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EVOLUTION OF THE CONCEPT MAP BASED ADAPTIVE KNOWLEDGE ASSESSMENT SYSTEM: IMPLEMENTATION AND EVALUATION RESULTS

JĒDZIENU TĪKLOS SAKŅOTAS ADAPTĪVAS ZINĀŠANU VĒRTĒŠANAS SISTĒMAS EVOLŪCIJA: REALIZĀCIJAS UN NOVĒRTĒŠANAS REZULTĀTI

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Concept map, adaptive knowledge assessment, multiagent system, degree of task difficulty, comparison algorithm of concept maps

1. Introduction

In the area of education many researchers support the idea that the educational process can be promoted by modern information and communication technologies (ICTs). ICTs enable student-centred and one-to-one learning in traditional as well as in computational environments [1]. A plethora of technology-enhanced educational systems that aim at facilitating teaching, learning, and assessment has been already developed and many others are under the development. At the same time even the most advanced so called intelligent tutoring systems provide intelligent support of the educational process that is far behind of that provided by a human-teacher who is able to adapt to each learner individually and to give flexible feedback. With the dissemination of technology-enhanced, in particular, distance learning, learning assessment has become a constant concern [2]. For example, in e-learning a regular knowledge assessment, as a rule, is based on tests that allow assessing of learners' knowledge only at the first four levels of the well-known Bloom's taxonomy [3] including three levels of lower order skills: knowledge, comprehension, and application, and analysis, that along with synthesis and evaluation belongs to three higher order skills. Even in traditional teaching, where regular knowledge assessment may be carried out quite easily, only final examinations are applied in practice due to the high workload of teachers.
The paper presents the approach ensuring systematic knowledge assessment through the use of the developed concept map based adaptive knowledge assessment system (KAS). Both teachers' assessment and learners' self-assessment are supported by the system that allows keeping track of person's learning progress. Section 2 introduces underlying concepts of the KAS. Section 3 describes four prototypes of the system and results of their evaluation. The section ends with detailed comparison of the prototypes reflecting the evolution of the system. Conclusions and future work are given in Section 4.

2. Underlying concepts of the system

In the sixties of the last century, Ausubel developed the Assimilation Theory [4, 5] in concordance with which human beings learn meaningfully via acquisition and retention of concepts and propositions that are stored in their cognitive structures in a particular, idiosyncratic way. As it turns out, this idea is not easy to put into teaching practice without proper understanding of the process through which people learn meaningfully, i.e., there is a fundamental necessity of learning the concepts of progressive differentiation and integrative reconciliation before applying them to school topics [2]. Aware of this, Novak has developed a pedagogical tool called a concept map (CM) [6, 7]. According to Novak, a CM represents a part of a person's cognitive structure, revealing his/her particular understanding of a specific knowledge area. CMs are a specific kind of mental models that are used for representation and measuring of individual's knowledge by visualization of a graph with labelled nodes corresponding to concepts and with arcs (links) indicating relationships between pairs of concepts. Arcs may be undirected or directed, as well as may have the same or different weights [8]. Finally, arcs may be without or with linking phrases on them that specify a kind of relationship between concepts. A proposition is a semantic unit of CMs presented as a concept-link-concept triple that is a meaningful statement about some object or event in a problem domain [9]. A CM is constructed by the continued application of progressive differentiation and integrative reconciliation [2]. 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 [10]. CMs are a viable, computable, and theoretically-sound solution to the problem of expressing and assessing students' learning [2]. The concept mapping approach offers a reasonable balance between requirements to assess higher levels of knowledge and complexity of a KAS [11], and can be used as an alternative to usual essays, decreasing the amount of teacher's work during assessment [2]. That is why in educational settings CMs have become a valuable tool of a teaching, assessment and learning toolbox, as they enhance learning, promote reflection and creativity, and enable students to externalize their knowledge structures [6].

Besides the abovementioned advantages there are several additional reasons that motivate the development of the CM based adaptive KAS. First, the use of CM based tasks for assessment allows seeing students' cognitive (knowledge) structure. Thus, CMs promote system thinking that frequently is a critical point even for university students. Second, CMs allow offering of tasks with different degrees of difficulty that can be ranged from high-directed to low-directed depending on information provided for students. All tasks are divided into "fill-in-the-map" tasks where a CM structure is given and "construct-the-map" tasks where students themselves must create a CM structure and choose its contents [12]. Fill-in tasks belong to high-directed tasks because a CM structure and sets of concepts and/or sets of linking phrases are given. Some concepts may be already filled in, linking phrases defined, links marked with weights or students must define concepts and/or linking phrases. In construction tasks a CM structure is not given. Lists of concepts and/or linking phrases may be given or students must define them by themselves. Consequently, CM based tasks are suitable for adaptive knowledge assessment. The adaptation to students' knowledge level can be reached in several ways. At each stage, a student can receive a task that corresponds to his/her current knowledge level, and at the next stage task difficulty can be changed depending on previous results of knowledge assessment. Third, CMs support process oriented learning in which a teacher divides a study course into several stages and carries out knowledge assessment at the end of each stage. Thus, systematic assessment is provided that, in its turn, allows not only to assess a current knowledge level of each individual learner, but also allows to change teaching methods and learning content timely in order to achieve a desirable knowledge level and to promote qualitative teaching and learning process.

