DEVELOPMENT OF CONCEPT MAP BASED ADAPTIVE KNOWLEDGE ASSESSMENT SYSTEM

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ABSTRACT

The paper describes the developed adaptive system for knowledge assessment and self-assessment based on usage of concept maps. The concept mapping approach offers a reasonable balance between complexity of knowledge assessment system and necessity to assess higher levels of knowledge according to the Bloom's taxonomy. The underlying concepts of the developed system which supports a process oriented learning are discussed. The architecture and functionality of the intelligent knowledge assessment system based on the intelligent agent paradigm is described. The system to the large extent can adapt to each individual learner by changing the degree of task difficulty and providing execution of two kinds of tasks – fill-in tasks and construction tasks of concept maps. Information about two prototypes which have been already implemented and tested in different study courses is given.

KEYWORDS

Knowledge assessment, concept map, adaptive system, process oriented learning, degree of task difficulty.

1. INTRODUCTION

Nowadays when knowledge society requires high-value workers who produce high-value output, sweeping changes affect the information age education. First, roles of main actors of teaching and learning process have changed. Teachers now should be guides and coaches while passive learners start to turn into active ones. These changes are very strongly promoted by modern information and communication (ICT) technologies which penetrate in education starting from kindergartens and ending with universities and organizations that provide life long education. ICT enables student centered and one-to-one learning in traditional as well as in e- and m-learning settings (Waterhouse 2004). A plethora of technology enhanced learning systems has been already developed and many others are under the development practically all over the world. At the same time, one is unable to deny that even intelligent tutoring systems (ITS) are still behind the desired level of teaching and learning quality. Even the most advanced ITSs provide intelligent support of education process that is far behind of that provided by a human teacher who is able to adapt to each learner individually, to give a flexible feedback such as help, explanation, motivation, generation of individual tasks with different degrees of difficulty, and an assessment. Among all facets of needed feedback, a knowledge assessment plays the central role. It is very important that both players (a teacher and a learner) can keep track of learner's progress. Unfortunately, even in traditional teaching where regular knowledge assessment may be carried out in natural way, due to the high workload of university teachers, in practice they usually apply only final examinations. In e-learning regular knowledge assessment, as a rule, is carried out using tests which allow to assess learners' knowledge only at the first four levels of the well known Bloom's taxonomy which includes three levels of lower order skills: knowledge, comprehension, and application, and three levels of higher order skills: analysis, synthesis, and evaluation (Bloom 1956).

The paper presents the approach in which a systematic knowledge assessment is carried out using the developed adaptive knowledge assessment system based on concept maps. The approach supports both kinds of knowledge assessment, namely, assessment given by a teacher, and self-assessment of learners. Knowledge self-assessment opportunities allow a learner to keep track of his/her progress, and to give a teacher feasibility to inform a learner about expected progress and to adjust a learning process making it more individualized.

The paper is organized as follows. In the next section the motivation and underlying concepts of the developed system are given. Its architecture and functionality is described in the third section. Information about implementation and testing is represented in the fourth section. Conclusions summarize the proposed approach and outline some directions of future work.

2. MOTIVATION AND UNDERLYING CONCEPTS OF THE KNOWLEDGE ASSESSMENT SYSTEM

Computer-assisted knowledge assessment systems have been developed for decades. The most widespread systems are based on various tests with pre-defined answers (CAA Centre n.d.). Different types of questions are used: multiple choice questions, multiple response questions, text/numerical input questions, graphical hotspot questions, fill in blanks and matching questions (CAA Centre 1999). Built-in mechanisms to operate with tests are included in virtual learning environments, for example, Blackboard (Blackboard n.d.). There are also a number of specialized assessment systems. CASTLE (CASTLE n.d.), TAL (TAL n.d.), TRIADS (TRIADS n.d.), Hot Potatoes (Hot Potatoes n.d.), WebQuiz XP (WebQuiz XP n.d.), Questionmark^{TM} Perception^{TM} (Questionmark^{TM} Perception^{TM} n.d.), and Respondus (Respondus n.d.) are only few examples. These systems have a number of advantages, but their main drawback is a level of intellectual behavior which can be assessed (Anohina et al. 2007a). According to several authors (Bull n.d., Mogey and Watt 1996), it is not above the fourth level of Bloom's taxonomy (Bloom 1956). In all conscience, it is needed to mention that in (CAA Centre n.d.) this statement is called to be erroneous and it is pointed out that designing of test questions to assess higher order skills may be time consuming and requires skill and creativity. In this context, computer-assisted adaptive assessment systems (Mislevy and Almond 1997, Papanastasiou 2003, Castle Rock Research Center 2005) where a student receives more difficult or more easy test item depending on his/her previous testing results to the certain extent may prove this statement.

