher's interface of IKAS (see online version for colours)



The student module provides completion of CM-based tasks (Figure 2), use of students' support, managing types of concept explanations, provision of feedback to teachers through questionnaires, viewing and configuring the student model.

Figure 2 Student's interface of IKAS (see online version for colours)



The system is implemented as a Web-based three-tier client-server application consisting of the following architectural layers (Anohina et al., 2009):

1 a data storage layer represented by data base management system PostgreSQL

2 an application logics layer composed of the application server (Apache Tomcat), server side code, and a special persistence and query framework – hibernate

3 the representation layer based on swing, JGraph, and JGoodies libraries.

4 Evolution of IKAS

Evolution of five prototypes of IKAS is displayed in Table 6.

The first prototype developed in 2005 focused on the implementation of the conception and basic functional capabilities of IKAS. During that time, several fundamental things were developed: procedure for the creation and use of CMs, the overall scenario of system's functioning, important and less important relationships, and three modules of the system. However, only one task – insertion of provided concepts into the structure of a CM – was offered to students. Arcs were undirected and did not have semantics. The first version of the comparison algorithm that took into account only three constituent parts of a proposition and recognised five patterns of students' propositions was developed. Help was not offered, as well as feedback was minimal. The system was not adaptive. The two-tier client/server architecture was used.

Table 6 Evolution of IKAS prototypes

Features		*Prototype*					
		1st	*2nd*		*3rd*	*4th*	*5th*
			*1st A**	*2nd A**			
General							
Creation and use of CMs		+	+	+	+	+	+
Usage scenario		+	+	+	+	+	+
Tasks	Type**	F-M	F-M	F-M C-M	F-M C-M	F-M C-M	F-M C-M
	Number	1	1	3 2	3 2	3 2	4 2
Two operation modes		–	–	–	–	–	+
CMs							
Important and less important relationships		+	+	+	+	+	+
'Hidden' relationships		–	–	–	–	+	+
Linking phrases		–	–	+	+	+	+
Directed arcs		–	–	–	+	+	+
Definition and use of synonyms of linking phrases		–	–	–	+	+	+
Definition and use of synonyms of concepts		–	–	–	Can be defined, but not used		
Use of standard linking phrases		–	–	–	+	+	+
Help							
Changing the degree of task difficulty		–	+	+	+	+	+
Additional insertion of concepts		–	–	–	–	+	+
Explanation of a concept		–	–	–	–	+	+

Notes: '+' – available, '–' – not available
*different approaches
**F-M – 'fill-in-the-map', C-M – 'construct-the-map'
***E-presence of the relationship in the student's CM, T-correct type, P-correct location of concepts, LP-correct linking phrase, D-correct direction of the arc

Table 6 Evolution of IKAS prototypes (continued)

Features	*Prototype*					
	1st	*2nd*		*3rd*	*4th*	*5th*
		*1st A**	*2nd A**			
Feedback						
Maximum score	+	+	+	+	+	+
Actual score	+	+	+	+	+	+
Student's labelled CM	–	+	+	+	+	+
Time spent	–	–	–	–	–	+
Explanation of calculated score	–	–	–	–	–	+
Comparison with peers	–	–	–	–	–	+
CMDs	–	–	–	–	–	+
Individual study plan	–	–	–	–	–	+
Teacher's CM	–	–	–	–	+	+
Checking of propositions	–	–	–	–	+	+
Answers on questionnaires	–	–	–	–	–	+
Statistics on CM differences	–	+	+	+	+	+
Statistics on the use of types of concept explanations	–	–	–	–	+	+
Scoring students' CMs						
Mathematical model	–	+	+	+	+	+
Number of patterns of student's propositions	5	5	9	36	>36	>36
Contributions of constituent parts of a proposition***	E-50%, T-30%, P-20%	E-40%, LP-30%, T-20%, P-10%		E-40%, LP-30%, D-15%, T-10%, P-5%		

