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CONCEPT MAPS AS KNOWLEDGE ASSESSMENT TOOL: RESULTS OF PRACTICAL USE OF INTELLLIGENT KNOWLEDGE ASSESSMENT SYSTEM

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ABSTRACT

Concept maps as a pedagogical tool have stable positions in education being used for teaching, learning and knowledge assessment. The paper gives an insight into essence of concept maps and their usage for knowledge assessment. The concept map based adaptive intelligent knowledge assessment system (IKAS) is described. The kernel of IKAS is the intelligent knowledge assessment agent which is implemented as a multiagent system consisting from the agent-expert, the communication agent, the knowledge evaluation agent and the interaction registering agent. The knowledge evaluation agent compares a teacher's and a learner's concept maps on the basis of graph patterns and assigns score for submitted solution. Four years long experimental use of IKAS allowed gathering student opinion about concept maps as knowledge assessment tool and the functionality of IKAS. The paper presents the summary of evaluation results of both aspects collected from students' questionnaires.

KEYWORDS

Concept map, knowledge assessment, intelligent knowledge assessment system, agent, graph pattern.

1. INTRODUCTION

Concept maps (CMs), a pedagogical tool developed by Novak and Gowin (Novak and Gowin, 1984; Novak, 1998), holds a stable position in education. Advances in Computer Science have supported the use of technologies that allow for the construction of computational environments that aim at facilitating teaching, learning, and sometimes learning assessment, which with the dissemination of distance learning, however, has become a constant concern (da Rocha et al., 2008). Several reasons can be mentioned, but the most critical are two: lack of regular assessment mainly due to the high workload of teachers who have to cope with the assessment of hundreds of students, and lack of capacity for adaptation to each individual learner from the educational environment side (Grundspenkis and Anohina, 2009). Concerning the construction of educational environments two problems arise: the choice of learning theory on which the environment should be based, and the identification of implementable aspects of this theory (da Rocha et al., 2008). In the last decades Cognitivism has played a major role among learning theories. Most cognitive theories share the assumption that concept interrelatedness is an essential property of knowledge, i.e., that one aspect used in defining competence in a domain is well structured knowledge (Ruiz-Primo and Shavelson, 1996). As students acquire expertise through learning, training, and/or experience, their knowledge becomes increasingly interconnected.

Cognitive theory underlying concept mapping grew out of Ausubel's Assimilation Theory (Ausubel, 1968; Ausubel, 2000) and Deese's Associationist Memory Theory (Deese, 1965). The former postulated a hierarchical memory structure, whereas the latter postulated a network of concepts which may include a hierarchy, too. In addition, according to Novak, a CM represents a part of a person's cognitive structure, revealing his/her particular understanding of a specific knowledge area. From the assessment viewpoint CMs are a specific kind of mental models that are used for representation of individual's knowledge. The representation of knowledge structure is the topmost quality which substantiates the usage of CMs as alternative tool for knowledge assessment concurrently with different forms of tests and usual essays. In educational settings CMs have become a valuable tool for a teaching, assessment and learning toolbox, as they enhance learning, promote reflection and creativity, and enable students to externalize their knowledge structure (Novak and Gowin, 1984). So, CMs are a viable, computable, and theoretically sound solution to the problem of expressing and assessing students' learning results (da Rocha et al., 2008).

In (Ruiz-Primo and Shavelson, 1996) it is declared that although the potential use of CM to assess students' knowledge structures has been recognized, CMs are far more frequently used as instructional tools than as assessment tools. Thenceforth, as it follows from the analysis of literature, situation has been changed. In research level several approaches and systems supporting the assessment and feedback process have been worked out. Such systems as RFA (Conlon, 2006), Java Mapper (Hsieh and O'Neil, 2002), Verified Concept Mapper (Cimolino et al., 2003), COMPASS (Gouli et al., 2004), IKAS (Grundspenkis and Anohina, 2009; Grundspenkis, 2008), HIMATT (Pirnay-Dummer et al., 2008), and an approach based on domain ontologies and genetic algorithms (da Rocha et al., 2008) are some examples.