Tasks such as essays and free-text responses allow to assess higher order skills but requires more complex structure and functionality of the corresponding system which is based on the artificial intelligence techniques. Examples of such systems (Burstein et al. 2001, Leacock and Chodorow 2003, Sukkarieh et al. 2003, Perez et al. 2004) show that they are strongly subject and language dependent.

The concept mapping approach offers a reasonable balance between requirements to assess higher levels of knowledge and complexity of an assessment system. In teaching and learning concept maps started to appear around two decades ago (Novak and Gowin 1984). Concept maps are a specific kind of mental model and are used for representation and measuring of individual's knowledge by visualization of a graph which nodes and arcs represent concepts and relationships between them, respectively (Croasdell et al. 2003). Analysis of available publications shows that even if other conceptual structures like semantic networks (Fisher 1990, Fisher et al. 1990) or ontologies and genetic algorithms (da Rocha et al. 2004) are used, usually they are based on a concept map construction (Chang et al. 2001, Tsai et al. 2001, Gouveia and Valadares 2004, Ruiz-Primo 2004). Moreover, a number of useful learning tools which support such functions as concept map construction, navigation and sharing, for example AXON Idea Processor (AXON Idea Processor n.d.), Inspiration (Inspiration n.d.), Knowledge Master (Knowledge Master n.d.), SMART Ideas^{TM} (SMART Ideas^{TM} n.d.), IHMC Cmap Tools (IHMC Cmap Tools n.d.), and others are available. Considerably less knowledge map based tools are known for knowledge assessment (Chang et al. 2001, Gouli et al. 2004). Both tools may be used for various concept map construction tasks, provide evaluation and feedback functions, but don't support process oriented learning and aren't sensitive to the arrangement and coherence of concepts (Anohina and Grundspenkis 2006). Besides abovementioned shortcomings of known systems there are several additional reasons why the developed knowledge assessment system is based on concept maps. First, the use of concept map based tasks as test items for assessment allows to see students' cognitive structure, i.e. their knowledge structure. Thus, concept maps promote system thinking which frequently is a critical point even for university students because many single courses contain fragmentary knowledge without associations between knowledge units. Second, the use of concept maps supports a process oriented learning in which a teacher divides a study course into several stages. A stage is any logically complete part of a course, for example, a topic. At the end of each stage, a teacher makes assessment of learner's knowledge level. Thus, a systematic assessment is carried out which, in its turn, allows to change teaching methods and the learning content timely in order to achieve desirable knowledge level and to promote a qualitative teaching and learning process. Concept maps may be used to represent tasks given for assessment of student knowledge as it is shown in Figure 1.

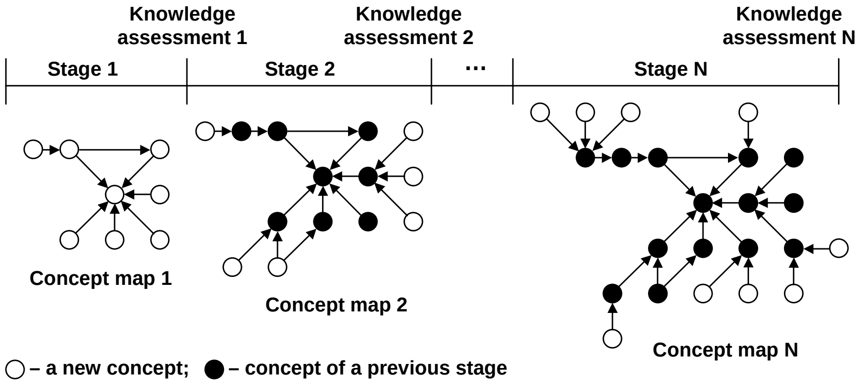

Figure 1. Use of concept maps in process oriented learning for learners' knowledge assessment