In order to support systematic knowledge assessment the following procedure for the creation and use of CMs has been developed [13]. Learners should acquire a certain set of concepts at the first stage of a study course. A teacher includes these concepts and relationships among them into the first CM. At the second stage new concepts are taught and the teacher adds them to the CM of the first stage without changing relationships among already existing concepts. So, each new CM is an extension of the CM of a previous stage. Reaching the last stage, a CM contains all concepts and relationships among them representing a complete knowledge structure of the study course. The overall scheme showing the use of CMs in systematic knowledge assessment is displayed in Fig.1.

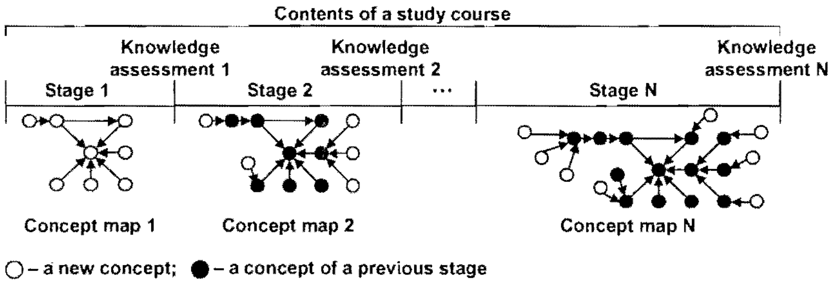

Fig.1. Use of concept maps in process oriented learning for learners' knowledge assessment

The developed KAS implements the following scenario. Using the system's graphical user interface, a teacher prepares CMs for each stage by drawing CMs on the working surface. During the creation of the first CM the teacher can freely add and delete concepts and links, but in the next stage he/she can freely operate only with new elements of the current CM. In order to make teacher's work easier, already developed ontologies of study courses may be transformed into CMs [14]. During knowledge assessment or self-assessment learners get a task (a CM) that corresponds to the current learning stage. After the completion of the CM, a learner confirms his/her solution and the KAS compares CMs of the learner and the teacher. A final score and the learner's CM are stored in a database. The learner receives feedback showing his/her CM with mistakes, but a correct CM remains hidden.
The KAS is designed as a multiagent system (Fig.2). The agent-expert forms a CM of a current stage using a teacher's CM and a learner's CM of the previous stage, and passes it to the communication agent for visualization. The agent-expert also delivers the teacher's CM and a corresponding ontology to the knowledge evaluation agent for comparison. The communication agent perceives learner's actions and is responsible for visualization of a CM received from the agent-expert, and for the output of feedback received from the knowledge evaluation agent. The latter compare the learner's CM with the teacher's CM and the corresponding ontology, and recognizes synonyms of concepts and several patterns (correct or incorrect) of the learner's solution (see Section 3). The interaction registering agent stores the learner's solution and score in a database. It is necessary to point out that each of the already implemented prototypes of the KAS has only limited functionality of the designed architecture that is under the development at the moment.

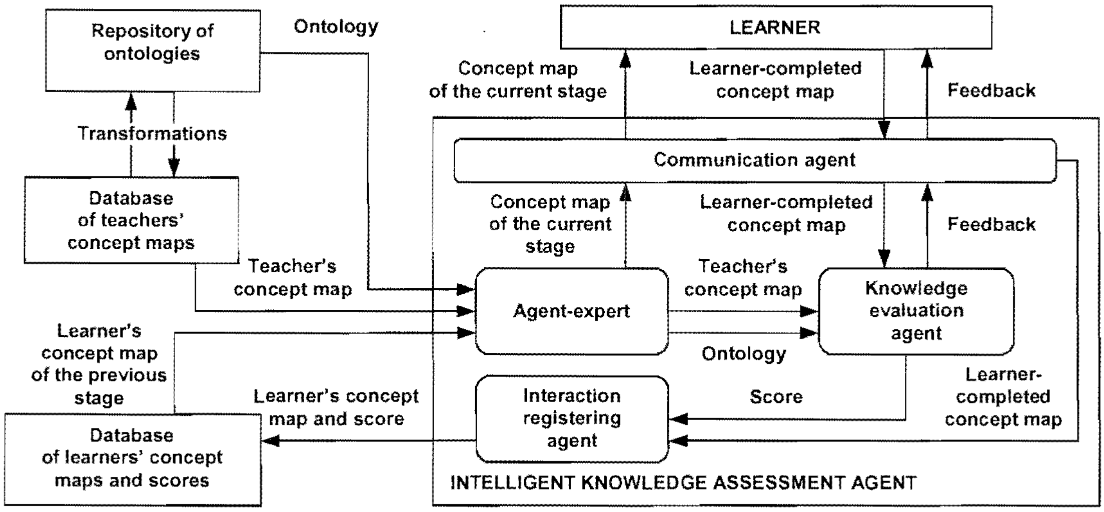

Fig.2. The architecture of the adaptive knowledge assessment system

3. Implementation of KAS prototypes

The development of the adaptive KAS started in 2005. Since that time four projects managed by the first author of this paper and funded by the Latvian Ministry of Education and Science, and Riga Technical University have been finished.

