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A hybrid cognitive assessment based on ontology knowledge map and skills

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ABSTRACT

An intelligent tutoring system plays vital role in education and its importance is constantly increasing, meanwhile the key challenge in the teaching learning process is assessing students' learning efficiently. In this paper, a hybrid assessment based-on ACT-R cognitive learning theory, combining ontology knowledge map with skills is proposed. In order to assess how well students master knowledge structure, an ontology knowledge map is constructed to describe declarative knowledge; and in order to assess how well students master knowledge skills, a problem solving process is constructed to describe procedural knowledge based on ACT-R. Finally, a student's mastery of knowledge is assessed through both the knowledge map and skills in the problem solving process, as well as auxiliary indicators like time usage, prior knowledge level, self-assessment, etc. This method is implemented in a geometric intelligent assessment system and is evaluated in a junior high school. Experiments show that the assessment results are consistent with students' actual learning levels. The hybrid cognitive assessment method can not only obtain the score of students' mastery of knowledge points and the structure through knowledge map, but also assess the learning skills in problem solving process through exercises quantitatively.

1. Introduction

An Intelligent Tutoring System (ITS) plays vital role in education and its importance is constantly increasing [1]. As we know, ITS is a computerized learning environment that incorporates computational models from the cognitive sciences, learning sciences, computational linguistics, artificial intelligence, mathematics, and other domains [2]. ITS can provide directed, customized and individualized instruction or feedback to learners [3]. Furthermore, it offers educational materials suitable for a learner's learning style, knowledge, interests and abilities, adapts the learning environment to the learner's preferences, executes adaptive tests appropriate to the learner's current knowledge level, and it is flexible in time and space [4].

While the key challenge in the teaching learning process of ITS is assessing the students' learning [1]. Assessments are usually used to improve the quality of instruction in the teaching learning process [5]. Therefore, the development of good assessment and feedback techniques is essential to the development of reliable tutoring systems in domain [6].

As is well known, traditional assessment methods are standard paper–pencil tests, which assess how students master knowledge by marks.

With the development of computer-aided instructions, the research on how to assess a student's mastery of knowledge arises more and more interests, and some new methods have been proposed.

One of them is the knowledge map or knowledge mapping. Knowledge map was proposed by Joseph D. Novak, professor of Cornell University, in 1960s, which can express the definitions, thinking and theories in the form of a graph structure. So it captures the relationships between concepts and can provide users with effective navigation. Especially in ITS, knowledge map is widely used as an effective assessment tool.

For example, based on Bloom's Taxonomy of Educational Objectives, knowledge maps with various difficulty levels are provided to students with different knowledge levels, allowing them to construct these maps for assessment, then adaptive knowledge assessment can be achieved by this method. Wu et al. [7] found the effectiveness of concept map as assessment tool. An assessment system based on Multi-Agent Intelligent knowledge map was proposed in [8]. The psychometric characteristics and practicality of concept mapping as a technique for classroom assessment were

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evaluated in literature [9], but it only took into account (a) the time required to train students to create concept maps; (b) the time required for students to create concept maps; and (c) the time required to score concept maps. [10] developed Human Performance Knowledge Mapping Tool (HPKMT), which enables trainees to express their understanding of a content area by creating graphical, network representations of concepts and links that define the relationships of concepts. Furthermore, literature [1] proposes concept map based on assessment from students learning using ontology mapping, and literature [11] presents different results and studies around the world about the Fuzzy Cognitive Maps.

But there are deficiencies in traditional knowledge maps. On one hand, they are static and knowledge has to be updated manually, which is time consuming and inefficient. On the other hand, concepts, rules and relationships between concepts of different knowledge maps are quite different from each other. Therefore, knowledge map is still not enough to fulfil a cognitive assessment of learning.

Concept map can be used to enhance the interaction of teaching and learning with the goal to foster problem solving skills [12]. Therefore, the ultimate goal for students is to train problem solving skills, so that they can work out problems correctly.

Some researches on how to assess problem solving skills are also proposed. Desmarais and Baker [13] reviewed the learner models and the latest advances in the modeling and assessment of learner skills. Walker et al. [14] developed models in computer-mediated peer tutoring by problem-solving context. Augustin et al. [15] uses Markov Chain procedure to assess skills with Competence-based Knowledge Structures. The results in [16] can be applied to construct efficient algorithms for the adaptive assessment of knowledge, including prerequisite relationships, but it did not yet take into account the possibility that students may make careless errors or lucky guesses. Observation of actual online interactions between tutors and students provides information related to the processes used in problem solving, which is useful for building dialog or interactivity in tutoring systems [17]. A fuzzy assessment method to assess special skills of mechanical manipulation is mentioned in [18] for improving the reliability of assessment. A multidimensional model to assess proof comprehension in undergraduate mathematics is proposed in [19], but it can be assessed in the context of a proof only in number theory. Literature [20] uses intelligent assessor to make the learning process (such as a proof of concept) effective and efficient through appropriate individualized feedback. Furthermore, cognitive decision support in digital ecosystems is concerned with cognitive processes for better decisions [21].