It is important to note how a concept map for each stage is formed. Learners should acquire a certain set of concepts at the first stage of a study course. These concepts and relationships between them are included into the first concept map. At the second stage, new concepts are taught. A teacher adds these concepts to the concept map of the first stage without changing relationships among already existing concepts. So, each new concept map is an extension of a concept map of a previous stage. A concept map of the last stage displays all concepts and relationships between them representing complete knowledge structure of a given study course.

Last, but not least, concept maps offer a wide variety of different tasks because concept maps themselves are different. Concept maps can have labels (linking phrases) on links between concepts, links may be directed or undirected, and may have the same or different weights, i.e., some links may be more important than others (Ahlberg 2004). Structure of a corresponding graph may be hierarchical or with crosslinks, and may contain cycles. An example of a concept map with directed links and linking phrases is given in Figure 2.

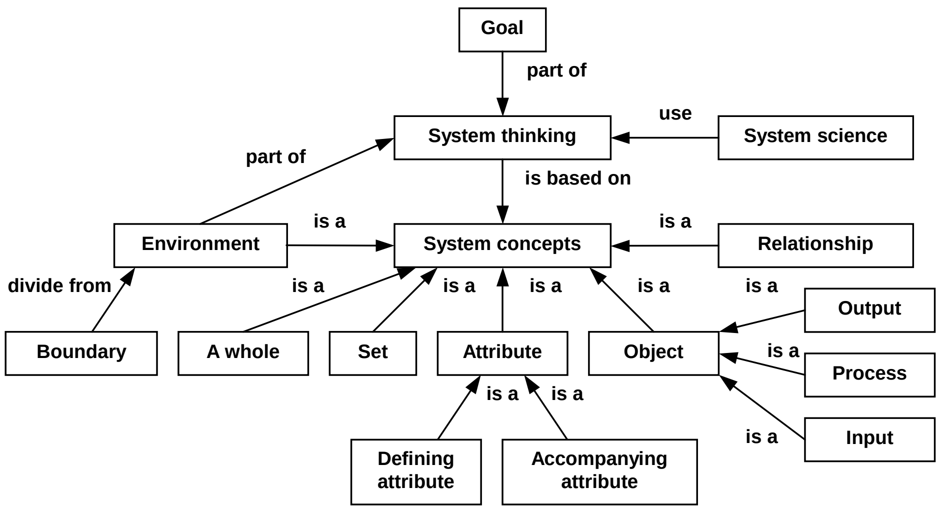

Figure 2. A part of concept map of study course "Systems Theory"

Concept map building tasks range from high-directed to low-directed depending on information provided for students. All tasks are divided into fill-in tasks where concept map's structure is given and construction tasks where students themselves must create a concept map's structure (Ruiz-Primo 2004). Fill-in tasks belong to high-directed tasks because a structure of a concept map as well as a list of concepts is given. Some concepts may be already filled in, linking phrases defined, links may be marked with weights, or students must define concepts and/or linking phrases. In construction tasks, a structure of a concept map is not given. Lists of concepts and/or linking phrases may be given or students must define them by themselves. A variety of concept map building tasks allows to conclude that they are suitable for adaptive knowledge assessment. In general, adaptiveness to students' knowledge level can be developed in different ways. At each stage, the individual student can receive a task which corresponds to his/her current knowledge level, and at the next stage a task difficulty can be changed giving more easy or more difficult task depending on previous results of knowledge assessment.

3. ARCHITECTURE AND FUNCTIONALITY OF THE SYSTEM

The developed adaptive knowledge assessment system consists of three modules (Figure 3). The administrator's module allows to manage data about users (learners and teachers) and study courses providing functions of data input, editing, and deleting. The teacher's module supports teachers in construction of concept maps. The main functions of this module are the following: editing and deleting of concept maps, evaluation of learners' completed concept maps and assigning the scores which characterize the level of correctness of learners' concept maps. The learner's module includes tools for completion of concept maps given by a teacher and for viewing feedback after the solution is submitted.