Notes: '+' – available, '–' – not available
*different approaches
**F-M – 'fill-in-the-map', C-M – 'construct-the-map'
***E-presence of the relationship in the student's CM, T-correct type, P-correct location of concepts, LP-correct linking phrase, D-correct direction of the arc

Table 6 Evolution of IKAS prototypes (continued)

Features	*Prototype*					
	1st	*2nd*		*3rd*	*4th*	*5th*
		*1st A**	*2nd A**			
Adaptation						
Student model	–	–	–	–	+	+
Adaptation of types of concept explanations	–	–	–	–	+	+
Adaptation of the degree of task difficulty	–	–	–	–	–	+
Questionnaire on learning styles	–	–	–	–	–	+
Architecture						
Three modules	+	+	+	+	+	+
Client/server architecture	2-tier	2-tier	2-tier	2-tier	3-tier	3-tier
Other						
Drag-and-drop technique	–	+	+	+	+	+
Help on the use of the system	–	–	–	–	+	+
Questionnaire system	–	–	–	–	–	+
English user interface	–	–	–	–	–	+

Notes: '+' – available, '–' – not available
*different approaches
**F-M – 'fill-in-the-map', C-M – 'construct-the-map'
***E-presence of the relationship in the student's CM, T-correct type, P-correct location of concepts, LP-correct linking phrase, D-correct direction of the arc

The second prototype developed in 2006 implemented several new solutions. New kinds of feedback were worked out both for teachers (statistics on differences between teacher's and students' CMs) and students (labelled students' CMs). Two approaches to changing the degree of task difficulty were developed. In the first approach, only one "fill-in-the-map" task was available and a student had the possibility to reduce the degree of task difficulty by inserting the chosen number of concepts into a CM. In the second approach, new tasks – three 'fill-in-the-map' and two 'construct-the-map' tasks (at present all tasks starting from the second difficulty degree) – were introduced and transition between them were implemented. Moreover, linking phrases were added. The comparison algorithm was modified by re-defining contribution of constituent parts of a proposition and extending the set of patterns of students' propositions. The drag-and-drop technique was implemented for manipulations with concepts. The first version of the mathematical model for scoring students' CMs emerged.

In 2007, the third prototype was developed on the basis of the previously described second approach. Directed arcs were introduced causing modifications in the comparison algorithm. An option to define synonyms of concepts and linking phrases was provided for teachers. A set of standard linking phrases was added.

In the fourth prototype, 'hidden' relationships were introduced. New kinds of help (additional insertion and explanation of concepts) and feedback (teacher's CM and checking of propositions) were offered. A new three-tier architecture was implemented with aim to make the system more secure and responsive. The first version of the student model was developed.

In the last prototype developed in 2009–2010, one more task was added and two operation modes were implemented. Feedback was carefully considered and improved. The mathematical model for the scoring of CMs was developed in detail. Several adaptation mechanisms were implemented on the basis of the revised student model. The questionnaire system was embedded in IKAS and the user interface was translated into English.

5 Results of experimental evaluation

Starting from 2005 all previously mentioned prototypes were evaluated in different courses (Table 7) by asking students to fill-in a questionnaire after solving CM-based tasks.

Table 7 Data of experimental evaluation of IKAS

Year	*Prototype*	*Number of courses*	*Number of students*	*Number of questionnaires*	*Number of questions*
2005	1st	6	95	84	15
2006	2nd	5	72	63	17 and 19
2007	3rd	1	40	37	22
2008	4th	1	39	36	33
2009–2010	5th	4	65	30	37

Typically questions in the questionnaire are related to the use of CMs as an assessment tool, IKAS functionality, user interface, and performance. The number of questions differs from one prototype to another because of introduction of new possibilities in each version of the system.

Table 8 displays the most interesting questions about CMs as a pedagogical tool. Typically students point out that they like using CMs and mention that they help to systematise their knowledge and to develop knowledge structure, promote logical thinking, and provide convenient and fast way for knowledge assessment.