At the same time more investigations are needed on various issues of practical applications of such systems. For example, wide range experiments with knowledge assessment systems should be carried out to yield evidence about students' solutions of CM tasks, their opinion about usage of CMs as assessment tool, about recommendable operation modes, functionality, convenience of interface, necessary content of feedback and its forms, etc.

The purpose of this paper is to represent the four year experience of practical usage of the adaptive intelligent knowledge assessment system (IKAS) (Grundspenkis and Anohina, 2009; Grundspenkis, 2008) which was developed at the Department of Systems Theory and Design of Riga Technical University. The system continuously has evolved and to some extent improvements are based on students' evaluation of IKAS functionality and operation. The paper is organized as follows. The CMs as knowledge assessment tool are briefly described in the next section. Section 3 is devoted to the developed IKAS. The summary of students' evaluation results collected from questionnaires is given in Section 4. The paper ends with conclusions and the outline of future work.

2. CONCEPT MAPS AS KNOWLEDGE ASSESSMENT TOOL

CMs are semi-formal knowledge representation tools visualized by graphs and used natural language to represent concepts and propositions, i.e. to represent semantic knowledge and its conceptual organization (structure). Mathematically a CM is undirected or directed graph consisting of finite, non-empty set of nodes, which represent concepts of a knowledge domain, and finite, non-empty set of arcs (undirected or directed), which represent the relationships between pairs of concepts. A CM can be represented by an attribute graph which set of arcs contains attributes (words or linking phrases) used to specify the kind of relationship between concepts (de Souza et al., 2008). Moreover, the corresponding graph may be homogeneous in sense that all arcs have the same weight, or heterogeneous if weights of arcs are different. The latter reflects the fact that from the expert's (teacher's) point of view some relationships are more important than others (Ahlberg, 2004). A proposition is a semantic unit of CM, i.e., a concept-relation-concept triple which is meaningful statement about some object or event in a problem domain (Cañas, 2003). Variety of CMs represented by graphs is shown in Figure 1.

The framework for conceptualizing CMs as a potential assessment tool is proposed in (Ruiz-Primo and Shavelson, 1996). According to this framework an assessment is considered as a combination of three components: a task given to a student, a format for a student's response and a scoring system by which students' CMs can be evaluated. There is a wide variability of CM tasks.

Three ways in which these tasks may vary are identified in (Ruiz-Primo and Shavelson, 1996), namely, a) task demands, b) task constraints, and c) task content structures. Task demands are related to demands made on students in generating their CMs. Usually two classes are distinguished: fill-in-the-map and construct-the-map tasks. If fill-in-the-map task is offered, as a rule, students receive the structure of CM with blank nodes where concept names must be placed. In construct-the-map case students must draw a map by themselves. Other task demands refer to such tasks as "organize cards", "rate relatedness of concept pairs", "write an essay", "respond to an interview" (Ruiz-Primo and Shavelson, 1996). Task constraints refer to the restrictiveness of the task. For example, students may or may not be a) provided with a list of concepts used in the task; b) provided with a list of linking phrases; c) asked to define concepts and/or linking phrases; d) asked to construct-the-map collectively; e) allowed to use more than one relationship between two concepts; f) allowed to use synonyms of concepts and/or linking phrases; g) provided with lists of concepts and/or linking phrases that contain erroneous words, and so on. Task content structures refer to the intersection of the task demands and constraints with the structure of the subject domain to be mapped (Ruiz-Primo and Shavelson, 1996).