3.1. The first prototype

The development of the first prototype mainly was focused on the implementation of the overall conception and basic functional capabilities. The architecture of the system included three modules: the teacher module, the learner module and the administrator module. The following tools were chosen: Borland JBuilder 9.0, JGraph, PostgreSQL DBMS 8.0.3 and JDBC driver for PostgreSQL.

The two layer client-server architecture was used (Fig.3). A learner accesses the application using any browser. The client application is downloaded from the server via WebStart and installed on the user's machine (the client side). Data exchange between the database on the server side and the client application is carried out when the learner interacts with the KAS. The application connects the server directly and communicates using the JDBC driver and SQL or PL/SQL commands.

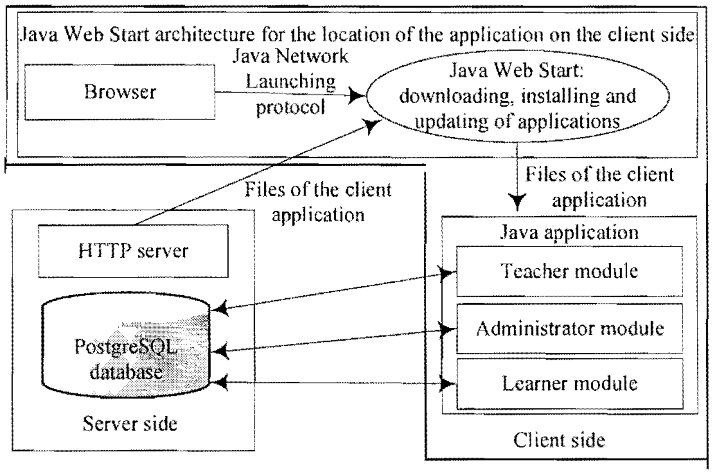

Fig.3. The two-layer architecture of the KAS's first prototype

In fact this system is not adaptive at all because learners can solve only fill-in-the-map tasks receiving the given CM structure. The task for learners is to put concepts from a given list in correct nodes of the structure. However, there are limited possibilities to change the degree of task difficulty by increasing or decreasing the number of teacher's predefined concepts already placed in correct places. Arcs are undirected and without semantics. Only two predefined weights reflecting importance of relationships (important and less important) are used. At the next stage learners receive an extended CM where all correctly placed concepts are left, but incorrectly placed and new ones are given in the corresponding lists.

A novel algorithm for comparison of CMs has been developed and implemented in the system. This algorithm is sensitive to the arrangement and coherence of concepts. For demonstration of algorithm's performance let's suppose that a learner has received a high-directed fill-in-the-map task where the CM structure is defined (Fig.4a). An example of the learner's solution is shown in Fig.4b. Operation of the algorithm is based on the assumption that understanding of relationships between concepts is the most important for knowledge assessment while types of links and places of concepts are of secondary importance. The algorithm carries out the comparison of concept pairs of the teacher's constructed CM (Fig.4a) and a learner's completed CM (Fig.4b).

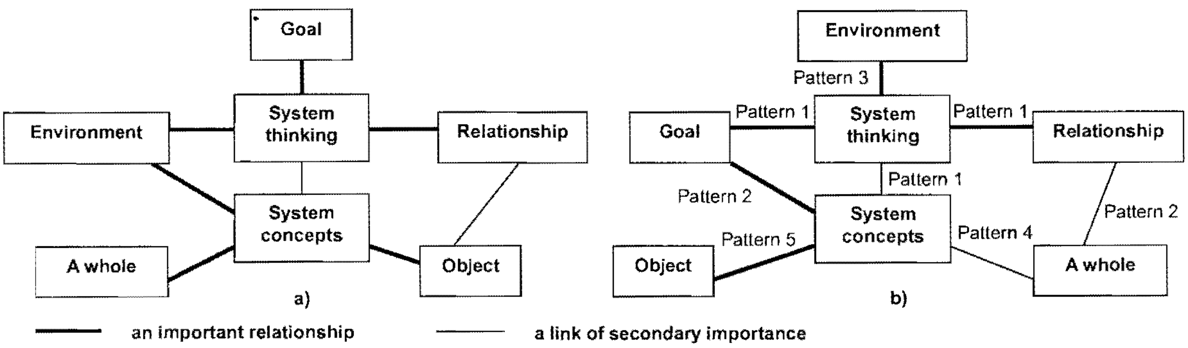

Fig.4. Comparison of concept maps based on five patterns

Five patterns are identified [15, 16]. Pattern 1 corresponds to a correct solution, and the learner receives the maximal score. Pattern 2 represents a completely incorrect solution (the learner has defined a relationship that does not exist and receives zero score). Pattern 3 originates when the learner has defined a correct relationship but at least one of concepts is placed incorrectly (he/she receives 80% from the maximal score). Pattern 4 occurs in case if the learner has defined an incorrect type of a relationship and at least one of concepts is placed incorrectly (the learner receives 50% from the maximal score). Pattern 5 means that a concept is incorrectly placed but its place is unimportant (the learner receives maximal score).