Answers to questions on functionality partly triggered off continuous improvements of IKAS. So, after the evaluation of the first prototype, students suggested implementing drag-and-drop technique and pointed out that textual format of feedback is not informative enough. The mentioned suggestions were taken into account in the second prototype. As a result, students approved a new graphical interface and evaluated feedback as useful and showing students' mistakes. Questionnaires revealed that students could not find a suitable linking phrase for a relationship and reflected suggestions to define synonyms of linking phrases and to implement the possibility to use directed graphs which may make easier the selection of linking phrases. In the third prototype, both a set of standard linking phrases and option to define synonyms were introduced. During evaluation of first three prototypes, students always found that it would be helpful to provide more informative feedback and to improve the system's response to user actions. Those were impulses for further improvements realised in the fourth and fifth prototype where the main attention was paid to the provision of informative and tutoring feedback, adaptation of tasks, and revising of architecture.

Table 8 Questions about CMs

Question	*Answer*	*Percentage of answers*				
		Prototype				
		1st	*2nd*	*3rd*	*4th*	*5th*
Do you like to use CMs as a knowledge assessment tool?	Yes	69	78	84	92	70
	Neutral	–	11	0	8	17
	No	31	11	16	0	133
Did the use of CMs facilitate the better understanding of the learning material?	Yes	63	71	41	58	40
	Partly	–	–	51	36	43
	No	37	29	8	6	17
Would you like to use such a knowledge assessment method in other courses?	Yes	33	71	62	50	27
	Probably	55	22	27	47	53
	No	12	7	11	3	20

Unexpected results were revealed as well. In average less than 50% of students used the reduction of the degree of task difficulty (a mechanism in which the developers of IKAS have put considerable efforts) regardless of difficulties met during completion of CM-based tasks. Questionnaires helped to find reasons: one part of students was sure about their knowledge, while another part did not want to lower their scores. Regarding explanations of concepts the greatest part of students who used this option confirmed that for them definitions were most informative, others answered that descriptions were most informative, but nobody put examples in this category.

However, CM-based tasks still seem difficult to students. The main reasons stated in questionnaires more frequently are lack of understanding of the idea of CM, insufficient knowledge in a course, or lack of experience with different diagrams. Students stressed that CMs require unusual way of thinking and ability to see 'a whole picture'. It is interesting to point out that computer science students reached considerably better results than students of pedagogical programme. That may be because computer science students are familiar with different software products and diagrams used in software engineering.

Additional information concerning experimental results can be found in (Grundspenkis, 2009).

6 Conclusions

Regardless of the certain level of maturity of IKAS, its development is not finished yet. At the moment several problems are under consideration. Firstly, at present only one teacher's CM is used in evaluation of students' CMs in a course. This fact introduces certain subjectivity in assessment process. As a result, possibilities to integrate several teachers' CMs of the same course and to use them in combination for the evaluation of students' CMs are considered.

In order to increase the variety of tasks and their suitability for different assessment goals research concerning the development of the extend set of tasks compatible with the already implemented ones has been started. It demands not only to select new tasks, but also to map them to possible assessment goals and characteristics of the student model.

However, the main considered and the most difficult problem is related to the fact that manual creation of CMs, as a rule, is time consuming process. Research on the possibility to generate CMs from unstructured text, for example, lecture notes and to adjust them by the teacher is in progress. First results are achieved in creation of draft CMs by automatically extracting key concepts and some of their relationships from Latvian language texts using a robust morphological analyser developed at the University of Latvia for Latvian language processing (Vilkelis et al., 2010). At the moment, only nouns are considered as concepts. The preliminary research revealed difficulties;

a to process collocations (multi-word units)

b to understand linkage between nouns and pronouns in long and syntactically complicated sentences

c to process words with the same spelling, but different meaning

d to process sentences where there is only one concept, for example, 'a dog can run'

e to detect property names for adjective.

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