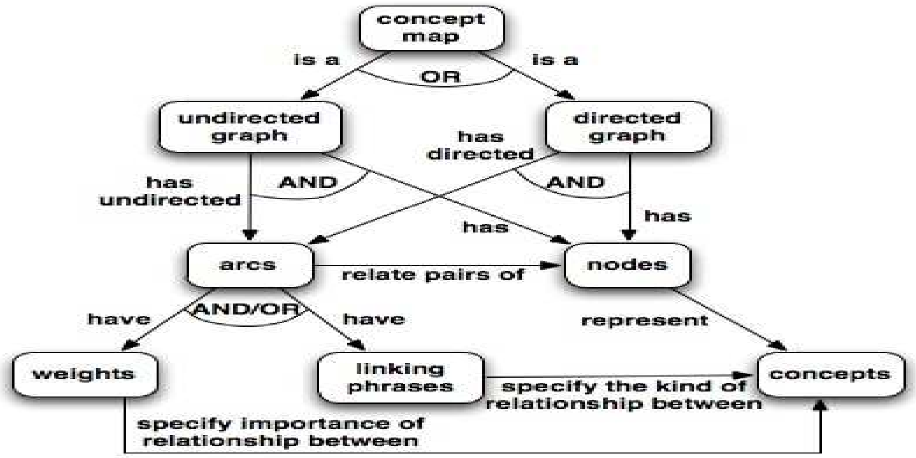

Figure 1. Variety of concept maps

Response format is closely related to the task characteristics. It refers to the response that student makes, for instance, fill-in or drawing a CM, or giving an oral explanation. There are three types of response variations: a) the response mode (paper and pencil, oral, computer generated), b) the characteristics of the response format (usually fitting with specifics of the task), and c) the mapper who draws the map (expert and/or students) (Ruiz-Primo and Shavelson, 1996). It is easy to see that all possible combinations of response mode, characteristics and mapper correspond to a wide variety of response formats that can be generated. However, which format and in which task may be preferred over another still is an open question.

A scoring system is a systematic method used for evaluation of students' CMs. There is a lot of alternative scoring systems that can be classified into three general scoring strategies: a) score the components of the student's CM (for instance, propositions, hierarchy, crosslinks, and examples as it is proposed in (Novak and Gowin, 1984)); b) compare the student's CM with an expert's CM (different methods have been developed, but their overview is out of the scope of this paper); c) use a combination of both strategies. More details about several already developed scoring systems are given in (Ruiz-Primo and Shavelson, 1996), but novel scoring systems are dispersed in numerous publications.

3. THE DEVELOPED ADAPTIVE INTELLIGENT KNOWLEDGE ASSESSMENT SYSTEM

The IKAS was designed with purpose to support student-centered systematic knowledge assessment. A teacher divides a study course into several stages. Learners should acquire a certain set of concepts at each stage. A teacher includes concepts and relationships taught at the first stage into the first CM and uses it for knowledge assessment. At the second stage new concepts are taught and a teacher adds them to the CM of the first stage. So, each new CM used for knowledge assessment is an extension of CM of the previous stage. At the last stage the CM contains all concepts and relationships among them, and the CM represents a complete knowledge structure of the study course (Anohina and Grundspenkis, 2006).

From the systems viewpoint the IKAS is embedded in the environment that consists from two types of human agents – teachers (experts) and learners (students) who use the corresponding modules. The teacher's module supports construction of CMs. Its main functions are editing and deleting of CMs. The learner's module includes tools for completion of CM tasks given by a teacher and for viewing feedback after a solution is submitted. The system includes also the administrator's module that allows managing data about users (learners and teachers) and studying courses providing functions of data input, editing, and deleting. The kernel of the IKAS is the intelligent knowledge assessment agent which is implemented as a multiagent system that consists of four software agents, namely, the communication agent, the interaction registering agent, the agent-expert and the knowledge evaluation agent. The IKAS and its environment (learners and teachers) is shown in Figure 2 (the administrator's module is excluded).