When comparison is finished, a learner receives feedback with information about incorrectly related pairs of concepts, a list of not inserted concepts, the maximal possible score at this stage for the absolutely correct solution, and the actual score he/she has achieved. In turn, the teacher receives feedback with information about the maximal and actual scores of all learners, and their CMs with mistakes highlighted on them. More details about the first prototype of the KAS are given in [15, 17].

The first KAS prototype was evaluated in 6 study courses (5 engineering and 1 pedagogical course) both in Riga Technical University and Vidzeme University College. In total 102 students participated in evaluation and 84 of them submitted questionnaires after the use of the KAS. Fifty eight (69%) students answered that CM based knowledge assessment promotes logical thinking and better understanding of learning material. For 41 (49%) students the user interface was relatively convenient and perceivable. However, 19 (23%) of them pointed out that textual format of feedback is not informative enough, and 15 (18%) thought that feedback should contain information about missing knowledge units. At the same time for 44 (52%) students fill-in-the-map tasks were difficult, and for 6 (7%) students even very difficult. They also reveal causes: the method is unusual, requires active thinking, and the KAS has limited functionality. Practically all students supported the use of CMs in other study courses if the abovementioned drawbacks will be avoided. The students suggested to use the drag-and-drop technique for fill-in-the-map tasks, and to elaborate the feedback in order to identify mistakes in a graphical form.

3.2. The second prototype

The drawbacks of the first prototype were eliminated in the second prototype which roughly corresponds to the multiagent architecture (see Fig.2). Several new solutions have been implemented. First, new kinds of feedback were worked out both for teachers and learners. For teachers the system collects statistical data about non-existing relationships that learners often define, about correct relationships that learners define rarely, and about important relationships that learners define as links of secondary importance. These data may draw teachers' attention and facilitate changes in teaching. Feedback for learners is more instructive and is given in a graphical form. A learner receives his/her completed CM with labels representing his/her received points for each relationship. Labels are given in the form "x out of y," where y denotes maximum of points for a certain relationship, and x corresponds to points acquired by a learner. Relationships also have different colours according to their correspondence to patterns.

Second, two approaches how to change the degree of task difficulty have been developed, namely, by inserting additional concepts into a CM or by offering different types of tasks. In the first approach only fill-in-the-map tasks are available. During task performance, a learner can ask to reduce the degree of task difficulty, and the system inserts additional concepts into a CM. Reduction of task difficulty has two steps. First, the analysis of learner's CM is carried out; incorrectly inserted concepts are removed and added to a list of concepts. Second, a learner chooses the number of concepts he/she wishes the system would insert. Note that this number depends on the minimal number of concepts pre-defined by a teacher that a learner must insert by him/herself [18]. The system reacts by inserting additional concepts. This is a duty of the agent-expert that uses the developed algorithm that is based on the identification of degrees (the number of incoming and outgoing arcs) of free nodes (nodes that do not contain concepts). Free nodes are sorted in descending order. The node with an average index is chosen and a corresponding concept is inserted into a CM. If the learner wishes to insert more than one concept, the process continues. In that way, nodes with an average degree are inserted first of all.

This decision is based on the assumption that concepts with smallest degrees give too little help, but concepts with highest degrees are keywords that learners must know.
The approach was evaluated in 4 study courses both in Riga Technical University and Vidzeme University College. Forty four students took part, and 35 questionnaires were received after knowledge assessment. Thirty students (86%) liked the usage of CMs for knowledge assessment, and 26 (74%) considered that CMs help them to understand learning material better. For 21 (60%) student it was difficult, and for 4 (11%) even very difficult to solve fill-in-the-map tasks. However, only 10 (29%) students used the system's offered possibility to reduce the degree of task difficulty. At the same time 8 (80%) of them pointed out that it facilitates further execution of tasks. Remaining 25 (71%) students explained that they did not want to reduce their total score. Students approved the system's user interface (19 students or 54%) considering that it is convenient and perceivable, but 14 students (40%) found it relatively convenient and comprehensible. Twenty seven (77%) students indicated that the provided feedback was useful showing what kind of knowledge is missing. The form of feedback was evaluated as being demonstrative (19 or 54% of students) or partly demonstrative (14 or 40% of students). So, evaluation of feedback is significantly higher in comparison with the first prototype where a textual format of feedback was used.
In the second approach, five tasks (3 fill-in-the-map and 2 construct-the-map) providing adaptive capabilities of the KAS have been selected and sorted starting with the easiest high-directed one where a structure of a CM and linking phrases are given, and ending with the most difficult low-directed task where a CM must be constructed if only a list of concepts is given [13, 19]. At the first stage, a learner receives a task that has a teacher's defined degree of difficulty. During task performance, the learner can ask to reduce the degree of task difficulty. The ordinal number of the task in the sorted list of tasks is reduced by one in this case. The task difficulty depends on a learner's result at the previous stage. So, if the learner has reached a teacher's predefined minimal score without reduction of the task difficulty, the system delivers the more difficult task at the next stage. This is the system's adaptive reaction to the learner's behaviour.
Addition of construct-the-map tasks extends a set of patterns and causes modification of points received for relationships. Considering an absolutely correct relationship as 100%, its constituents are defined as follows: 40% for understanding of relationships between concepts, 30% for understanding correct semantics (linking phrases), 20% for understanding of a correct type (important or less important) of a relationship, and 10% for placement of both concepts in correct places [17]. Nine patterns have been identified that can be distinguished by the developed algorithm for comparison of the teacher's CM (Fig.5a) and the learner's CM (Fig.5b).