According to the above investigations, an assessment combing ontology knowledge map and skills based on ACT-R is proposed in this paper. In ACT-R model, knowledge is divided into declarative knowledge and procedural knowledge [22]. Therefore, ontology knowledge map used to describe declarative knowledge is constructed in order to assess how students master knowledge structure, and exercises based on problem solving process used to describe procedural knowledge are provided in order to assess how students master skills. Furthermore, an assessment system based on the assessment result of knowledge map and skills is built to evaluate students' learning levels. We also conduct a real case study in geometry and run experiments to show the efficiency and intelligence of the assessment method.

In Section 2, the structure of knowledge map and skills of problem solving will be described respectively. In Section 3, a hybrid cognitive assessment combining knowledge map with skills in problem solving process will be proposed. In Section 4, a geometry intelligent assessment system will be implemented based on the hybrid cognitive assessment algorithm, and two experiments will be tested in detail.

2. Knowledge map and skills

In this section we introduce the process of building declarative knowledge and procedural knowledge on ontology, then describe a structure assessment based on ontology knowledge map and a skill assessment based on problem solving respectively.

2.1. Structure of knowledge map

It is necessary to construct an ontology for adaptive knowledge map. An ontology is a formal, explicit specification of a shared conceptualization, representing knowledge as a set of concepts within a domain and the relationships between those concepts [23].

Concepts of a disciplinary ontology constructed in this paper contain declarative knowledge such as definitions, theorems, propositions, skills, the methods it employs, and specific examples it relates to. The disciplinary ontology in our assessment model mainly includes three classes: knowledge topic, skill and knowledge point. Knowledge topic is a learning target in a certain section during students' learning process. Skill is a special method during problem solving process related to the knowledge topic. Knowledge point is either a definition, a theorem or a proposition related to the knowledge topic. Relationships of the disciplinary ontology constructed in this paper contain not only traditional relationships such as SubclassOf and SubpropertyOf, but also domain relationships such as HasKnowledge, HasSkill, HasExample. One framework of the knowledge ontology is shown in Fig. 1.

In Fig. 1, a knowledge topic is usually related to skills, including $S_1, S_2, \ldots, S_n$. *HasSkill* represents relationships between knowledge topics and skills. A skill is usually related to knowledge points, such as $P_1, P_2, \ldots, P_n$, and then *HasKnowledge* represents relationships between skills and knowledge points. In addition, *HasSkill(T,S)* means the prerequisite of grasping knowledge topic T is grasping skill S. *HasKnowledge(S,P)* means the prerequisite of grasping skill S is grasping knowledge point P, and $HasKnowledge(S,p_1) \bigwedge HasKnowledge(S,p_2) \bigwedge HasKnowledge(S,p_3)$ means the prerequisite of grasping skill S is grasping knowledge points p_1, p_2 and p_3.

For example, suppose knowledge topic t_1 represents topic of triangles congruent, skill S_1, S_2, S_3 represent skills of proving Triangle Congruence using SSS Congruence Theorem, SAS Congruence Theorem, AAS Congruence Theorem respectively, and knowledge point p_1, p_2, p_3 represent knowledge points of SSS Congruence Theorem, SAS Congruence Theorem, and AAS Congruence Theorem respectively. If we want to learn knowledge topic t_1, we need to know skill S_1, S_2 and S_3, so we can get $HasSkill(t_1,S_1) \bigwedge HasSkill(t_1,S_2) \bigwedge HasSkill(t_1,S_3)$. Furthermore, if we want to learn skill S_1, S_2 and S_3,

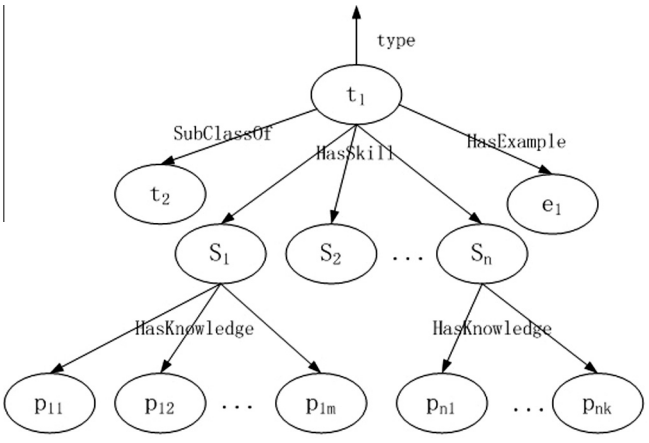

Fig. 1. Part of knowledge map.