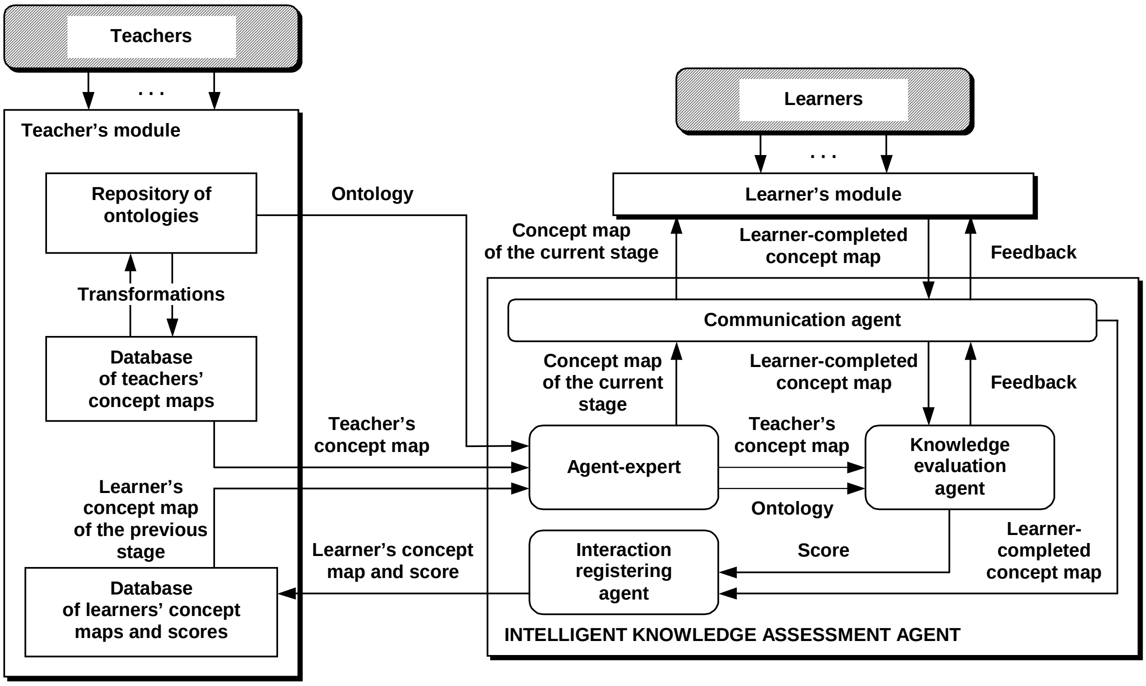

Figure 2. The IKAS and its environment

The developed system supports the following scenario. Using graphical user interface, a teacher prepares a CM for each stage (the system supports teacher's actions for drawing CMs on the working surface). In order to make his/her work easier, already developed ontologies of study courses may be transformed into CMs (Graudina and Grundspenkis, 2008). During knowledge assessment learners get a CM task that corresponds to the current stage of learning process. After finishing the completion of CM, a leaner confirms his/her solution and the knowledge evaluation agent compares CMs of a learner and a teacher on the basis of so called graph patterns (or simply patterns) described below. The final score and a learner's CM are stored into the database, and a leaner receives feedback with information about correctness of his/her solution. The intelligent knowledge assessment agent operates as follows. The agent-expert forms a CM of a current stage using a teacher's map and a learner's map of the previous stage, and passes it to the communication agent for visualization. The agent-expert also delivers a teacher's CM and corresponding ontology to the knowledge evaluation agent for comparison. The communication agent perceives learner's actions and is responsible for visualization of CMs received from the agent-expert, and for the output of feedback received from the knowledge evaluation agent. The latter compares both CMs and recognizes patterns (correct or incorrect) of learner's solution. Patterns are subgraphs like, for example, a learner's defined relationship exists in a teacher's map, but the direction of the arc (relationship) is incorrect, or defined relationship is found in a teacher's map, concepts and a linking phrase are correct but one concept is placed in a wrong place (more examples of patterns are given in Table 1). The interaction registering agent after receiving a learner's solution and its assessment stores them in the database.

The development of the IKAS is based on the framework for conceptualizing CMs as a potential assessment tool proposed in (Ruiz-Primo and Shavelson, 1996) which is shortly described in the previous section. In the IKAS tasks vary depending on task demands and task constraints. Two classes of CM tasks, namely, fill-in-the-map and construct-the-map tasks are used. The fill-in-the-map class includes three different tasks. Common for all of them is that CM's structure and a list of concepts is given. The distinction is that for the first task all linking phrases already are inserted in the structure, for the second task the linking phrases are not used at all, and for the third task students must insert the linking phrases by themselves. The construct-the-map class includes two tasks. For both tasks students must relate concepts from a given list. For the first task linking phrases are not used, but for the second task linking phrases from a given list must be inserted in a CM. From the presented description of IKAS it is clear that referring the response format response is computer generated and there are two kinds of mappers: teachers (experts) and learners (students).