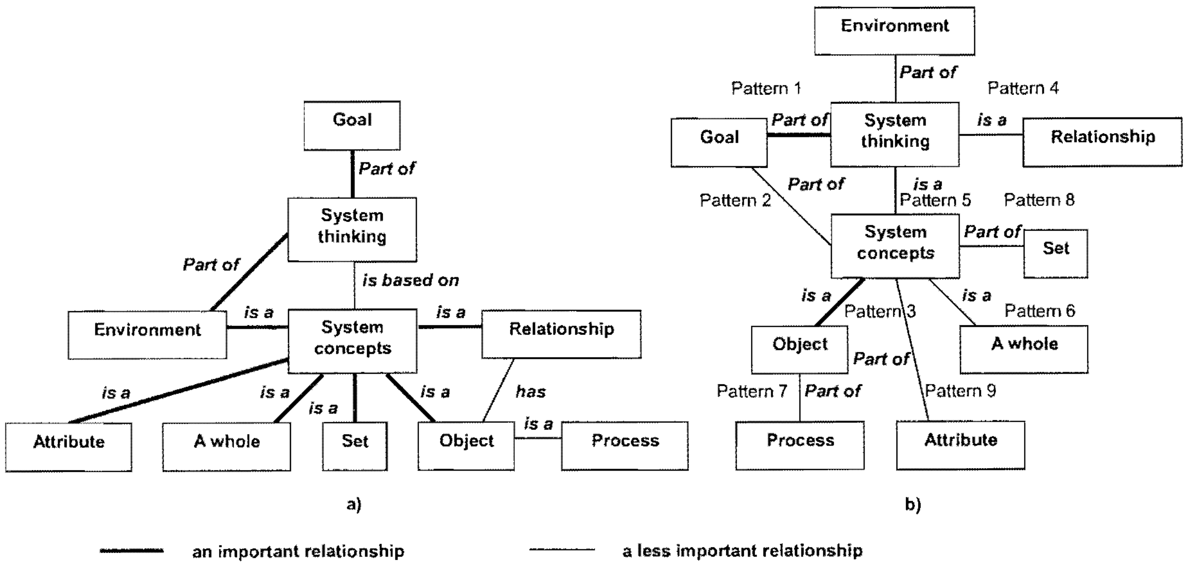

Fig.5. Comparison of concept maps based on nine patterns

Patterns represent the following cases. Pattern 1 represents a correct solution (a learner receives the maximal score (max S): 5 points for important and 2 points for less important relationship). Pattern 2 corresponds to the completely incorrect solution (the score is zero). Pattern 3 means a correct solution with exception that at least one of concepts is placed incorrectly (a learner receives 0.9 max S). Pattern 4 is valid only for construct-the-map tasks. It represents the case if a type of a relationship is incorrect (a learner receives 0.8 max S). Pattern 5 represents a solution in which a linking phrase is incorrect (a learner receives 0.7 max S). Pattern 6 corresponds to a situation where a type of the relationship is incorrect and at least one of concepts also is placed in an incorrect place (a learner receives 0.7 max S). Pattern 7 occurs in case if the learner has defined a correct relationship, but both its type and a linking phrase are incorrect (a learner receives 0.6 max S). Pattern 8 is another case that is valid only for construct-the-map tasks. It reflects a situation in which both a type and a linking phrase are defined incorrectly for the existing relationship (a learner receives 0.5 max S). Pattern 9 is similar to the pattern 8, but at least one of concepts is placed incorrectly (a learner receives 0.4 max S).
The second approach was evaluated in one engineering course "Fundamentals of Artificial Intelligence" in spring of 2007. Totally 30 students took part and 28 of them completed the questionnaire. From questionnaires it may be concluded that once again CM based knowledge assessment is approvingly evaluated by 68% (19) of students. The same number (19 or 68%) students pointed out that such approach helps better understanding of logical organization and interconnectedness of mastered concepts. Once again rather high number of students answered that CM based tasks are difficult for them (16 students or 57%). Twelve students (75%) from those who had difficulties used possibility to reduce the degree of task difficulty, and 11 of them (92%) found that the system offered an easier task. At the same time the system increased the degree of task difficulty for 9 students (32%), and 8 of them agree (89%) that the task offered by the system was more difficult. Evaluating feedback, students mentioned that it is demonstrative (17 students or 61%). They liked the graphical form that shows weak points in their answers.