The modules interact sharing a common database where data about teachers and their courses, learners, teacher created and learners' completed concept maps, as well as learners' final scores are stored (Figure 3).

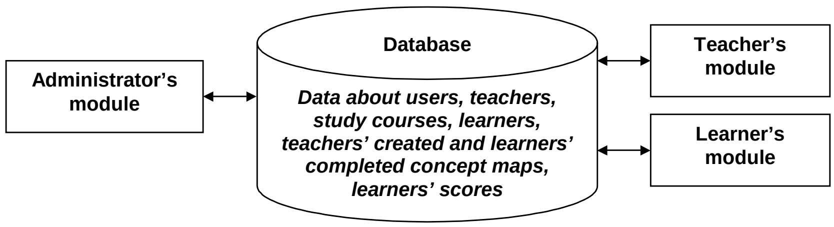

Figure 3. The systems architecture in terms of modules

The developed system supports the following scenario. A teacher divides a study course into N stages and defines all concepts and relationships between them. Using the system's graphical user interface, a teacher prepares concept maps for each stage, i.e. the interface is used for concept map development and editing. The system supports teacher actions for drawing concept maps on the working surface. After creation of the first concept map a teacher can freely add and delete concepts and links. However, during creation of concept map for the next stage, he/she can freely operate only with new elements of the current concept map. So, a teacher must be familiar with the idea of concept maps. In order to make his/her work easier, already developed ontologies of study courses may be transformed into concept maps (Graudina 2008). During knowledge assessment or self-assessment learners get a task (a concept map) that corresponds to the current stage of learning process. After finishing the completion of concept map, a learner confirms his/her solution and the system compares concept maps of the learner and the teacher on the basis of patterns of learners' solutions described below. The final score and the learner's concept map are stored into the database, and a learner receives feedback about correctness of his/her solution. This feedback comprises information about concepts which aren't inserted and about incorrectly connected concepts, that is, a learner's completed concept map with mistakes is displayed, but he/she can't see a correct concept map or to perform a task once again.

The system is a multiagent system which is shown in Figure 4. The agent-expert forms a concept map of a current stage using a teacher's map and a learner's map of previous stage, and passes it to the communication agent for visualization. The agent-expert also delivers a teacher's concept map to the knowledge evaluation agent for comparison. The communication agent perceives the learner's actions and is responsible for visualization of concept maps received from the agent-expert, and for the output of feedback received from the knowledge evaluation agent. The latter compares a learner's concept map with a teacher's map and recognizes patterns (correct or incorrect) of learner's solution. Patterns of solutions are subgraphs, for example, a learner's defined relationship exists in a teacher's map, but the type of relationship is incorrect, or a learner's defined relationship exists in a teacher's map, concepts and names of relationships are correct, but at least one of the concepts is placed in an incorrect place (all patterns are described in (Anohina et al. 2007b)). The interaction registering agent, after receiving a learner's solution and its assessment, stores them in a database.