As it is already mentioned above the scoring system is based on comparison of patterns, i.e. subgraphs or, in other words, paths with limited length. Some examples of graph patterns are given in Table 1. The main differences between patterns in all versions of IKAS briefly are described below. Due to the scope of the paper details of patterns are not presented (for full description see (Grundspenkis and Anohina, 2009; Grundspenkis and Strautmane, 2009)).

Table 1. Some examples of patterns

Pattern No	Description	Score
Pattern 1	Completely correct (conforms with a teacher's CM): both concepts are in correct places and the type of relationship and the linking phrase between them is correct	S_{max} (maximal number of points, i.e. 5 for important relationship and 2 for less important relationship)
Pattern 5	Both concepts are in correct places but the linking phrase is incorrect	0.7 S_{max}
Pattern 8	The relationship defined by a learner is in a teacher's CM but both the type of the relationship and the linking phrase are incorrect	0.5 S_{max}

To certain extent the IKAS has a capacity for adaptation to each learner's current knowledge level. It is reached in two ways. First, the degree of task difficulty may be changed initialized by a learner or by the system. During fill-in-the-map task solving a learner can ask the system to insert a chosen concept into the right place (node) of CM. Thereby a learner receives easier task. A learner also may ask to replace a task with more easy or more difficult one, for example, to change the third task from the fill-in-the-map class of tasks (the structure is given, concepts and linking phrases must be inserted using given lists) to more difficult construct-the-map task or to more easy fill-in-the-map task in which linking phrases are not used. It is worth to stress that depending on learner's results the IKAS can change the degree of task difficulty, too (Grundspenkis and Anohina, 2009).

Second, learners can choose the form of feedback that contains explanation of those concepts with which learners have difficulties. The IKAS can provide a definition, a short description or an example of concept. A learner can choose the initial form of explanation and change it during solution of CM task. Moreover, the system keeps track of learner's actions and determines which form of explanation are of greatest value for a particular student in his/her efforts to create a correct pattern (Grundspenkis and Anohina, 2009).

The present version of IKAS (the fourth in a row) has three-layer architecture that includes three conceptual elements: the database server, the client application and the application server Apache Tomcat. The IKAS is implemented using the following technologies: Eclipse 3.2, Apache Tomcat 6.0, Postgre SQL DBMS 8.1.3, JDBC drivers, Hibernate, VLDocking, JGoodies and JGraph.

The main characteristics of developed IKAS reflecting its evolution are given in Table 2.

Table 2. Evolution of CM based IKAS

Characteristics	Number of version			
	1st (2005)	2nd (2006)	3rd (2007)	4th (2008-2009)
Tasks for learners	F-M*	F-M	F-M, C-M*	F-M, C-M
Scoring (number of patterns)	5	9	36	>36
Types (number of weights) of relationships	2	2	2	2
Linking phrases	–	+	+	+
Directed arcs	–	–	+	+
Drag-and-drop technique	–	+	+	+
Use of student model	–	–	–	+
Changing the degree of task difficulty	–	+	+	+
Feedback (the score)	+	+	+	+

Characteristics	Number of version			
	1st (2005)	2nd (2006)	3rd (2007)	4th (2008-2009)
Feedback (learner's CMs with highlighted mistakes)	+	+	+	+
Feedback (checking of propositions)	–	–	–	+
Help (explanation of concepts)	–	–	–	+

* F-M – fill-in-the-map tasks; C-M – construct-the-map tasks

The number of graph patterns depends on task demands and task constraints. In the first two versions of IKAS only fill-in-the-map tasks were used. Links were undirected and had only two weights (important and less important links defined by a teacher; the same weights are used also in the third and fourth version of IKAS). In the first version five patterns from two classes containing two related concepts or three concepts and two relationships were recognized by the developed comparison algorithm of CMs. In the second version linking phrases were included. As a result, there were nine patterns and the knowledge evaluation agent used the developed algorithm for their recognition. All graph patterns of first two versions are described in (Grundspenkis and Strautmane, 2009). Starting from the third version construct-the-map tasks were added and CMs were both undirected and directed graphs. The number of recognized patterns were 36. In those construct-the-map tasks where learners have freedom to define concepts and linking phrases the number of patterns is even higher (the fourth version of IKAS). The reason is that synonyms of concepts as well as so called "hidden relationships" (Grundspenkis and Strautmane, 2009) must be recognized. In fact, the algorithm implemented in the knowledge evaluation agent must compare population of CMs and assess correct solutions. A novel algorithm for comparison of more complicated patterns is developed (Grundspenkis and Strautmane, 2009). Currently it is implemented and will be integrated in the IKAS.