3.3. The third prototype

The third prototype continues improvements of the adaptive KAS in the following directions:

- a teacher is provided with option to define synonyms of concepts and linking phrases;
- directed arcs are introduced;
- a set of standard linking phrases are defined such as "is a" (subclass-class relationship), "is instance of" (instance-class and instance-subclass relationship), "has attribute" (object-attribute relationship), "has value" (attribute-value relationship), and "part of" (part-whole relationship);
- a list of linking phrases frequently defined by a learner that are not synonyms of correct linking phrases are determined. The aim of such list is to make a teacher aware of the facts. A teacher may make a decision is a linking phrase valid and to extend a set of synonyms for a corresponding relationship;
- a set of patterns of learner solutions is extended taking into account directions of arcs.

In 2007 a theoretical research focused on possibilities to transform study course ontology into CMs also was completed. In result the algorithm for transformations of OWL ontology into a CM has been developed [14]. This algorithm is not integrated into the prototype because it requires time consuming re-implementation of the system.
Performance of the third prototype was evaluated in the study course "Methods of Systems Theory" by 40 students. They have submitted 37 questionnaires after the use of the KAS for knowledge assessment. Answers showed that for 16 (43%) students it was easy, but for 21 (57%) student it was difficult to solve given CM based tasks. As the main reasons of difficulties 10 (47%) students mentioned insufficient learner's support from the system's side, 8 (38%) students pointed out lack of work experience with CMs and 6 (29%) students declared that they have not mastered learning material deeply enough. Those students who did not have problems underscore that they have good understanding of essence of CMs (7 students or 44%), have experience of using different software products (5 students or 31%) and have good knowledge of learning material (4 students or 25%).

3.4. The fourth prototype

The development of the fourth prototype has not finished at the moment. Three main directions in improvement of the already existed KAS are worked out.
First, new three-layer architecture is implemented to make the system more secure providing protection of students' data and their results. The architecture shown in Fig.6 has three conceptual elements: the database server, the client application and a newly introduced application server. So, the application is secure enough because the database server is open for connections only from one computer, namely, the application server Apache Tomcat. The new version of the KAS is implemented using the following technologies: Eclipse 3.2, Apache Tomcat 6.0, PostgreSQL DBMS 8.1.3, JDBC drivers, Hibernate, VLDocking, JGoodies and JGraph [20].

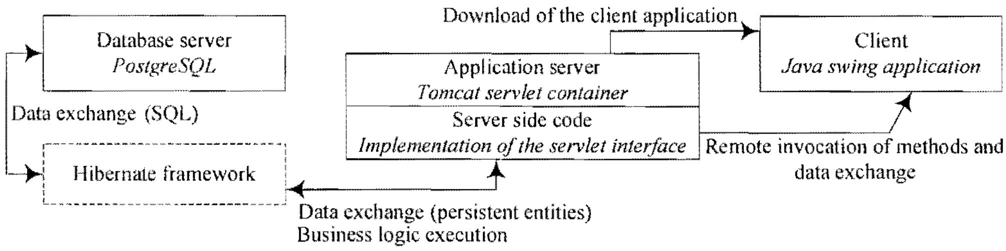

Fig.6. The three-layer architecture of the concept map based knowledge assessment system

Second, new kinds of learners' support have been designed [21] dividing them into two categories: provided help during execution of tasks and offered feedback during and after completion of tasks (Table 1).

Table 1

Kinds of help and feedback and their characteristics

Type of support	Types of tasks	Nature	Status
Help			
Changing the degree of task difficulty	F-M*, C-M*	H*	Implemented
Additional insertion of concepts	F-M	H	Under implementation
Explanation of a concept	F-M, C-M	H, T*	Under implementation
Feedback			
Numerical data	F-M, C-M	I*	Implemented
Labeled learner's CM	F-M, C-M	I	Implemented
Checking of a proposition	F-M, C-M	H, T, I	Under implementation

* F-M – "fill-in-the-map"; C-M – "construct-the-map"; H – help; T – tutoring; I – informative

Additional insertion of concepts is initiated by a learner who asks the system to insert a chosen concept into the right place (node) of CM. It is obvious that there is not any tutoring because the system only helps the learner reducing the total number of concepts that he/she should insert coincidently reducing the degree of task difficulty. Explanation of a concept occurs when a learner asks the system to explain the chosen concept. Explanation may be given in three forms (a definition of a concept, a short description or an example) and depends on learner's preferences captured in a student model. The initial form of explanation is determined asking a learner for his/her choice. A learner can change the form of explanation. Moreover, the system keeps track of learner's actions and determines which form of explanation has the greatest contribution to the creation of a correct CM. This, in turn, enables to modify a student model. Checking of a proposition (a pair of concepts) allows a learner to indicate a created proposition so that the system can check its correctness, and provide explanation (tutoring) in case if a proposition is incorrect. More sophisticated checking of propositions based on larger patterns, e.g. patterns containing three concepts and two relationships is under the development [22]. It will help to separate which parts of a student's CM is different from a teacher's CM and which are just different reflections of the same structure, as well as to increase the level of automation of knowledge assessment. Larger patterns are described by production rules that are used to expand a teacher's CM by adding to it all possible extra (default or hidden) relationships. Afterwards the expanded CM is compared with a CM constructed by a learner. This technique allows assessing learner's knowledge more precisely. Production rules can also be used to find additional relationships in longer concept chains that consist from more than three concepts and two relations. In this case the algorithm iteratively goes through a CM searching for patterns and adding extra relationships whenever rules order it. The algorithm stops when there is not any new relationship that can be added.