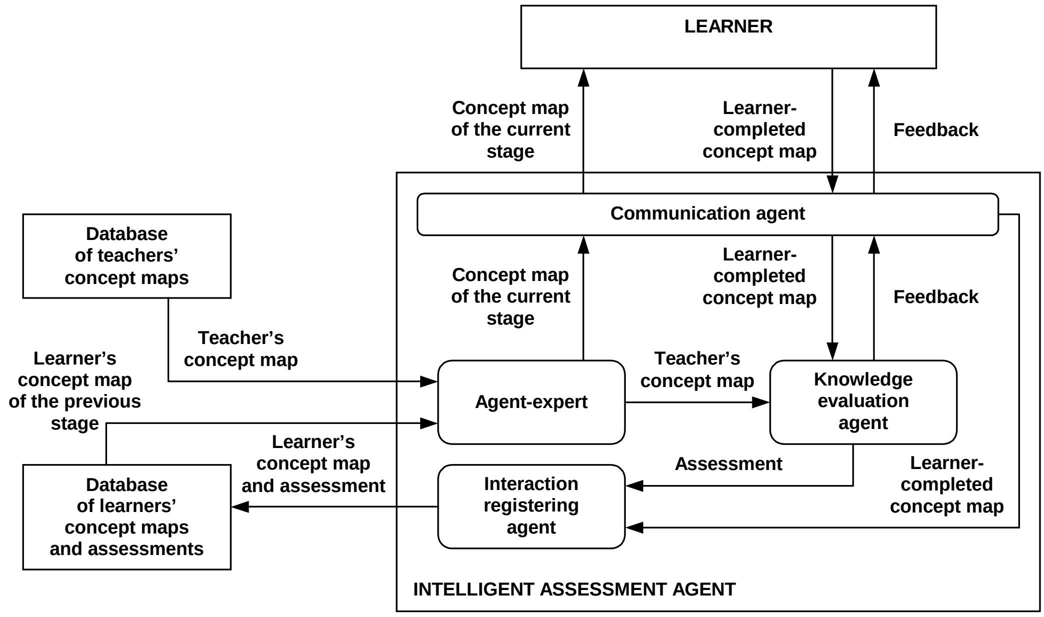

Figure 4. The architecture of the intelligent knowledge assessment system

4. IMPLEMENTATION AND TESTING

The first prototype of the system has been developed using the following tools: Borland JBuilder 9.0, JGraph, Postgre SQL DBMS 8.0.3, and JDBC drivers for Postgre SQL. In fact this system has not adaptability at all because all learners can receive only a given structure of a concept map of the current stage where a teachers predefined concepts are already filled in. The number of concepts and links is unlimited because scrolling is used for displaying a concept map. The task of a learner is to put concepts from a given list in correct places. The links have only two predefined weights reflecting their importance (important and less important). At the next stage a learner can see an extended map where only correctly placed concepts are given. Concepts placed incorrectly as well as new ones are given in corresponding lists.

Nevertheless the system has several advantages. It is a Web-based application that allows to use it from any remote location with Internet connection. It has the convenient and clear graphical user interface both for teachers and learners. The system supports process oriented learning and allows a teacher to extend the initially created concept map for the new stage of assessment. A novel algorithm for comparison of teacher's and learner's concept maps 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 lets suppose that a learner has received a high-directed fill-in task where a structure of concept map and all linking phrases are given. An example of learner's completed concept map is shown in Figure 5. Operation of algorithm is based on the assumption that understanding of relationships between concepts is the most important for knowledge assessment. The algorithm carries out comparison of concept pairs of teacher's constructed concept map (see Figure 2) and a learner's completed concept map shown in Figure 5. In this example four cases are identified. Case 1 reflects correct solutions while Case 2 represents incorrect ones. In Case 3 a learner has defined correct relationships but concepts are placed differently from a teacher's concept map (the answer is correct and maximum score is given for the relationship). In Case 4 a learner has defined correct relationships but at least one of concepts is placed incorrectly (he/she receives 80% from maximum score for the corresponding relationship). When comparison is finished, a learner receives a feedback with information about incorrectly related pairs of concepts, list of concepts that are not inserted (if any) and the information about the maximum possible score and the score he/she has achieved. The first prototype in details is described in (Anohina and Grundspenkis 2006). The prototype has been tested in four study courses (both engineering and social sciences). Seventy-four students have been involved in the testing process. In their questionnaires 65% of them answered that they liked the idea to use concept maps for knowledge assessment, and 62% declared that completion of concept maps helped them to understand study material better. Students also have specified several drawbacks: not enough informativeness of used feedback and a guidance how to perform the current task, and lack of drug-n-drop facility for concept map fulfillment.