Remaining content of Table 2 represents characteristics implemented in corresponding versions of IKAS ("+" and "–" denotes characteristics which are and are not implemented, respectively).

4. RESULTS OF PRACTICAL USE OF IKAS

Developers of IKAS have four year experience of practical use of the system in different study courses. Starting from year 2005 all four versions were evaluated by students who handed in questionnaires after CM task solving. Data of practical testing of the system are given in Table 3.

Table 3. Data of practical testing

Year	Version of the IKAS	University	Number of courses	Number of students	Number of questionnaires
2005	1st	RTU, VUC[1)]	6[2)]	95	84
2006	2nd	RTU, VUC	5[3)]	74	63
2007	3rd	RTU	1	40	37
2008	4th	RTU	1	36	36

1) RTU – Riga Technical University
VUC – Vidzeme University College

2) 3 computer science courses at RTU
2 computer science courses at VUC
1 pedagogical course at RTU

3) 2 computer science courses at RTU
2 computer science courses at VUC
1 pedagogical course at RTU

The questionnaire is organized as follows: questions are grouped in 4 groups. Questions from the first group are related to CMs as learning and assessment tool. Questions from the second group refer to functionality of IKAS. Student opinion about reduction of the degree of task difficulty is obtained from the third group of questions. Questions from the fourth group are focused on student opinion about quality of received feedback and help.

Most interesting and informative questions from the first group and percentage of student answers are given in Table 4.

Table 4. Questions from the first group

No	Question	Answer	Percentage of answers			
			Number of version			
			1st	2nd	3rd	4th
1.	Do you like CM as knowledge assessment tool?	yes	69	78	84	92
		neutral	–	11	0	8
		no	31	11	16	0
2.	Does CM task help better understanding of material?	yes	63	71	41	58
		partly	–	–	51	36
		no	37	29	8	6
3.	Do you want to use CM in other courses?	yes	33	71	62	50
		probably	55	22	27	47
		no	12	7	11	3
4.	Are CM tasks difficult or easy?	difficult	52	59	49	69
		very difficult	7	11	8	0
		easy	37	24	43	28
		very easy	4	6	0	3

Among reasons why they liked to use CMs as knowledge assessment tool students mentioned that it helped to systematize their knowledge and to develop knowledge structure, promoted logical thinking, and that it is convenient and fast way for knowledge assessment. Opposite opinion was expressed by students who did not understand the idea of CM, had insufficient knowledge or had not work experience with diagrams. In fact those who found that CMs tasks are difficult or very difficult mentioned the same reasons. They underline 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. So, for them it is easy to work with the IKAS and CMs which is not entirely new technique for them.

Answers to questions from the second group triggered off continuous improvements of IKAS. So, after testing of the first version students suggested implementing drag-and-drop techniques. They also pointed out that textual format of feedback is not informative enough and does not help to understand mistakes; it should contain information about missing knowledge units and should identify mistakes in a graphical form. The drawbacks of the first version were eliminated in the second version of IKAS.

Students approved new graphical interface that was implemented in the second version. At the same time they found that it would be helpful if the system's given feedback in addition with the final score would contain information from which elements it is composed. Students also wished to see their progress in terms of correct patterns, have possibility to inspect the correct CM after a task completion and have faster response from the system. Those were impulses for further improvements realized in the third version. Practice with latter and information found in questionnaires helped to find necessary innovations. Students who worked with the third version wanted further extension of feedback, namely, inclusion of descriptions of mistakes and theoretical material for explanation. It was done in the fourth version of IKAS.

Practical use of IKAS revealed unexpected action from students. In average less than 50% of them used reduction of the degree of task difficulty (a mechanism in which the IKAS developers have put considerable efforts) regardless of difficulties met during CM task solution. Questionnaires helped to find reasons: one part of students was sure about their knowledge, while another part did not want to lower their scores. The mechanism was improved providing change of the degree of task difficulty initiated by students or the system in both directions: towards easier and more difficult tasks. Several questions from the third group were aimed at clearing up correctness of mechanism for change of the degree of task difficulty (see Table 5).