3.5. Summary

Evolution of the developed CM based adaptive KAS is summarized in Table 2 that reveals details how the developed KAS undergoes an evolution step-by-step moving towards the final goal – the development of truly intelligent KAS based on CM and ontology formalisms.

Table 2

Evolution of the concept map based knowledge assessment system

Characteristics	**Number of prototype**				
	1st	**2nd**		**3rd**	**4th**
		1st A*	**2nd A***		
Procedure for the creation and use of CMs	+	+	+	+	+
The interaction scenario	+	+	+	+	+
Task(s) for learners	F-M	F-M	F-M, C-M	F-M, C-M	F-M, C-M
Evaluation mechanisms of CMs (number of patterns)	5	5	9	36	> 36
Creation of concept maps					
Two types of relationships	+	+	+	+	+
Semantics of arcs	-	-	+	+	+
Directed arcs	-	-	-	+	+
Definition of synonyms of linking phrases	-	-	-	+	+
Definition of synonyms of concepts	-	-	-	+	+
Use of standard linking phrases	-	-	-	+	+
Help offered to learners					
Changing the degree of task difficulty	-	+	+	+	+
Additional insertion of concepts	-	-	-	-	+
Explanation of a concept	-	-	-	-	+
Feedback offered to learners					
Maximal score for the current task	+	+	+	+	+
Actual learner's score for the current task	+	+	+	+	+
Addition score in comparison with the previous stage	+	-	-	-	-
List of not inserted concepts	+	-	-	-	-
List of pairs of incorrectly related concepts	+	-	-	-	-
Learner's CMs with points for each relationship	-	+	+	+	+
Teacher's CM	-	-	-	-	+
Checking of propositions	-	-	-	-	+
Feedback offered to teachers					
Learners' CMs with highlighted mistakes	+	+	+	+	+
Maximal score for the current task	+	+	+	+	+

Characteristics	Number of prototype				
	1st	2nd		3rd	4th
		1st A*	2nd A*		
Learners' scores	+	+	+	+	+
Statistical information about differences between teacher's and learners' CMs	-	+	+	+	+
Architecture of the system					
Three modules	+	+	+	+	+
Client/server architecture	2-layer	2-layer	2-layer	2-layer	3-layer
Other					
Drag-and-drop technique	-	+	+	+	+
Multiple execution of the same task	-	+	+	+	+
Use of a student model	-	-	-	-	+
Help about the use of the system	-	-	-	-	+

* 1st A – the first approach; 2nd A – the second approach

4. Conclusions

In this paper rather longitudinal research and development of the adaptive multiagent based KAS using CMs is described. Three prototypes have been already implemented, tested and evaluated and the fourth is under development at the moment. The experience obtained manifests that the KAS based on CMs is able to adapt to the knowledge level of each individual learner by offering a wide variety of tasks with different degrees of task difficulty.

Within all four sequential projects there is step-by-step progression towards a truly intelligent adaptive KAS by improving the CMs comparison algorithms. To make system more flexible, semantics of links and directed arcs are introduced. The set of patterns for comparison is extended from 5 in the early prototypes till 36 in the third. In the fourth prototype the set of patterns is expanded by adding so called larger patterns that include more than two concepts and one relationship between them. This will allow assessing of learners knowledge more precisely.

System's experimental evaluation showed that engineering curriculum students who study computer science achieved considerably higher scores in comparison with students of pedagogical curriculum. The hypothesis get from these first experiments is that computer science students are familiar with various diagrams used in software engineering therefore a CM is not absolutely new technique for them. Certainly much more testing experiments are needed in order to conclude which study courses and areas are especially suited for CMs.

Future work is also directed towards extension of the developed KAS. First, the algorithm for transformation of study course ontology into CMs should be integrated into the system. Second, the new algorithm that uses a larger set of patterns for CMs comparison should be implemented, too. Third, the multiagent architecture should be realized in full scale where a student model is developed and implemented, too. And last, but not least, the system should include also an ontology based facilities to choose learning material that learners can revise to fill gaps in their knowledge structure.