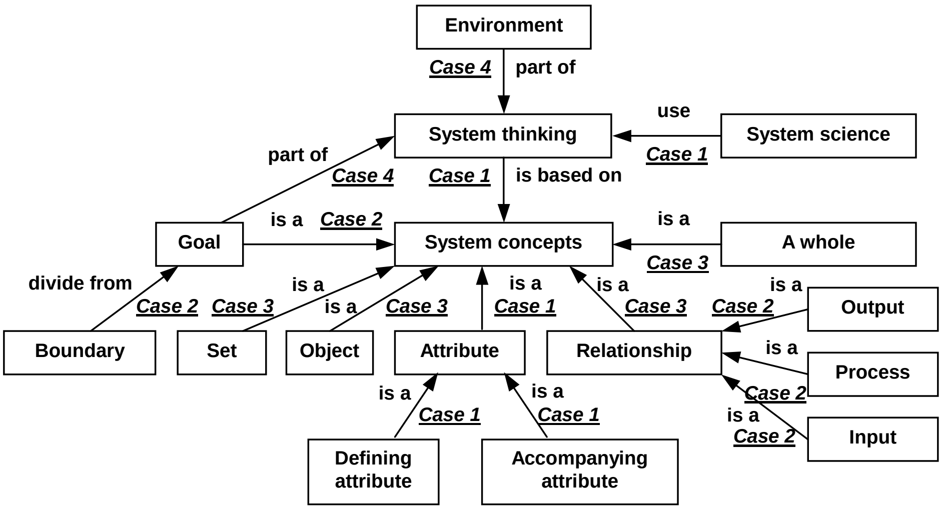

Figure 5. A learner's completed concept map

These drawbacks have been eliminated in the second version of the system which has been implemented using open code environment Eclipse 3.2 for code generation and several other tools, for example, JGraph for graph building and editing. This system to the large extent can adapt to each individual learner's knowledge level. The system can change the degree of task difficulty and can operate in two modes. In the first mode a learner can complete only a fill-in task. During a task performance, a learner can ask to reduce the degree of task difficulty, and the system inserts additional concepts into a structure of a given concept map. Reduction of task difficulty has two steps. First, the analysis of learner's concept map 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. The system reacts by inserting additional concepts according to the degrees of free nodes of concept map. This is the duty of agent-expert that uses the developed algorithm (Anohina 2007).

In the second mode, both fill-in and construction tasks are used which also provide adaptive capabilities of the developed system. Five tasks have been selected starting with the easiest one where a structure and linking phrases are given but concepts must be inserted, and ending with the most difficult task where a concept map must be constructed if only lists of concepts and linking phrases are given (Anohina and Grundspenkis 2007, Anohina et al. 2007b). At the first stage, a learner receives a task which has a teacher's predefined degree of difficulty (usually it is medium degree). During the task performance, a learner can ask to reduce the degree of difficulty. If a learner has reached a teacher's specified score without reducing the task difficulty, the system increases the task difficulty at the next stage.

The second version of the system has been tested, too. Forty-four students took part in testing of the first operation mode. One third of them used the difficulty reduction and stated that it was useful because it facilitates their further performance. Thirty students participated in testing of the second operation mode, and 43% of them used the opportunity to change the degree of task difficulty. Others did not want to reduce the score.

At present, the third version of the system is under the development. In this system much wider spectrum of fill-in and construction tasks is used. The system's architecture is extended and a repository of ontologies is added because in Internet there are available quite a lot of ontologies that correspond to study courses. Their usage may help teachers to create the corresponding concept maps. For this purpose, algorithms for ontology transformations into concept maps have been worked out (Graudina 2008).

5. CONCLUSIONS

In this paper the development of adaptive agent-based knowledge assessment system is described. Two systems have already been implemented and tested, and the third is under the development at the present moment. The experience obtained manifests that concept maps are very useful for assessment of learners' knowledge at higher levels of Bloom's taxonomy.

Using concept maps, the knowledge assessment system is able to adapt to the knowledge level of each individual learner. Testing results showed that engineering programme students who are studying computer science achieved considerably higher scores in comparison with students of social science programme. The main reason may be that computer science students are familiar with various diagrams used in software engineering. So, having experience working with diagrams, they can easily understand interpretation of concept maps. Moreover, students of social science programme not always have enough skills to work with computer programs and may meet difficulties using them. This should be considered only as the hypothesis get from the first experiments with the developed knowledge assessment system. Certainly much more testing experiments are needed to conclude about study courses and areas which are specially suited for concept maps.

The third version of the system will provide more flexible knowledge assessment taking into account semantics of relationships. Future work is also directed towards improvement of feedback given to a teacher and each individual learner. In addition, to reach the final goal – to develop truly intelligent knowledge assessment system, it should include also ontology based facilities to choose a learning material that learners should revise to fill gaps in their knowledge structure.

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