Data collected from questionnaires that are summarized in Table 5 give conclusive proof that the mechanism built in the IKAS for change of the degree of task difficulty is working correctly (especially in the fourth version). The reduction of task difficulty enables solution of CM tasks. The IKAS offered easier task if a student has problems. In case if a student achieves a good result the system reacts and offers a new more difficult type of task and students confirm that this task is really more difficult.

Table 5. Questions from the third group

No	Question	Answer	Percentage of answers		
			Number of version		
			2nd	3rd	4th
1.	Does reduction of the degree of task difficulty make the task execution easier?	yes	80	25	81
		partly	–	50	19
		no	20	25	0
2.	Is the task offered by the system easier than the previous task?	yes	–	50	74
		neutral	–	25	15
		no	–	25	11
3.	Does the system offer new more difficult type of task at the next stage?	yes	–	50	86
		no	–	50	14
4.	Is the new task more difficult than the task at the previous stage?	yes	–	58	84
		neutral	–	16	10
		no	–	26	6

The feedback given to students was improved step-by-step starting from the first version of IKAS. In the fourth version the feedback contains explanation facilities (help). Explanation of chosen concept occurs if a learner asks the system for it. The greatest part of students (58%) used this possibility. The IKAS provides explanation in three forms: a) the definition; b) the short description; c) the example. The initial form of explanation is determined asking a learner for his/her choice and is added to student's model. A learner can change the form of explanation. Among questions from the fourth group is the question "Which form you used?" Student answers showed that 53% of them used the definition of concept, 31% used the description, and 49% used the example. Hence, some students used combinations of explanation forms. It is worth to point out that the IKAS keeps track of learner's actions and determines which form of explanation has the greatest contribution for creation of correct CM. The system offers to change the form of explanation if the form chosen by a learner does not match with that determined by the IKAS.

Questionnaires showed one more unexpected result. Student answers confirmed that for 65% of them definitions were most informative. Others answered that descriptions were most informative, but nobody put examples in this category. New option to check correctness of chosen proposition was implemented in the fourth version of the IKAS, too. Checking of proposition means that the system checks correctness of proposition and provides explanation (tutoring) if a proposition is incorrect.

Students who worked with the fourth version of IKAS were asked to rank alternative ways of help provided by the system. The criterion was "most useful way which makes problem solving easier". The result is: 1. Change of the degree of task difficulty; 2. Explanation possibility; 3. Checking of proposition correctness; 4. Insertion of concepts into CM.

Only part of results obtained from practical use of IKAS is represented in this section. Questionnaires contain much more information that will be analyzed and processed in future.

5. CONCLUSIONS

The paper reflects results extracted from practical use of the developed concept map based adaptive intelligent knowledge assessment system. Results allow drawing the conclusion that number of students who liked to use CMs as knowledge assessment tool does not depend on universities that teach study courses and on courses themselves. Moreover, regardless of improvements of the system (more convenient interface, faster response, more informative feedback, explanation and help facilities, etc.) the percentage of students who consider that CM tasks are difficult is relatively stable. Students confirmed that CMs helped to systematize their knowledge and to develop knowledge structure, as well as promoted logical thinking. At the same time student opinion is that CMs may be used as knowledge assessment tool for "pass/fail" assessment and for intermediate assessment thereby supporting process oriented learning. They argue that for final assessment oral explanation of CM elements should be used.

In the beginning the IKAS was designed and implemented as knowledge self-assessment tool but in result of evolution in fact it is transformed into the tutoring system which provides adaptive help and feedback if students have difficulties. Future work is directed towards further extension of IKAS. New algorithm based on graph patterns for more efficient CMs comparison is under the implementation. The complete student model will be created and integrated into the IKAS in near future. Research is going on to develop the scoring system by which students' CMs can be evaluated accurately and consistently taking into account such factors as changes of the degree of task difficulty initiated by a student or by the system, number of student requests for help from the system or for checking of correctness of propositions, and some others.

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