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Grundspeņķis J., Anohina A. Jēdzienu tīklos sakņotas adaptīvas zināšanu vērtēšanas sistēmas evolūcija: realizācijas un novērtēšanas rezultāti

Rakstā ir apskatīta jēdzienu tīklos sakņota adaptīva zināšanu vērtēšanas sistēma. Jēdzienu tīklu priekšrocības ir analizētas, uzsverot, kas tie piedāvā pieņemamu risinājumu, kas ļauj novērtēt augstākā līmeņa zināšanas pēc Blūma taksonomijas un vienlaicīgi saglabāt zināšanu vērtēšanas sistēmas relatīvu vienkāršību. Jēdzienu tīkli ļauj atklāt studentu zināšanu struktūru, veicina sistēmisku domāšanu un atbalsta procesa orientētu apmācību, kurā mācību kurss tiek sadalīts stadijās un katrā no tām tiek veikta zināšanu vērtēšana. Izstrādātā zināšanu vērtēšanas sistēma sastāv no pasniedzēja, studenta un sistēmas administratora moduļiem, un tā ir realizēta kā daudzaģentu sistēma. Ir aprakstīti četru projektu gaitā izstrādātie sistēmas prototipi. Pirmajā prototipā ir realizēti tikai definētās jēdzienu tīkla struktūras aizpildīšanas uzdevumi, ievietojot jēdzienus no iepriekš definēta saraksta. Otrs prototips nodrošina uzdevumu grūtības pakāpes maiņu, tādējādi adaptējoties apmācāmā zināšanu līmenim. Uzdevumu klāsts ir papildināts ar tādiem, kuros apmācāmajam ir jākonstruē jēdzienu tīkls. Trešajā prototipā veiktie uzlabojumi ļauj lietot jēdzienu tīklus ar loku orientāciju un ar standarta attieksmju semantiku. Savukārt ceturtajā prototipā realizēta trīs līmeņu arhitektūra ļauj paaugstināt sistēmas drošību. Bez tam ir ievērojami paplašināts apmācāmā atbalsts, kas sniedz apmācāmajam gan palīdzību, gan mācību materiālu. Rakstā doti arī prototipu novērtēšanas rezultāti dažādos studiju kursos. Raksts noslēdzas ar visu četru prototipu salīdzinājumu pēc visiem galvenajiem realizētās zināšanu vērtēšanas sistēmas raksturojumiem.

Grundspenkis J., Anohina A. Evolution of the Concept Map Based Adaptive Knowledge Assessment System: Implementation and Evaluation Results

The paper represents the concept map based adaptive knowledge assessment system. Advantages of concept maps are analyzed emphasizing that the approach offers a reasonable balance between requirements to assess higher levels of knowledge according to Bloom's taxonomy and complexity of a system. Concept maps allow revealing of student's knowledge structure, promote system thinking and support process oriented learning where a study course is divided into stages in each of which knowledge assessment is carried out. The developed knowledge assessment system consists from a teacher's, learner's and administrator's modules and is implemented as a multiagent system. Four prototypes of the system developed within four projects are described. The first prototype supports only fill-in-the-map tasks where a learner must put given concepts in correct places. The second prototype provides changing the degree of task difficulty, thus, performing adaptation to a learner's knowledge level. The set of tasks are also extended by construct-the-map tasks. Improvements implemented in the third prototype allow using of directed arcs and standard relationships in concept maps. The three-tier architecture used in the fourth prototype is chosen to rise the security level of the system. Besides that learner's support is considerably expanded giving help and tutoring to a learner. Results of evaluation of the developed system's prototypes in different study courses are presented. The paper concludes with the comparison of all four prototypes using all main characteristics of the developed knowledge assessment system.

Грундспенькис Я., Анохина А. Эволюция адаптивной системы оценивания знаний основанной на сетях понятий: результаты реализаций и оценки

В статье рассматривается адаптивная система оценивания знаний основанная на сетях понятий и приведен анализ преимуществ использования сетей понятий, подчеркивая, что такой подход обеспечивает решение, которое дает возможность оценивать высшие уровни знаний по таксономии Блума, сохраняя при этом относительно простую структуру системы. Сети понятий позволяют выявить структуру знаний обучаемого, способствуют развитию системного мышления и поддерживают ориентированное на процесс обучение, в котором учебный курс разделяется на стадии, в каждой из которых проводится оценивание знаний. Разработанная система оценивания знаний состоит из модулей преподавателя, обучаемого и системного администратора, и является реализованной в виде многоагентной системы. В статье описаны прототипы системы, разработанные в ходе четырех проектов. В первом прототипе реализована только задача заполнения предложенной структуры сети понятий понятиями из данного списка. Второй прототип обеспечивает изменение степени трудности решаемой задачи, таким образом реализуя адаптацию к уровню знаний обучаемого. Более того, множество задач дополнено задачами конструирования сети понятий. Усовершенствования, реализованные в третьем прототипе, дают возможность использовать сети понятий с ориентированными дугами и с семантикой стандартных отношений. В свою очередь, в четвертом прототипе использование трех уровневой архитектуры повышает надёжность системы. Кроме того, значительно расширена поддержка обучаемого, представляя обучаемому не только помощь, но и обучающий материал. В статье приводятся результаты оценки разработанных прототипов в различных курсах обучения. Статья заканчивается сравнением всех четырех прототипов на основе основных характеристик реализованных в системе оценивания знаний.